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# Advancing India's Green Steel Transition

## Leveraging Industrial Clusters to Decarbonise Small and Medium Enterprises

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Cover image: CEEW. Hemant Prakash Singh (CEEW) in conversation with a rotary kiln maintenance crew member at the fuel injection end during a field visit to a sponge iron plant in Bellary, Karnataka.

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Image: CEEW

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Thank you all for your generosity and support in this endeavour.

**The authors**


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# About CEEW

**INTEGRATED | INTERNATIONAL | INDEPENDENT**

The Council on Energy, Environment and Water (CEEW)—**a homegrown institution** with headquarters in New Delhi—is **among the world's leading climate think tanks**. We use **data, integrated analysis**, and **strategic outreach** to support public policy, transform markets, shape technology, and nudge behaviour. CEEW seeks to explain—and change—the use, reuse and misuse of resources. CEEW addresses pressing global challenges through an **integrated** and **internationally focused** approach. It prides itself on the **independence** of its high-quality research and strives to **impact sustainable development at scale**.

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**NATIONAL/INTERNATIONAL**
**2011** | National Water Resources Framework
**2014** | 175 GW renewables target
**2015** | International Solar Alliance
**2016** | PM *Ujjwala Yojana*
**2017** | *Saubhagya* Schemes
**2019** | Climate Vulnerability Index
**2021** | Net Zero by 2070
**2022** | Mission LiFE
**2022** | National Bioenergy Programme
**2022** | E-waste (Management) Rules
**2023** | G20 Green Development Pact
**2023** | National Green Hydrogen Mission
**2024** | Green Steel Taxonomy
**2024** | PM *Surya Ghar Yojana*
**2025** | National Critical Mineral Mission
**2025** | Rajya Sabha guidelines on crop residue burning
**2025** | National Adaptation Plan

**STATE**
**2022** | Rajasthan Organic Farming Mission
**2022** | Jharkhand Solar Policy
**2022** | Uttar Pradesh *Vidyut Sakhi* programme
**2023** | Rajasthan Green Hydrogen Policy
**2023** | Uttarakhand Solar Policy
**2024** | Net-zero roadmaps for Bihar & Tamil Nadu
**2025** | Green Odisha Initiative
**2025** | Maharashtra Climate Action Plan 2.0
**2025** | 50 Heat Action Plans (GJ, OD, MH, TN)
**2025** | Delhi Clean Air Action Plan
**2025** | Delhi EV Policy 2.0

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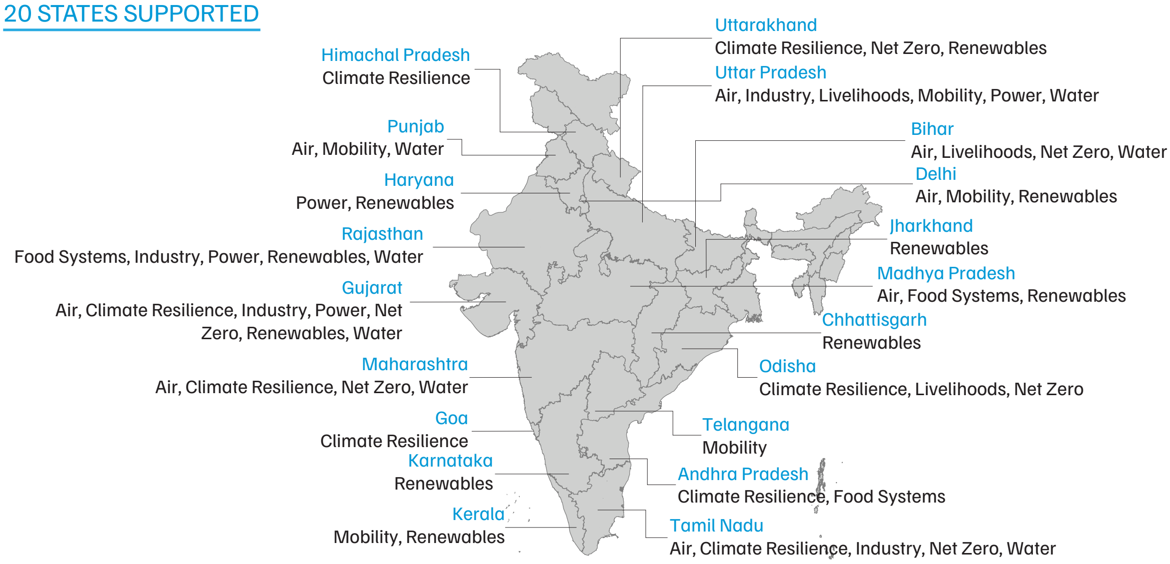


# About the Institute for Sustainable Communities

**The Institute for Sustainable Communities (ISC)** is a global organization with a **32-year track record** of enabling industries, cities, governments, and communities to address climate change and its environmental, economic, and social impacts. ISC has led more than **130 transformative projects in 31 countries**, including India, Thailand, Vietnam, Cambodia, Bangladesh, United States, and China with more than $215 million in public and private funding from the US and international donors. With presence in India, China and the US, ISC has a diverse portfolio of projects and services in areas such as industrial decarbonization, energy efficiency, renewable energy, sustainable supply chains, sustainable agriculture, water resources management, and environment, health, and safety (EHS) practices.

**ISC started its operations in India in 2016** and has implemented over 12 multi-stakeholder projects serving industries, national and sub-national government agencies, municipal corporations, agricultural communities, civil society organizations, and academic institutions. ISC's impact in India can be classified into three categories - sustainable manufacturing, sustainable agriculture, and sustainable cities.

ISC has adopted a market development approach in India to accelerate adoption of equitable climate solutions by stimulating demand, developing supply chains, and improving access and affordability of finance.

**Flagship Initiatives & Impact Highlights**

- **EHS+ Network**: Established industry training centers across India, China, and Bangladesh. Trained 45,000+ professionals from 160+ companies, promoting clean energy, EHS compliance, and sustainability in supply chains (supported by Apple, H&M, Mahindra & Mahindra, Walmart, MacArthur Foundation, USAID, SIDA, and others).

- **Energy Efficiency Alliance (E2 Alliance)**: Developed in partnership with EESL and P4G across India, Bangladesh, Vietnam, and Indonesia, the Alliance catalyzed clean energy markets, including the National Motor Replacement Program, mobilizing $36M in private investment for deployment of 70,000+ IE3 motors in 350 industries.

- **SME CleanTech & Textile Clean Energy Accelerator**: Enabled clean technology adoption among 116+ SMEs, reducing ~160,000 $MTCO_2$/year; engaged 200+ factories and 4,000+ workers in Tirupur through 23 clean tech demonstrations.

- **Women + Water Alliance**: In partnership with USAID and Gap Inc., reached 4,140 cotton farmers across 43 villages, reducing water use by 18%, GHG emissions by 46%, and increasing yields by 15%, while promoting women's leadership in water stewardship.

- **Clean Air Accelerator**: Piloted in Navi Mumbai, aligned with India's National Clean Air Programme, enhancing local air quality governance and benefiting urban-industrial communities.

- **ACE Manufacturing Project**: Advanced gender-equity in low-carbon transition of textile, chemical, and automotive sectors in Tamil Nadu, Gujarat and Maharashtra. Deployed clean technologies in over 1,000+ SMEs, performed energy audits across 50+ CETPs.

- **Building Smart Cities through Educational Linkages**: Conducted capacity building of urban officials from six Indian smart cities through U.S.-India exchanges on sustainable urban transport, urban governance, waste management, and renewable energy.

# About the India Climate Collaborative

**The India Climate Collaborative (ICC)** is a **first-of-its-kind collaborative** founded by prominent philanthropists and business leaders committed to accelerating India's development, while exceeding its climate goals.

The ICC was incubated by the Tata Trusts, and along with the Trusts, is supported by JSW Foundation, Rohini Nilekani Philanthropies Foundation and Rainmatter Foundation, among others. It is led by Shloka Nath, who also serves as its CEO. Shloka previously led the Sustainability and Policy & Advocacy portfolios at the Tata Trusts, and co-founded and was the Managing Partner of Sankhya Women Impact Funds, a gender lens fund with a focus on sustainability prior to that.

The ICC is legally registered as the Council of Philanthropies for Climate Action (CPCA). It has a Board of Directors that provides valuable oversight to the organisation and guidance to the senior leadership team. This Board is chaired by Siddharth Sharma, CEO of Tata Trusts, and consists of Gautam John, CEO of Rohini Nilekani Philanthropies Foundation, Naghma Mulla, CEO of EdelGive Foundation, and Jarnail Singh, India Deputy Director of the MacArthur Foundation.

The ICC cultivates the conditions for a **healthy Indian climate ecosystem**; one that is resilient, ambitious, and primed for impact. As a catalyst for systemic climate action, the ICC **strategically raises and directs philanthropic funding** to critical areas, driving meaningful and lasting change.

Through its work, the ICC:

- **Grows the volume of strategic philanthropy** by working with High NetWorth Individuals, Foundations and Corporate Social Responsibility (CSR).

- **Surfaces strategic funding opportunities** through enhancing intelligence of where funding is flowing, and builds a bank of fundable climate solutions, while backing and enabling a few critical climate programs.

- **Improves the coordination between climate actors** by leveraging its convening power, building avenues of visibility for climate philanthropy, and bringing funders and CSOs together.

In the last four years, the ICC has collaborated with more than 130 non-profits, community organisations, government intermediaries and others, to drive results for climate action across India.


Image: CEEW

# Contents


# Executive summary

India is the world's second-largest steel producer, accounting for 7.4 per cent of global output in 2023 (Verma et al. 2024). The steel industry contributes approximately 2 per cent to India's GDP (IBEF 2025) and supports nearly 2.8 million jobs. Yet, India's steelmaking remains among the most emissions-intensive globally, emitting 2.54 tonnes of carbon dioxide per tonne of crude steel ($tCO_2$/tcs) compared to the global average of 1.91 $tCO_2$/tcs. Among the key factors driving this gap is the predominance of **coal-based direct reduced iron (C-DRI)—a steel-making route where India is the world's largest producer**. C-DRI contributes nearly 30 per cent of the country's crude-steel output and **emits between 2.7 and 3.1 $tCO_2$/tcs** (Verma et al. 2024). Crude steel capacity in India increased at a rate of 10 per cent between 2003–04 and 2023–24, reaching 179.5 million tonnes (Mt) (JPC 2023–24). The National Steel Policy (MoS 2017) projects capacity to rise to 300 Mt by 2030–31. Expansion pathways differ; integrated steel plants are adding capacity mainly through the blast furnace route, while the sponge iron sector is expanding via coal-based rotary kilns. According to the Sponge Iron Manufacturers Association (SIMA), an additional 27 Mt of C-DRI capacity is planned to be added by 2030, on top of the current 48.2 Mtpa, potentially **locking in high-carbon capacity for decades without targeted intervention**.

While integrated steel plants generally possess the financial and technical capacity to pursue decarbonisation, the C-DRI sector is dominated by small, standalone units with limited resources. These units are typically clustered in resource-rich regions such as Chhattisgarh, Odisha, etc. Decarbonising C-DRI can reduce costs for smaller firms, increase competitiveness, and unlock new economic activity. With the steel sector accounting for nearly 12 per cent of India's total emissions (Verma et al. 2024), achieving the national targets of 45 per cent emissions-intensity reduction by 2030 and net-zero by 2070 will require the targeted transformation of C-DRI clusters.

A previously idle direct reduced iron plant in Bellary undergoing revival.

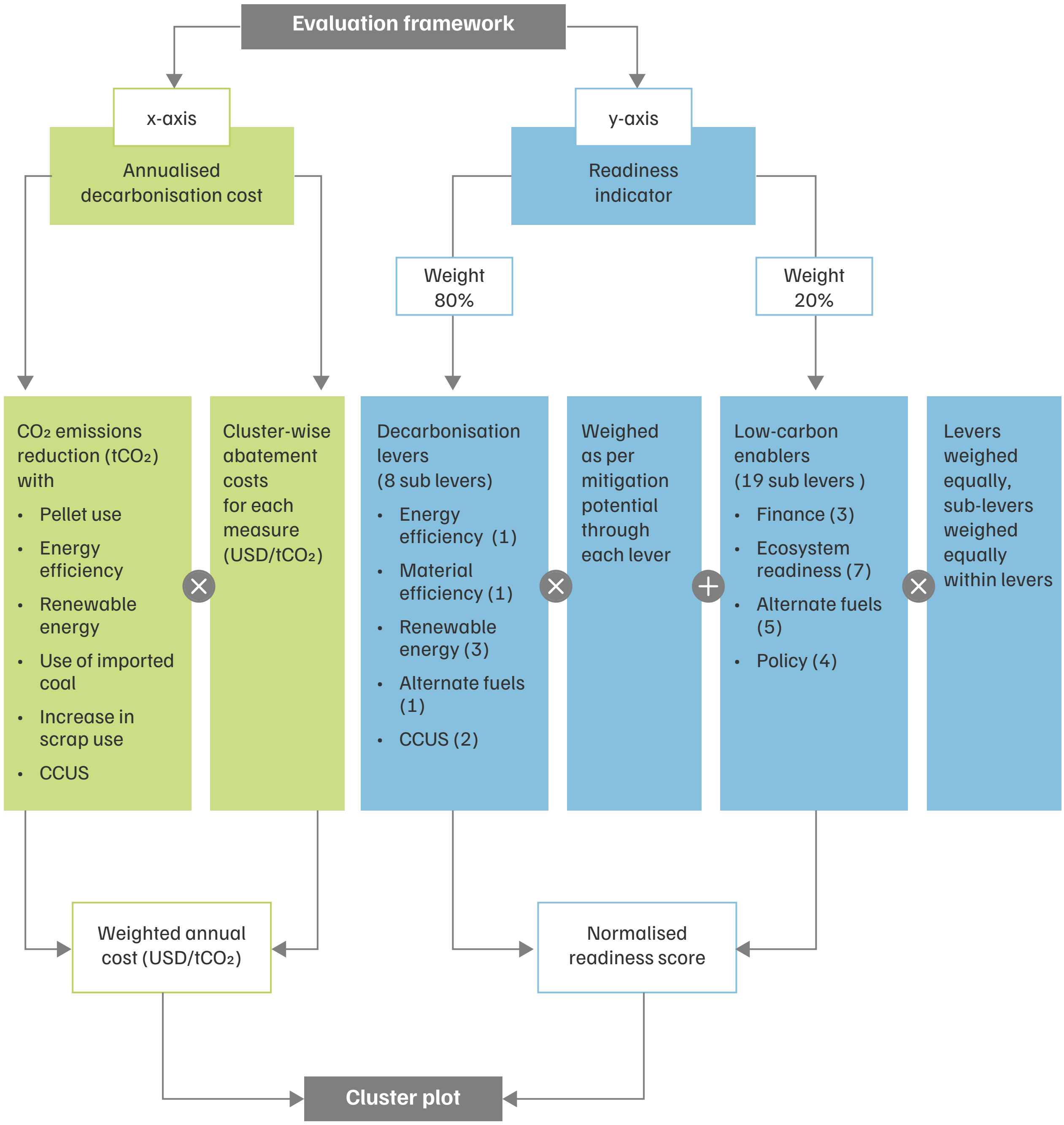
Despite variations in production mix, input use, and energy sources, C-DRI units within each cluster exhibit similar operational characteristics, enabling the deployment of shared infrastructure and common decarbonisation solutions. To harness this opportunity, **we developed an evaluation framework supported by a survey of prominent DRI clusters to assess and compare clusters in terms of cost and readiness for a low-carbon transition**. The framework evaluates emissions profiles, infrastructure gaps, and mitigation options. Insights from the framework inform cluster-specific strategies and cross-cutting recommendations with phased timelines, offering a roadmap to accelerate low-carbon transition in one of India's most emissions-intensive industrial segments and align it with national climate and development goals.

SME geographic clustering enables aggregated demand, shared resources, and lower-cost decarbonisation.

# A. Evaluation framework for cluster-level decarbonisation in the steel industry

The evaluation framework assesses India's C-DRI clusters along two key dimensions—**annualised decarbonisation cost and readiness** (Figure ES1). It serves as a **decision-support tool to compare decarbonisation potential, cost-effectiveness, and implementation feasibility across clusters**. Clusters are plotted on a cost–readiness matrix, with the x-axis representing annualised decarbonisation cost (USD/t$CO_2$ mitigated) and the y-axis representing readiness. The cost dimension captures the expenditure per tonne of $CO_2$ reduced, while readiness reflects each cluster's preparedness to decarbonise through levers such as energy efficiency (EE), renewable energy (RE), and ecosystem readiness, which together act as key enablers.

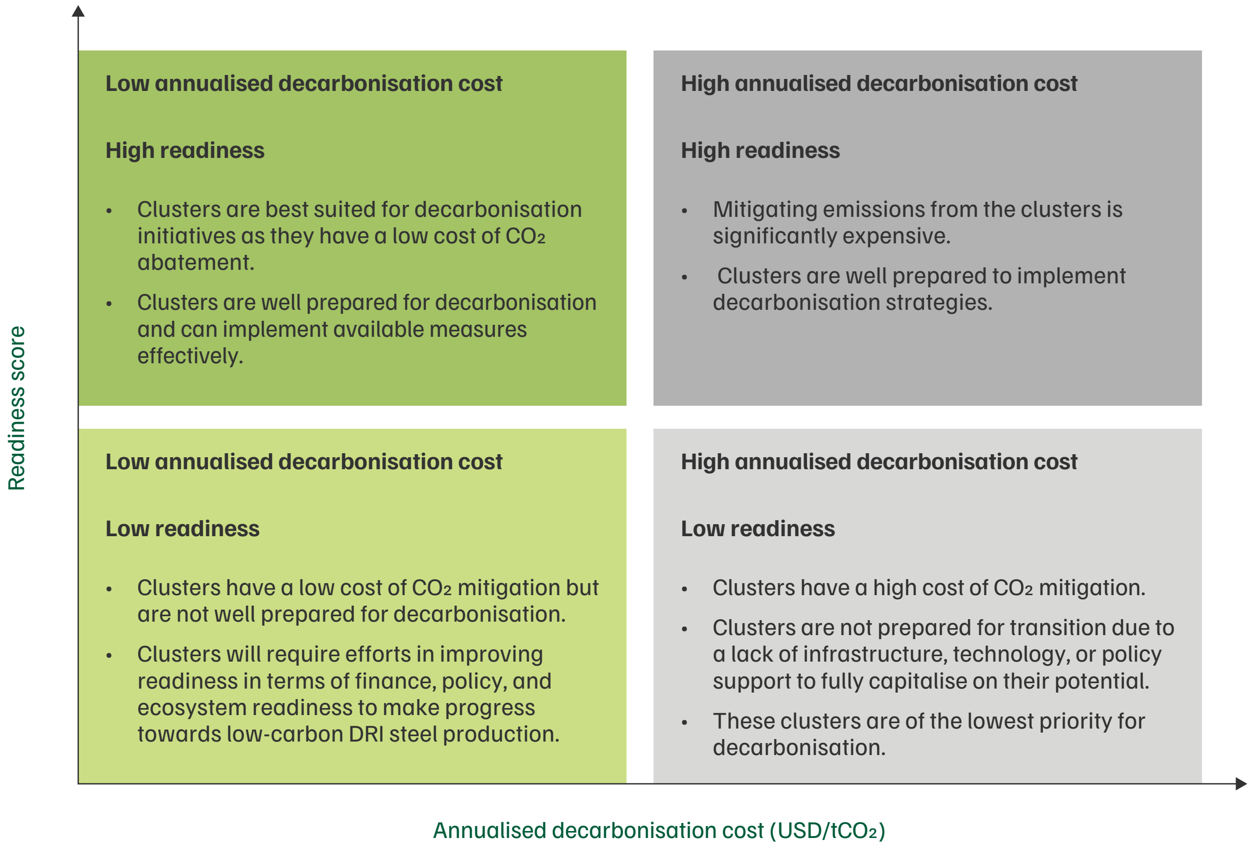
Figure ES1. The evaluation framework considers the decarbonisation potential and readiness of a cluster




*Source: Authors' illustration*

Based on these dimensions, clusters are grouped into four categories (Figure ES2). From an implementation perspective, clusters with low annualised decarbonisation costs and high readiness (dark green) are better suited for immediate decarbonisation and new capacity addition, whereas clusters that have high decarbonisation costs and low readiness (red) are not prepared for transition and will need significant efforts and policy support to decarbonise.

Figure ES2. Categories of clusters explained based on annualised decarbonisation cost and readiness levels



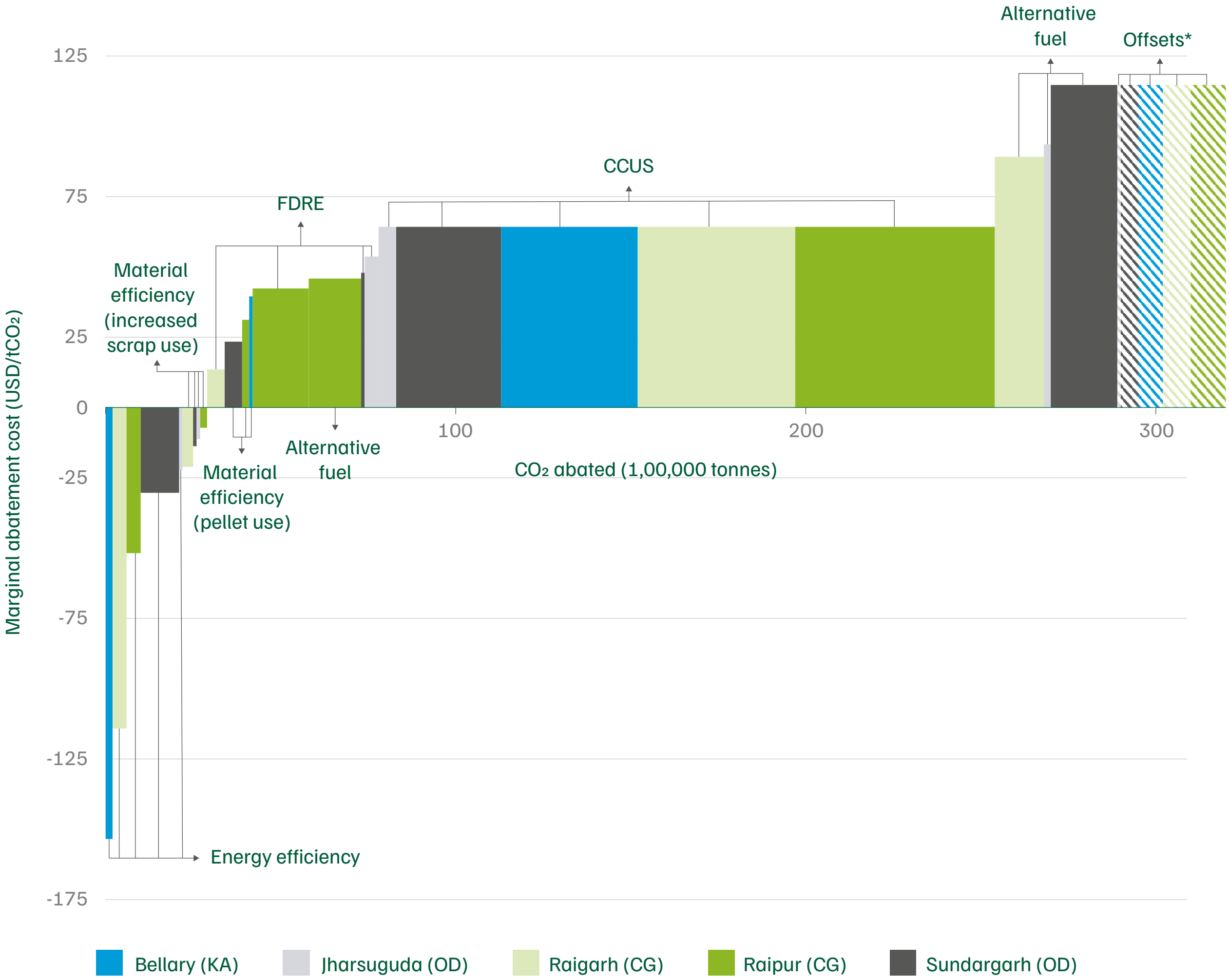

*Source: Authors' illustration*

# B. Cluster-level surveys, findings, and evaluation results

To operationalise the framework, we surveyed DRI units across three major clusters—**Sundargarh and Jharsuguda (Odisha) and Bellary (Karnataka)—covering about 29 per cent of installed capacity and 20 per cent of the number of units in these clusters**. Insights from earlier work in Raipur and Raigarh (Chhattisgarh) (Nitturu et al. 2024) were incorporated to complete the analysis across five clusters, which together account for over half of India's C-DRI production. The surveys captured plant-level data on technology use, fuel mix, and operational barriers. The key findings from the survey are discussed in Chapter 3 of the report.

Based on the survey data, we developed an emissions inventory for the five clusters (detailed in Chapter 4). Our results indicate that C-DRI units primarily drive emissions within steel clusters (ranging between 78–86 per cent). Larger clusters, such as Raipur (7.75 Mt) and Raigarh (10.66 Mt), record higher overall emissions owing to their greater DRI capacity of 3.4 and 3.46 Mt, respectively, as well as higher-capacity induction furnace (IF) (4.01 Mt) and electric arc furnace (EAF) (6.28 Mt) plants. Clusters with significant domestic fuel use, such as Sundargarh with 88 per cent, exhibit disproportionately higher emissions. In the next step, we use the emissions inventory and the penetration levels of various decarbonisation levers across clusters to **evaluate pathways for achieving net-zero emissions**. We followed the approach outlined in our earlier research (Elango et al. 2023), assuming that these measures can be implemented immediately under current conditions. The financial requirements associated with each decarbonisation lever are represented through a marginal abatement cost (MAC) curve (Figure ES3).

Figure ES3. Marginal abatement cost curves (MACs) for all the decarbonisation levers in the five clusters

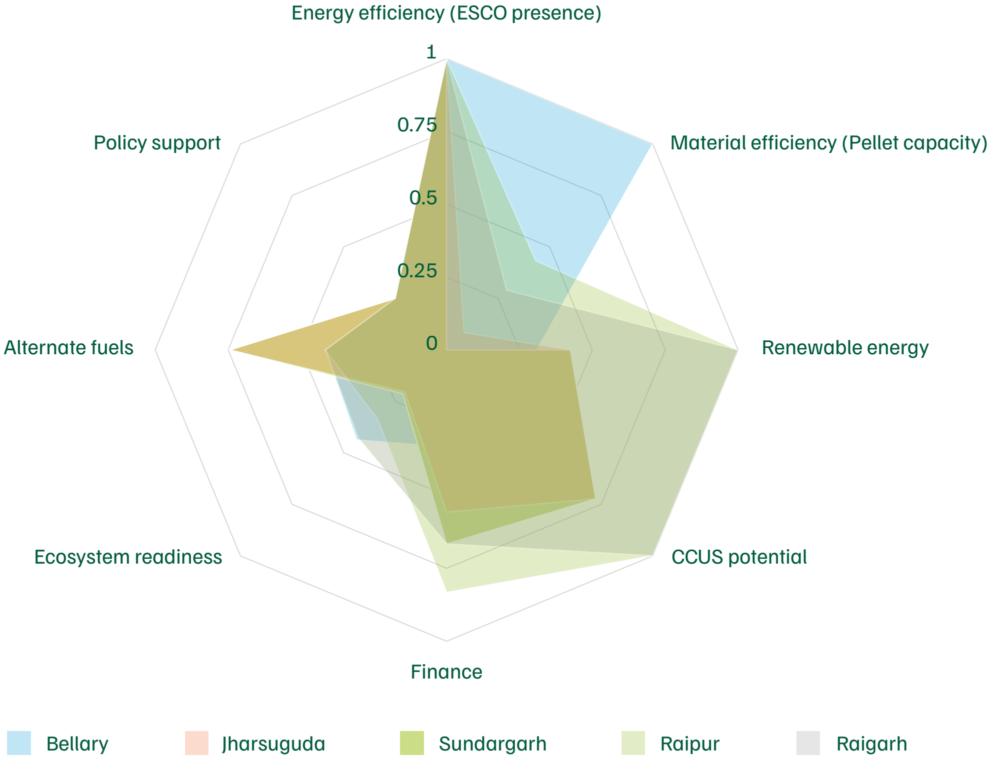



*Source: Authors' analysis*

Note: The MAC for offsets is only representational as an option for carbon mitigation without considering the cost of mitigation.

Generally, mitigation costs vary across clusters depending on the price of incumbent fuels, energy sources, and decarbonisation measures. Across all clusters, WHR consistently delivers cost savings (–153 to –22 USD/t$CO_2$) by displacing more expensive power sources. Scrap use also has a negative abatement cost (–4 to –7 USD/t$CO_2$) but contributes only marginally (0.76 Mt across 5 clusters) to overall emission reduction. In contrast, pelletisation, firm and dispatchable renewable energy (FDRE), alternative fuels, and CCUS have positive MAC values. Although pelletisation incurs lower abatement costs, its impact on emission reduction remains marginal. While FDRE can significantly mitigate emissions (2.52 Mt across 5 clusters), the cost of mitigation varies across clusters, depending on local cost of electricity and open access (OA) charges. The use of **imported coal (an alternative fuel) is particularly expensive** and is relevant mainly to clusters in Odisha that rely heavily on domestic coal. Among the available decarbonisation levers, CCUS dominates both in terms of cost and the share of emissions abated across each cluster.

Figure ES4. Cluster-wise relative readiness scores for all eight readiness levers




*Source: Authors' analysis*

Note: The scores show the relative readiness of the five clusters. The scales for each indicator are not comparable.

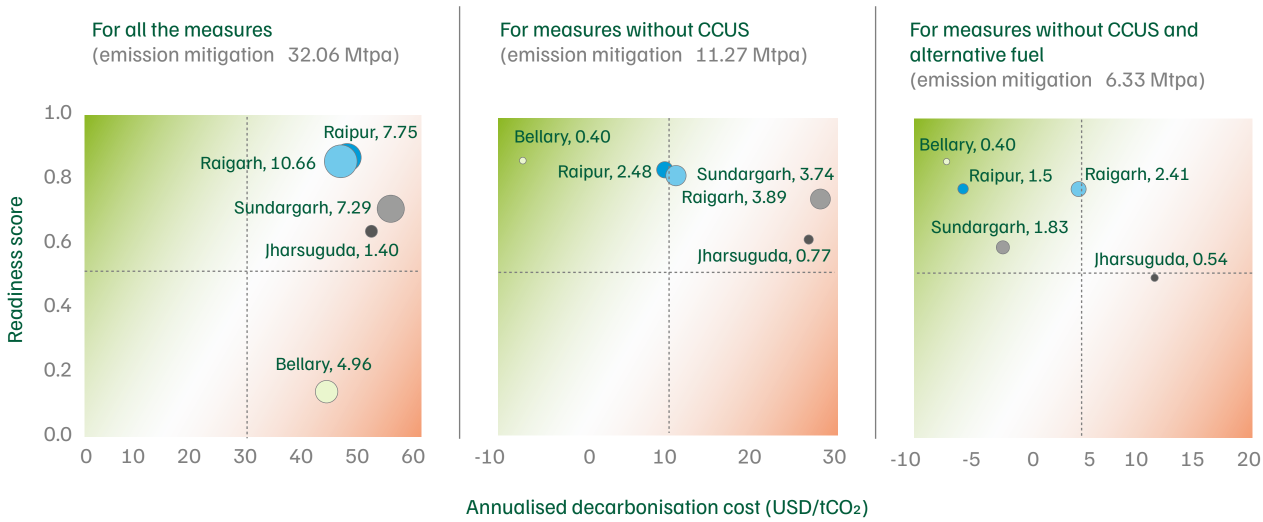
The readiness score (Figure ES4) aggregates scores across eight sub-levers—EE, ME, RE, CCUS potential, finance, policy support, alternative fuels, and ecosystem readiness—to produce a composite readiness index for every cluster. The detailed computation methodology and weighting structure are presented in Chapter 5 of the report. Overall, EE readiness is high across clusters, given the widespread presence of ESCOs and basic efficiency measures, though project-level engagement remains limited. ME readiness is strongest in Bellary and Raipur, which have sufficient pellet capacity, while Raigarh and the Odisha clusters lag behind. RE readiness is highest in Chhattisgarh and Karnataka, supported by operational green-OA rules and low tariffs, whereas Odisha's draft rules constrain progress.

For CCUS, favourable storage geology in Chhattisgarh and Odisha improves readiness. Financing conditions are better in Chhattisgarh and Odisha due to the presence of SIDBI branches, and a larger share of non-standalone units. Ecosystem readiness remains weak across clusters, reflecting limited awareness and low PAT coverage. Alternative fuels readiness is relatively stronger in Odisha, which has a state hydrogen policy, while Chhattisgarh faces high delivered NG prices. Policy support remains uniform nationwide, with central initiatives such as taxonomy in place but no state-level GPP frameworks yet operational.

Integrating cost and readiness as annualised decarbonisation cost and readiness score (methodology described in Chapter 5) yields cluster plots. Figure ES5 presents three cluster plots that illustrate annualised decarbonisation cost (x-axis) and readiness (y-axis) across three scenarios: (i) with all decarbonisation measures, (ii) excluding CCUS, and (iii) excluding both CCUS and alternative fuels. The volume of emissions mitigated is represented by the size of the bubble.

**When all decarbonisation levers are applied, all clusters exhibit high costs and—except for Bellary—high readiness**. Bellary records a lower annualised decarbonisation cost because its existing WHR capacity fully meets its power demand, and it already uses 100 per cent imported coal. Consequently, there is limited scope for additional RE or alternative fuel interventions, which would increase the cost of decarbonisation. As CCUS dominates across all clusters, both in terms of its mitigation share and its cost. This heavily skews the potential and readiness scores of all clusters. For example, in Bellary, 78 per cent of total mitigation depends on CCUS. However, because Bellary lacks CCS potential in the form of saline aquifers or basalt rocks, its readiness scores are significantly lower. By contrast, all other clusters possess CCS potential in the form of saline aquifers.

Figure ES5. All clusters have higher decarbonisation costs due to carbon capture utilisation and storage (CCUS)-related costs




*Source: Authors' analysis*

Note: The size of the bubble corresponds to the emission-reduction potential.

The second cluster plot excludes CCUS to better isolate lower-cost, near-term decarbonisation opportunities. Without CCUS, the annualised decarbonisation costs of all clusters decrease substantially, with the threshold for a high-decarbonisation cluster dropping from USD 30 per tonne $CO_2$ per year to USD 10. The emissions mitigated also decline significantly, indicated by the reduced bubble size.

- In this scenario, Raipur and Bellary emerge as low-decarbonisation cost clusters, while Raigarh's costs also approach low-cost levels.
- Bellary transitions from low readiness to high readiness. Its annualised decarbonisation cost turns negative, as it has no requirement for FDRE or imported fuels and substantial WHR potential, resulting in net cost savings.
- The MAC of FDRE is low in Raipur, owing to higher grid dependence and lower OA charges, which make FDRE deployment more economical, resulting in lower overall costs.
- Sundargarh becomes the highest cost cluster, as it must displace 88 per cent of domestic coal, and transitioning to imported coal remains expensive (as shown in Figure ES3).

Since using imported coal as a decarbonisation measure significantly increases costs, we developed another cluster plot that excludes alternative fuels in addition to CCUS. The clusters' annualised cost scores are now primarily shaped by the remaining four levers: WHR, scrap utilisation, FDRE, and pelletisation. In terms of readiness, the 80 per cent weight assigned to decarbonisation levers is allocated to EE, ME, and RE in proportion to the emissions mitigated by each measure. Emission reductions further decline in clusters that need alternative fuels (coal substitution with imported coal) to decarbonise.

- In this scenario, the Sundargarh cluster shifts from a high-cost to a low-cost cluster, as alternative fuels are excluded from the assessment.
- Jharsuguda remains a high-cost cluster owing to higher FDRE requirements than Sundargarh and a low WHR potential.
- The Raigarh cluster incurs higher costs because it depends on FDRE, whereas WHR only partially meets its power requirements.
- All clusters exhibit high readiness, ranging from 0.50 in Jharsuguda to 0.87 in Bellary. Odisha faces lower readiness scores due to higher OA charges, and its *Green Energy Open Access Rules* (GEOAR) are still in draft form. This is particularly relevant to clusters requiring FDRE. In addition, Odisha's clusters have lower pelletisation capacity than those of other states, further reducing their readiness.

Excluding CCUS and coal substitution substantially cuts costs but lowers mitigation potential from 32 to 6 Mtpa.

Regardless of changes in the annualised decarbonisation cost and readiness levels arising from the inclusion or exclusion of specific decarbonisation levers, the evaluation framework remains scalable. It allows for new clusters and improved data to be incorporated over time. With additional surveys and stakeholder inputs, the framework can evolve into a robust national planning framework for decarbonising India's secondary steel sector.

# C. Policy recommendations and conclusions

## Cross-cutting recommendations

Given our findings on the limited near-term feasibility and costs of CCUS and expensive alternative fuels through imported fuel use, this section concentrates on interventions that can be implemented immediately and suggests piloting CCUS.

**Ecosystem enablers (short-term)**

- The Udyam platform should be leveraged to disseminate information on potential support and policy mechanisms introduced by the Ministry of Steel (MoS) for small and medium enterprises (SMEs) in the steel sector. Further, SIMA and state-level associations, supported by the MoS, BEE, and other relevant institutes (such as SIDBI and think tanks), should enhance policy awareness among SMEs through SIMA-led conferences, cluster-level workshops, and the establishment of instant messaging channels designed to disseminate knowledge tailored explicitly to DRI units.

- The BEE should implement disclosure and reporting of emissions data by DRI units by formulating standardised monitoring and verification frameworks supported by digital tools, including AI-based and other platforms. These datasets should be made publicly accessible and updated annually.

- The MoS, in collaboration with various ecosystem players, should develop a programme to identify two or three sustainability champions within state sponge iron associations. These champions would work with the ESCOs to implement decarbonisation initiatives and develop model plants within the cluster. They should also coordinate SME participation, promote engagement, and recognise the top three SMEs with rewards and incentives.

**EE (short-term)**

- The MoS should assess the feasibility of pooled procurement models to aggregate demand for WHR and to benefit from economies of scale. State sponge iron associations should coordinate cluster-level procurement to achieve economies of scale and reduce procurement costs.

Ecosystem readiness is essential to unlock finance and scale advanced decarbonisation technologies.

**ME (medium-term)**

- The BEE should mandate the inclusion of standalone pellet plants in National Carbon Market (NCM) frameworks, including the *Carbon Credit Trading Scheme* (CCTS) and future emissions trading schemes. Emissions abated from pellet use should be fully credited downstream to C-DRI producers.

**RE (short to medium-term)**

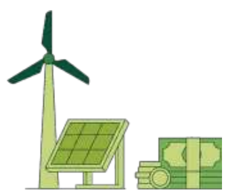
- State energy departments and discoms seeking coal power capacity should assess opportunities to reallocate the power from captive coal power plants through power purchase agreements (PPAs) or by selling power in secondary markets, thus freeing up capacity for RE integration.
- State electricity regulatory commissions (SERCs) should rationalise cross-subsidy surcharges (CSSs) and additional surcharges for RE-based OA procurement. They should reduce CSSs as per Karnataka's tariff order (KERCb 2024) and adopt models implemented in Tamil Nadu and Gujarat to assess additional surcharges more accurately.
- State industry associations should aggregate RE demand at the cluster level. States can establish or utilise their renewable energy implementing agencies (REIAs). Additionally, the respective state renewable development agencies should introduce single-window clearance systems to streamline approvals, land access, and grid connectivity for RE developers.
- State energy departments, in collaboration with SERCs, should explore the feasibility of behind-the-meter RE, peer-to-peer energy trading, and group captive procurement models to increase renewable adoption and bypass high OA and wheeling charges.

**Demonstration and pilots (short to medium-term)**

- The MoS should establish a model low-carbon DRI plant using the natural-gas route and rotary kilns equipped with all decarbonisation levers at the cluster level. The plant would demonstrate integrated decarbonisation strategies and serve as a replicable learning hub for SMEs.
- The MoS should also explore the feasibility of developing a pilot group-captive vertical-shaft furnace for gas-based DRI production. The Steel Research and Technology Mission of India (SRTMI) can play a crucial role in guiding the research and development (R&D) activities and disseminating information about the pilot study across all clusters.

**Cluster-specific recommendations**
**(Cluster-wise recommendations are depicted in Chapter 6)**

Clusters such as Bellary and Sundargarh, with high WHR potential, should focus on maximising WHR utilisation and enabling local sale of surplus power to nearby induction furnaces. Clusters with limited access to pellets (Odisha and Raigarh) require policy and infrastructure support to expand pelletisation capacity and lower transport costs through slurry pipelines. Chhattisgarh should reduce the value-added tax on natural gas, which currently raises delivered prices by nearly 30 per cent compared to Karnataka. States with lower OA charges, such as Chhattisgarh, should leverage these advantages to expand RE supply across clusters. Karnataka should notify green hydrogen policies and reduce OA charges to enable early adoption and offtake aggregation in industrial clusters. Strengthening institutional mechanisms, including the revival of defunct associations such as OSIMA in Odisha, will be crucial for coordinating decarbonisation efforts in the state.



WHR and renewable energy offer meaningful reductions at lower costs for near-term emissions cuts.

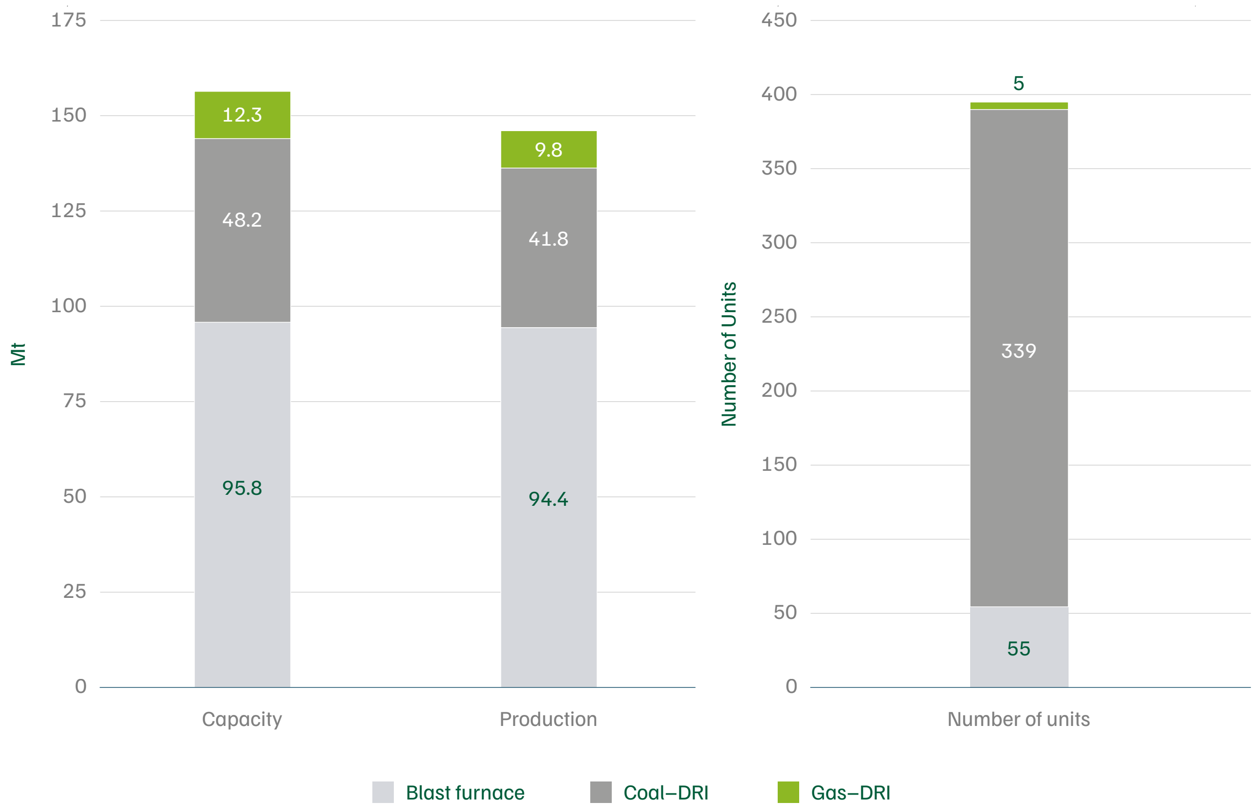

# 1. Introduction

India is the second-largest steel producer in the world, accounting for 7.4 per cent of global steel production (World Steel Association 2024). The sector contributes approximately 2 per cent to the nation's gross domestic product (GDP) (IBEF 2025) and plays a significant role in job creation, employing around 2.8 million people directly and indirectly (Verma et al. 2024). India's steel production grew at a compound annual growth rate (CAGR) of 7 per cent between 2003–04 and 2023–24. Crude steel output reached 144.3 million tonnes (Mt) in 2023–24, against a total capacity of 179.5 Mt. According to the *National Steel Policy*, capacity is expected to rise to 300 Mt by 2030–31, with crude steel production reaching 255 Mt and finished steel production reaching 230 Mt (PIB 2024a). Figure 1 presents India's iron-making capacity and production for FY 2023–24. On the production side, India's iron-making capacity is dominated by the blast furnace–basic oxygen furnace (BF–BOF) route, followed by the coal-based direct reduced iron–induction furnace (DRI–IF) route. India also remains the world's largest producer of direct reduced iron (DRI), with 55 Mt of installed capacity in 2023–24 (Verma et al. 2024). In terms of units, coal-based DRI (C-DRI) units dominate the iron-making industry, suggesting smaller unit capacities.

The steel sector forms a cornerstone of India's development landscape but remains energy- and carbon-intensive. Unlike producers in developed countries, who benefit from higher scrap usage, greater pellet uptake, cleaner electricity grids, and affordable natural gas (NG), Indian steel units face significant resource limitations. These include limited scrap availability, a reliance on low-grade coal and iron ore, dependence on emissions-intensive captive or grid power for auxiliary operations, and prohibitively high NG prices. As a result, the Indian steel industry continues to rely predominantly on coal-based blast furnaces and rotary kilns for steelmaking, given the limited economic viability of cleaner alternatives. Consequently, India's steel plants are among the most carbon-intensive globally, with an average emission intensity of 2.54 tonnes of $CO_2$ per tonne of crude steel ($tCO_2$/tcs)—significantly higher than the global average of 1.91 $tCO_2$/tcs (Verma et al. 2024). Given the sector's projected growth, decarbonising steel production is critical for India to achieve its national climate commitments (Verma et al. 2024).

Among steelmaking routes, the C-DRI route is the most emissions-intensive, with an emissions intensity of 2.70–3.10 $tCO_2$/tcs (Verma et al. 2024). Unlike the larger, more integrated BF–BOF or natural-gas-based direct reduced iron–electric arc furnace (NG-DRI–EAF) routes, C-DRI production in India comprises a significant number of clustered, non-integrated units. It consists of a large number of small- and medium-sized units operating in industrial clusters. Many of these units often fall outside the scope of major government decarbonisation initiatives such as the *Perform, Achieve, and Trade* (PAT) scheme (BEE 2023). Targeted efforts to decarbonise the C-DRI sector are therefore essential within India's broader steel sector transition.

Figure 1. Coal–direct reduced iron (C–DRI) represents a significant share of India's iron-production routes




*Source: Authors' illustration based on Verma, Neha, et al. 2024. Greening the Steel Sector in India: Roadmap and Action Plan. New Delhi: Ministry of Steel, Government of India.*

## 1.1 Direct reduced iron sector in India

India has remained the world's largest producer of DRI for the past 20 years. The DRI sector relies primarily on non-coking coal (both imported and domestic), iron ore (typically hematite), and limestone or dolomite. In FY 2023–24, it contributed approximately 29 per cent to the total steel production in India, amounting to 41.8 Mt (Figure 1). The country currently has 344 DRI units, of which 339 are coal-based and only 5 are gas-based. The sector exhibits significant diversity in production capacities. More than half (61 per cent) of these DRI plants are standalone units, in which DRI is produced as the final product. Most DRI plants in the country are small- and medium-sized, with capacities of ≤0.15 million tonnes per annum (Mtpa) (Verma et al. 2024).

Over the past five years, DRI production trends have fluctuated, though overall production has risen. Gas-based production declined steadily from 2018–19 to 2020–21, reaching a low of 6.15 Mt, before rising to 8.98 Mt in 2021–22 and then decreasing slightly again in 2022–23. In contrast, coal-based production has mostly risen, from 28 Mt in 2018–19 to a high of 36 Mt in 2022–23, despite some fluctuations. As a result, total production followed a similar path–dipping in 2020–21 but recovering strongly to reach its peak in 2022–23 at 44 Mt (Figure 2). This trend indicates that while gas-based production has been unpredictable, coal remains the dominant force driving overall growth in the sector (SIMA 2023).

Figure 2. C-DRI continues to dominate India's DRI production and growth


*Source: Authors' illustration based on data from Sponge Iron Manufacturers Association (SIMA), DRI Production Data (FY2019–FY2023). 2024.*

## Challenges in the DRI sector

The DRI sector faces several challenges, including its high reliance on coal-based production processes and low energy efficiency (EE). Natural gas–based DRI production through vertical-shaft kilns emits around 65 per cent lower $CO_2$ emissions than C-DRI at the plant boundary level. However, it is not widely adopted in India due to high capital costs and higher gas prices (Nduagu et al. 2022). Within the more prevalent C-DRI segment, the penetration of EE measures remains low, especially among lower-capacity kilns. For instance, CEEW's 2023 survey of 16 DRI plants with a capacity below 300 tonnes per day (tpd) found that only one plant had installed a waste heat recovery boiler (WHRB). Adoption of other EE interventions, such as preheating, variable voltage frequency drives (VVFDs), and ore beneficiation, was below 10 per cent (Nitturu et al. 2024).


C-DRI emits 2.7–3.1 $tCO_2$/tcs; decarbonising this 30% production share is critical to achieving India's national climate goals.

Further, low-hanging measures, such as EE and renewable energy (RE), have a limited role in the decarbonisation of C-DRI steelmaking. The bulk of decarbonisation will need to come from carbon capture, utilisation, and storage (CCUS) (Elango et al. 2023; Sripathy et al. 2025). The steel industry's inherent complexities, such as long asset lifespans and high replacement costs, further complicate the transition to low-carbon technologies. Addressing these challenges requires a comprehensive set of legislative, regulatory, policy, and institutional frameworks to support the sector's low-carbon transition.

## Policy and institutional support for decarbonisation

The Ministry of Steel (MoS) and nodal agencies such as the Bureau of Energy Efficiency (BEE) have recognised the importance of decarbonisation in the sector. Key initiatives, such as the BEE's PAT scheme, set specific energy consumption (SEC) targets for designated consumers in the steel sector. Decarbonisation efforts are also being advanced by integrated steel plants (ISPs), such as JSW steel and Tata Steel. Recent developments in 2024, such as the Green Steel Roadmap (Verma et al. 2024) and the Green Steel Taxonomy (MoS 2024), signal further momentum for decarbonising the sector.

However, these initiatives have primarily benefited larger ISPs and some DRI units. Coordinated, cluster-level interventions could help extend these benefits to smaller DRI units in the cluster. Under its *Small and Medium Enterprises: Energy Efficiency Knowledge Sharing* (SAMEEKSHA) initiative, the BEE has undertaken situation analyses of secondary steel industry (SSI) clusters in Raipur and Sundargarh. These studies offer valuable insights into manufacturing processes, technology use, and energy consumption. However, they do not adequately address the specific challenges faced by the DRI sector, particularly in the small-and-medium-enterprise (SME) segment. Decarbonisation in this segment remains constrained by low awareness, limited technological alternatives, and inadequate access to finance.

Nonetheless, large parts of the industry will fall under the ambit of the upcoming National Carbon Market (NCM), which aims to set emission-reduction obligations for designated entities and replace the PAT scheme. However, its effectiveness will depend on the readiness of smaller units to measure, report, and verify (MRV) emissions accurately and participate in credit trading mechanisms. Without complementary technical and financial support, many DRI–IF units may face compliance burdens rather than transition opportunities. Strengthening technical capacity, establishing dedicated financing mechanisms at the cluster level, and improving coordination between state and central programmes will be essential to ensure that policy instruments such as the NCM lead to meaningful, on-ground decarbonisation outcomes across clusters.

## Exploring a cluster-based approach for DRI units

Given the complexity and unique structure of India's DRI steel sector, this study aims to explore the scope for adopting a cluster-based approach to decarbonise the steel industry. Such an approach is particularly relevant for SMEs in the DRI segment, which are often unable to implement decarbonisation alternatives as individual units. Due to the proximity and similar characteristics of plants in the same cluster, it is easier to implement shared technologies, enhance EE, and reduce emissions. The scoping study aims to provide an overview of the DRI sector and undertakes a detailed assessment of select clusters: Raipur and Raigarh in Chhattisgarh, Jharsuguda and Sundargarh in Odisha, and Bellary in Karnataka. Beyond describing these clusters, the report outlines an operational framework to guide the phased implementation of decarbonisation measures in the selected regions.

SME steelmaking is currently dominated by coal-based DRI–IF routes, creating a carbon lock-in with high emission intensities across clusters.

The study's objectives are to:

- Strengthen the foundational understanding of the DRI sector by conducting comprehensive plant-level surveys to outline emissions profiles, complemented by an in-depth analysis of cluster-level ecosystems to provide a holistic perspective.
- Leverage insights from the study to develop an evaluation framework that ranks clusters based on their potential for intervention and design a phased action plan with detailed financial estimates to facilitate implementation.
- Develop sector-level and cluster-specific recommendations to enable decarbonisation of the sector.

# 1.2 Research framework and methodology

**Step 1: Understanding the landscape**: As a first step, secondary data obtained from the *Joint Plant Committee Report* (JPC 2021–22) were used to identify prominent steel clusters across India. This was done based on the number of plants and their total production capacity at both the state and cluster levels.

**Step 2: Selection of suitable clusters**: Following secondary research, consultations were held with the Sponge Iron Manufacturers Association (SIMA), the apex body for DRI steel production in India, to identify clusters for in-depth analysis. The objective was to develop an operational framework that leverages cluster-level characteristics to facilitate demand aggregation and enable a low-carbon transition.

**Step 3: Site visits**: Once clusters were identified, site-level assessments were conducted. Preparatory steps included developing a survey questionnaire and a list of questions to explore ecosystem-level characteristics. A list of DRI plants was obtained from SIMA, and local state-level sponge iron associations and experts were engaged to support and facilitate plant visits.

**Step 4: Cluster profiling through data analysis**: The data collected through plant-level surveys and consultations were analysed to determine each cluster's emissions profile, extent of EE interventions, and adoption of RE. The analysis also highlighted key cluster characteristics that could facilitate the transition to a low-carbon steel cluster.

**Step 5: Development of the evaluation framework**: Data collection and preliminary analysis are followed by defining the broad elements of the evaluation framework. The framework comprises two key dimensions–decarbonisation cost and readiness–to integrate both quantitative and qualitative aspects necessary for a low-carbon transition. A list of suitable indicators for each dimension was identified and refined to ensure relevance. Alternate approaches were also explored to allow the model flexibility and ensure adoption.

**Step 6: Cluster comparison and policy recommendations**: As a final step, the evaluation framework was applied to the five selected clusters, and the scores were plotted on a graph. The analysis and findings informed a detailed set of recommendations for the sector and cluster-specific actions to guide implementation.

Primary surveys populate the framework, enabling cluster comparisons and evidence-based policy recommendations.


# 2. Cluster selection for survey

Sponge iron units and finished steel-producing plants, such as IFs and rolling mills are often found near each other, forming industrial clusters. Most of these clusters are located in mineral-rich regions, benefiting from the availability of iron ore, coal, and other allied infrastructure. However, these vary widely in characteristics, based on the capacity and number of sponge iron and steel-producing units, the type of raw material (lump ore or pellets), fuel source (domestic or imported coal), and the scrap used. Some units operate as standalone DRI plants, while others have downstream integration with IFs/EAFs and/or rolling/rerolling mills. Certain steel mills also have upstream integration, with the presence of pellet-making and/or beneficiation plants. This chapter reports a pre-analysis of these industrial clusters based on their characteristics and identifies suitable clusters for further detailing and surveys.

## 2.1 Steel clusters in India

The first step in cluster-level decarbonisation is to identify key DRI clusters across India. We achieve this by mapping all major sponge iron plants and assessing their geographic distribution and production capacities. We first determine the state-level DRI production capacities and then identify, within each state, the top districts with the highest sponge iron production capacities. Based on the GIS plots created, we identify sponge iron clusters within the top districts in each state. Since this research focuses on steel clusters rather than sponge iron clusters alone, we also map IFs, EAFs, and rolling/rerolling mills in the sponge iron clusters to provide a holistic perspective on cluster-level decarbonisation.

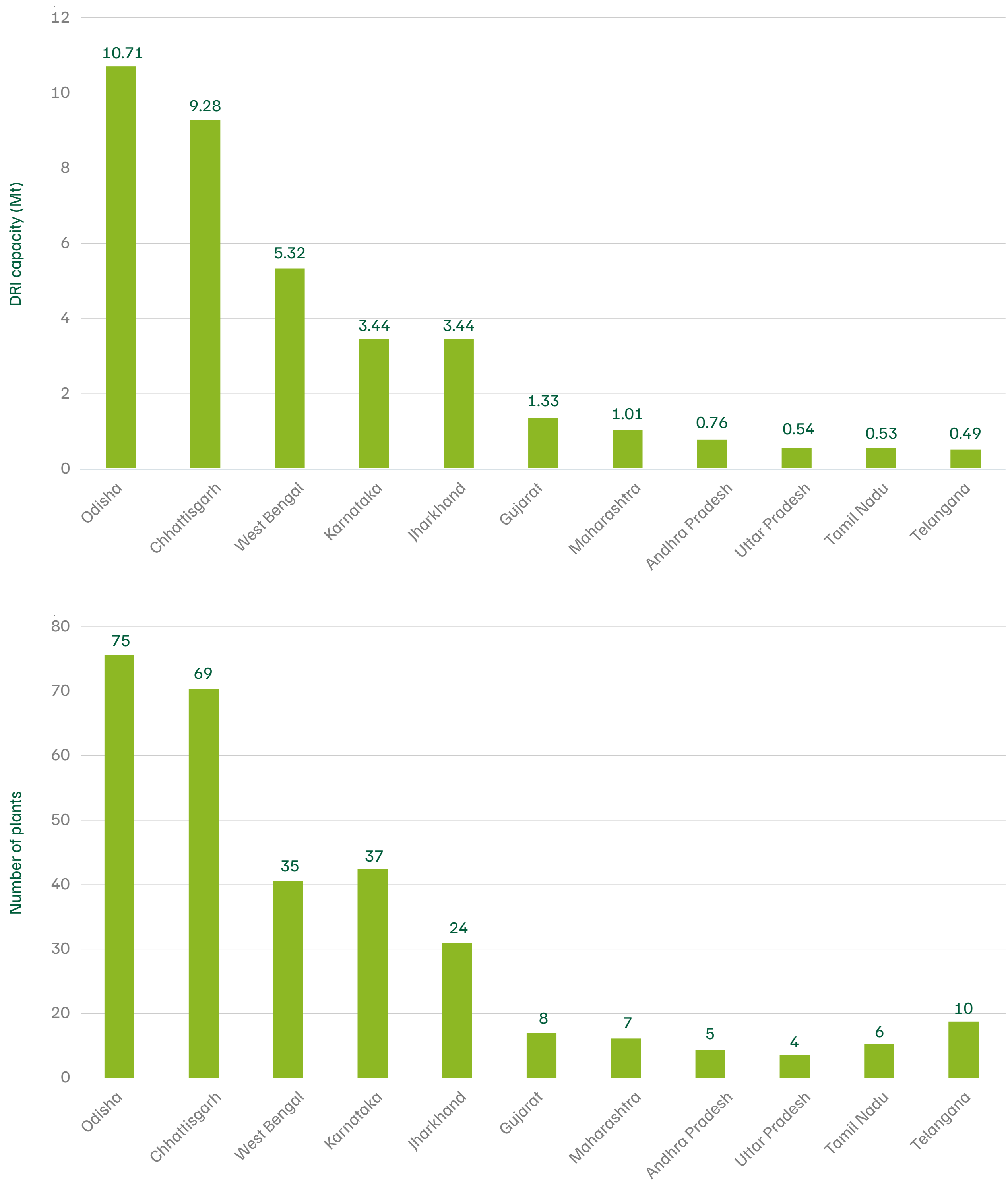
We mapped India's DRI plants using data on resources, industry, terrain, and transition infrastructure.

In addition to steel-related characteristics, we also characterise the clusters based on the availability of decarbonisation levers, such as RE (wind and solar potential), $CO_2$ storage reservoirs (oil and gas fields, coal fields, basalts, and saline aquifers), crop-residue-based biomass availability, and access to NG pipelines. We also map the regulatory ecosystem, such as the coverage of steel plants under the PAT scheme, as well as the financial profile of units, such as distinguishing between listed and unlisted companies.

## 2.2 District-level analysis of steel clusters in India

For the district-level analysis, we use datasets available from both primary and secondary sources (JPC 2021–22; Verma et al. 2024) for 2021–22. In that year, India had a total sponge iron production capacity of 37 Mtpa distributed across 283 plants. As indicated in Figure 3, this capacity is concentrated mainly in the coal- and/or iron-rich states of Odisha, Jharkhand, Chhattisgarh, West Bengal, and Karnataka, which together constitute 86 per cent of India's total DRI capacity and 85 per cent of the total number of sponge iron plants in the country.

Figure 3. Top five states account for 86% of India's DRI capacity and 85% of its sponge iron plants




*Source: Authors analysis based on data from Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata.*

Very few districts dominate DRI production capacity within the top five states indicated in Figure 3. Our research identifies 52 districts in India with DRI units, of which only 10 have a capacity exceeding 1 Mtpa. These 10 districts together account for 72 per cent of the country's total capacity. For detailed analysis and pre-cluster assessment, we selected the top 6 districts, which together produce about 19.67 Mtpa (53 per cent of total production capacity). A comprehensive mapping of all districts and their capacities is provided in Annexure 1.

Table 1 and Table 2 list the DRI production capacities and number of plants across these top six districts. Since the analysis focuses on steel cluster-level transitions, the tables also include corresponding values for IFs, EAFs, and finished steel production across these districts. Our research indicates that the Raipur and Raigarh districts in Chhattisgarh have the highest DRI production capacities, with the Raipur cluster showing significantly higher IF capacity, while the Raigarh cluster hosts large-capacity EAF units. The number of DRI units is also significantly higher in Raipur than in Raigarh. In both districts, crude-steel capacity exceeds DRI capacity, indicating that IF and EAF units additionally rely on scrap, import hot-briquetted iron from other clusters, or use hot metal for steel production. Finished-steel production capacity exceeds crude-steel production capacity in Raipur but falls short in Raigarh.

Table 1. Raipur and Raigarh district in Chhattisgarh have the highest capacity of DRI and induction furnace (IF) plants

| Sr no | State | District | DRI capacity (Mt) | IF capacity (Mt) | EAF capacity (Mt) | Finished steelmaking capacity (Mt) |
|---|---|---|---|---|---|---|
| 1 | **Chhattisgarh** | Raipur | 5.02 | 5.23 | 1.19 | 8.50 |
| 2 | **Chhattisgarh** | Raigarh | 3.76 | 1.94 | 5.10 | 3.17 |
| 3 | **Odisha** | Sambalpur | 3.16 | 0.44 | 2.75 | 0.38 |
| 4 | **Odisha** | Sundargarh | 2.98 | 1.51 | 0.00 | 1.01 |
| 5 | **West Bengal** | Bardhaman | 2.38 | 3.53 | 0.47 | 8.35 |
| 6 | **Karnataka** | Bellary | 3.56 | 0.37 | 2.00 | 4.06 |
| | **Total** | | **20.87** | **13.01** | **11.51** | **25.48** |

*Source: Authors' analysis based on data from Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata.*

The Sambalpur and Sundargarh clusters have similar DRI production capacities but differ significantly in the number of sponge iron plants. Sambalpur hosts a few large-capacity DRI plants, whereas Sundargarh has a large number of small-capacity units. This is also evident from the presence of a large-capacity EAF unit in Sambalpur and several IF units in Sundargarh. The Bardhaman district in West Bengal exhibits characteristics similar to the Sundargarh district in Odisha. Bellary presents a unique case, showing significant diversity in sponge iron units but only two IFs, one EAF, and four finished steel production plants.

Table 2. Raipur has the highest number of DRI and IF plants, followed by Sundargarh

| Sr no | State | District | DRI plants | IF plants | EAF plants | Finished steel plants |
|---|---|---|---|---|---|---|
| 1 | **Chhattisgarh** | Raipur | 44 | 54 | 1 | 109 |
| 2 | **Chhattisgarh** | Raigarh | 17 | 29 | 2 | 13 |
| 3 | **Odisha** | Sambalpur | 8 | 2 | 1 | 1 |
| 4 | **Odisha** | Sundargarh | 40 | 28 | 0 | 14 |
| 5 | **West Bengal** | Bardhaman | 20 | 24 | 2 | 27 |
| 6 | **Karnataka** | Bellary | 26 | 3 | 1 | 4 |
| | **Total** | | **155** | **140** | **7** | **168** |

*Source: Authors' analysis based on data from Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata.*

## 2.3 Cluster pre-analysis across select districts

This section of the report builds on the district-level analysis reported in Section 2.2 and extends it to the steel clusters across these districts. As discussed earlier, in addition to the steel plants, we also consider decarbonisation levers, infrastructure availability, and regulatory enablers for the cluster pre-analysis. The factors considered for the pre-analysis include:

1. **Natural resources and geological features**: Solar and wind availability for meeting electricity demand, along with the presence of $CO_2$ storage reservoirs (basalt, saline aquifers, oil fields, and coal fields) in the cluster are the key decarbonisation levers considered in developing the evaluation framework. Data on RE availability and the location of $CO_2$ storage reservoirs are obtained from our earlier research (Mallya et al. 2024; Bakshi et al. 2023).

2. **Industrial facilities**: The presence of industrial facilities in the cluster can act as an enabler for decarbonisation. In this regard, our pre-cluster analysis accounts for proximity to upstream emission-mitigating enablers, such as pellet plants and iron ore mines. The presence of fertiliser (urea and non-urea) plants and refineries can also help support the development of a green hydrogen ecosystem in steel clusters. Therefore, industries that are end consumers of green hydrogen are also considered in our assessment. The PAT scheme has provided important institutional and technical learnings—particularly in target-setting, certificate trading, and monitoring, reporting, and verification (MRV)—that inform the design of the upcoming *Carbon Credit Trading Scheme* (CCTS). Therefore, we also separately identify steel mills covered under the PAT scheme. We also consider publicly listed companies as a parameter, as they are more likely to get access to the finance needed for decarbonisation due to stronger balance sheets.

3. **Topography**: Biomass is a potential fuel that can be used for transition in the steel cluster. Therefore, we also consider croplands as a key resource in our pre-cluster analysis.

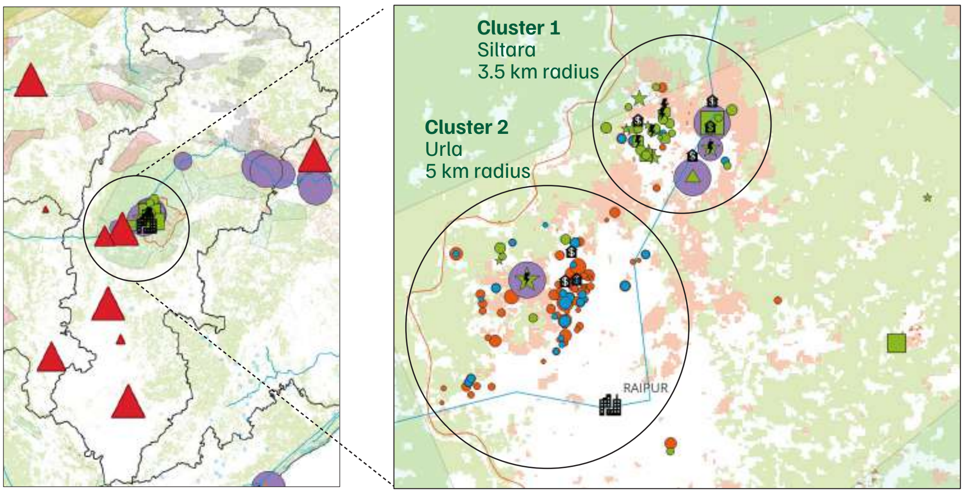
4. **Infrastructure**: Natural gas represents a transitional fuel towards green hydrogen for the steel industry. However, access to NG remains limited across major steel-producing states. Therefore, the infrastructure for decarbonisation through the NG route is also considered as a factor in our pre-cluster analysis. Additionally, proximity to district headquarters is also considered, as it provides access to financing institutions and other enablers that might be required for supporting the transitions in the steel cluster.

In this section, we detail the pre-cluster analysis and mapping of three significant districts across three different states–Raipur (Chhattisgarh), Bellary (Karnataka), and Sundargarh (Odisha). The remaining districts–Raigarh (Chhattisgarh), Sambalpur (Odisha), and Bardhaman (West Bengal)–are detailed in Annexure 1.

## Raipur district

Figure 4 maps the Siltara and Urla clusters in the Raipur district. Based on the parameters outlined in Section 2.3, the cluster radius was determined by encircling closely located units. The Siltara cluster has a radius of 3.5 km, while the Urla cluster extends over a 5 km radius. Siltara is dominated by DRI units (30) and DRI–IF units (20), whereas Urla hosts a higher concentration of rerolling units (72). Both clusters are situated relatively close to the district headquarters. The clusters have a notable concentration of pellet-making units and are surrounded by croplands, which offer opportunities to utilise biomass in iron-making. The clusters also have high solar energy potential, access to an NG pipeline, and a saline aquifer, which can aid in carbon capture and storage (CCS). Raipur has access to iron ore from mines in Durg and other southern districts of Chhattisgarh, which produce high-grade iron ore within the Durg–Bastar–Chandrapur haematite belt. However, the clusters in Raipur lack wind potential. Despite this, the Raipur clusters remain the most diverse and extensive among those studied, making them well-suited for decarbonisation initiatives.

Figure 4. Siltara and Urla are the major steel clusters in Raipur



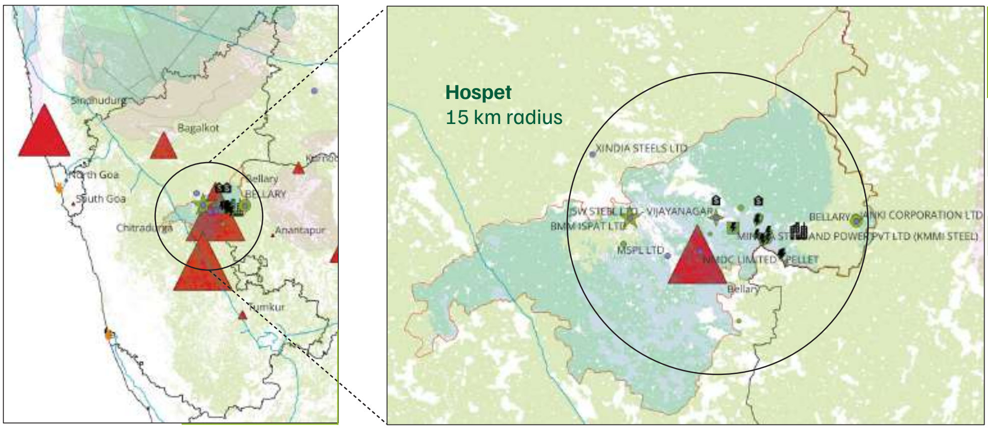

| Iron ore mine District | Share of ore above 60% Iron content |
|---|---|
| Dantewada | 99.5% |
| Durg | 91.7% |
| Kanker | 35.1% |
| Narayanpur | 2.9% |
| Rajnandgaon | 6.6% |

*Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and Climate Nexus. New Delhi: Council on Energy, Environment and Water; Indian Bureau of Mines. 2024. Indian Minerals Yearbook 2022: Mineral Reviews, Volume III. Nagpur; and other public data.*

## Bellary district

Figure 5 highlights the Bellary cluster, distinguished by its significant RE potential, both solar and wind. Bellary is located in Karnataka's iron ore–rich region, ensuring easy access to ore materials. The cluster spans a radius of 15 km and is well spread out. It has several DRI units (27) and very few IF and rerolling units. The lack of domestic coal availability means the cluster is dependent on imported coal to operate its rotary kilns. Additionally, the NG pipeline passing through the Vijayanagara district is at least 70 km away from the cluster. The cluster also lacks any CCS potential.

Figure 5. The Bellary cluster has abundant wind and solar power




| Iron ore mine District | Share of ore above 60% Iron content |
|---|---|
| Bagalkot | 0.0% |
| Bellary | 49.5% |
| Chitradurga | 6.2% |
| Tumkur | 0.0% |

Standalone DRI · DRI–IF · DRI–EAF · DRI–IF-rerolling · DRI–EAF-rerolling · Standalone IF · Standalone rerolling

Solar availability · Wind availability · Basalt · Saline aquifer · Oil fields · Coal fields · Pellet plant · Iron ore mine

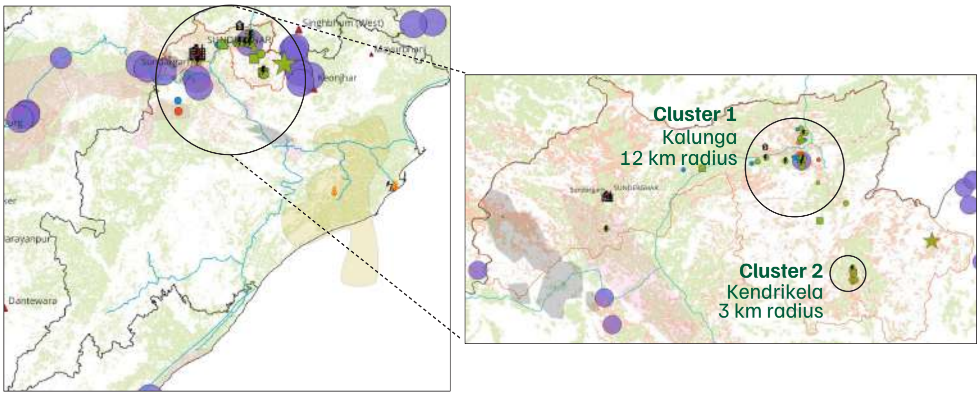
Cropland · Bare land · NG pipeline · Non-urea plants · Urea plants · Refineries · Under PAT · Listed company · District HQ

*Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and Climate Nexus. New Delhi: Council on Energy, Environment and Water; Indian Bureau of Mines. 2024. Indian Minerals Yearbook 2022: Mineral Reviews, Volume III. Nagpur; and other public data.*

## Sundargarh district

Figure 6 maps the clusters in Sundargarh, with units located in the Kalunga (12 km radius) and Kendrikela (3 km radius) clusters. Although smaller in capacity than the clusters in Raipur and Bellary, the Sundargarh clusters host 26 DRI units, 5 IF units, and 9 rerolling units in Kalunga, and 8 DRI units and 2 IF plants in Kendrikela. Like the Chhattisgarh clusters, Sundargarh also has high solar potential but no wind potential. It has the presence of NG pipeline and saline aquifers, both of which can significantly aid in low-carbon DRI production. It also benefits from the presence of minerals, including iron ore and coal, in nearby districts. While there is only 1 pellet-making unit in the cluster, the state has 12 pellet plants in total.

Figure 6. Sundargarh has two clusters and an abundant availability of coal and iron ore




| Iron ore mine District | Share of ore above 60% Iron content |
|---|---|
| Keonjhar | 75.2% |
| Mayurbhanj | 5.8% |
| Sundargarh | 62.9% |

Standalone DRI | DRI–IF | DRI–EAF | DRI–IF-rerolling | DRI–EAF-rerolling | Standalone IF | Standalone rerolling

Solar availability | Wind availability | Basalt | Saline aquifer | Oil fields | Coal fields | Pellet plant | Iron ore mine

Cropland | Bare land | NG pipeline | Non-urea plants | Urea plants | Refineries | Under PAT | Listed company | District HQ

*Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and Climate Nexus. New Delhi: Council on Energy, Environment and Water; Indian Bureau of Mines. 2024. Indian Minerals Yearbook 2022: Mineral Reviews, Volume III. Nagpur; and other public data.*

## 2.4 Rationale for cluster selection

We use a mix of quantitative and qualitative research and inputs to select clusters for further detailing and to develop an evaluation framework. The quantitative selection criteria are based on the diversity of units and capacities across various stages of secondary steelmaking, as well as on geographical considerations, such as the presence of iron ore mines, coal reserves, basalt, and saline aquifers. They also consider infrastructure availability, such as the presence of NG pipelines, that can aid in decarbonisation. The qualitative criteria are shaped by stakeholder consultations, industry priorities, prior research, practical challenges, and efforts in order to develop a holistic and robust evaluation framework.

Table 3 compares the key characteristics of various clusters based on their production capacities, number of units, and geographical spread. The listed clusters include those from Chhattisgarh, Odisha, West Bengal, and Karnataka, with indicators such as DRI, IF, finished steel capacities, the number of plants, and cluster radius. As the primary objective of this study is to develop an evaluation framework for transition in DRI clusters, preference is given to clusters with higher capacity and a greater number of DRI units. Among the clusters analysed, Siltara, Punjipatra, and Kalunga are more suitable for detailed surveys due to their higher number and capacity of DRI plants. Additionally, these clusters have a higher concentration of IFs and finished steelmaking units than the rest.

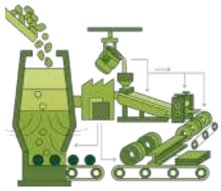
Table 3. Siltara, Punjipatra, Kalunga, and Hospet have high DRI capacities and number of units

| Sr no | Cluster (district, state) | DRI capacity (Mt) | IF capacity (Mt) | EAF capacity (Mt) | Finished steel capacity (Mt) | No of DRI plants | No of IF plants | No of rerolling mills | Cluster radius (km) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **Siltara (Raipur, Chhattisgarh)** | 3.39 | 3.60 | 1.19 | 3.04 | 30 | 20 | 15 | 3.5 |
| 2 | **Urla (Raipur, Chhattisgarh)** | 0.91 | 1.89 | 0.00 | 4.22 | 6 | 24 | 72 | 5.0 |
| 3 | **Punjipatra (Raigarh, Chhattisgarh)** | 3.46 | 0.85 | 5.10 | 2.69 | 16 | 19 | 12 | 12.0 |
| 4 | **Rengali (Sambalpur, Odisha)** | 3.04 | 0.44 | 0.17 | 0.17 | 7 | 2 | 1 | 18.0 |
| 5 | **Kendrikela (Sambalpur, Odisha)** | 0.52 | 0.19 | 0.00 | 0.00 | 8 | 2 | 0 | 3.0 |
| 6 | **Kalunga (Sundargarh, Odisha)** | 1.46 | 0.69 | 0.00 | 0.58 | 26 | 5 | 9 | 12.0 |
| 7 | **Jamuria (Bardhaman, West Bengal)** | 1.54 | 1.64 | 0.00 | 1.44 | 8 | 6 | 7 | 4.5 |
| 8 | **Durgapur (Bardhaman, West Bengal)** | 0.60 | 1.07 | 0.24 | 1.84 | 7 | 10 | 12 | 6.0 |
| 9 | **Hospet (Bellary, Karnataka)** | 2.36 | 0.25 | 2.00 | 3.97 | 21 | 2 | 3 | 15.0 |
| | | **14.03** | **10.62** | **8.7** | **17.95** | **129** | **90** | **131** | **-** |

*Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata.*

Note: Clusters with relatively higher capacity and plant count are highlighted in green.

The nine clusters listed in Table 3 are compared to develop a pre-cluster analysis score, which helps identify the clusters best suited for the survey. The overall scores are presented in Annexure 1. The scoring is based on comparisons of capacities and unit counts across DRI, IF, EAF, pellet-making plants, and rerolling mills. In addition, a binary scoring system is applied to capture the presence or absence of enabling factors, such as listed companies (Annexure 3), PAT-covered units (Annexure 3), NG pipelines, biomass availability, RE potential, open-access (OA) and grid-tariff conditions, CCS potential, and the proximity of refineries or fertiliser plants.



A combined quantitative–qualitative approach guided the selection of representative steel clusters.

The pre-cluster analysis using quantitative parameters in Table 3 indicates that Siltara, Urla, Punjipatra, and Hospet are favourable clusters for further detailing. Figure 7 summarises each cluster considered in the pre-cluster analysis. Clusters indicated in green and blue are most suited for further analysis, while those indicated in orange are considered not significant, aligning with the results of the quantitative analysis in Table 3.

The Siltara and Urla clusters in Raipur are identified as the most suitable for detailed analysis. However, these clusters have already been evaluated in earlier studies (TERI 2024). Additionally, we have data from our prior surveys in the Raipur, Raigarh, and Hospet clusters (indicated in blue) (Nitturu et al. 2024). Based on these findings, stakeholders such as SIMA recommended prioritising emerging clusters in Odisha and re-evaluating Bellary, where ownership structures have recently changed. Accordingly, we conducted new surveys in Bellary, Sundargarh, and Jharsuguda. The evaluation framework is therefore developed for five clusters: Raipur (Siltara and Urla), Raigarh (Punjipatra), Bellary (Hospet), Sundargarh (Kalunga), and Jharsuguda.

## Figure 7. Considerations for cluster selection also involve qualitative factors

### Siltara (Raipur)

- Highest DRI capacity (3.39 Mt) and number of plants (30)
- Highest IF capacity (3.6 Mt) and number of plants (20)
- Covers all categories of plants DRI/IF/EAF/rerolling
- Smaller cluster radius of 3.5 km meaning dense cluster
- Has CCS potential
- Significant no. of plants under PAT scheme (5)
- Most number of listed companies (4)
- OA charges lower than grid power
- Accessible to NG pipeline

### Hospet (Bellary)

- Second-highest DRI capacity (2.36 Mt) and 21 DRI plants
- Second-highest EAF capacity (2 Mt)
- Cluster radius of 15 km
- Highest number of plants under PAT scheme (11)
- RE availability – only cluster with solar and wind potential
- OA charges lower than grid power

### Kalunga (Sundargarh )

- Less DRI capacity (1.46 Mt) but has higher number of plants (26)
- Cluster radius of 12 km
- Moderate IF coverage (5)
- Significant number of plants covered under PAT scheme (5)
- Accessible to NG pipeline

### Jamuria (Bardhaman)

- Fairly distributed DRI/IF/rerolling capacity
- Dense cluster of 4.5 km radius
- Has only 8 DRI plants, one standalone IF, no EAF plants
- No plants under PAT scheme
- No listed companies

### Urla (Raipur)

- Low DRI capacity (0.91 Mt)
- No EAF plant, hence less diversity
- Cluster has mostly rerolling mills (72) – 55% of rolling mills alone in Urla within the selected districts
- No listed DRI units – 3 plants listed are standalone IF and re-rolling mills
- Can be clubbed with Siltara cluster due to geographical proximity

### Punjipatra (Raigarh)

- Largest DRI capacity (3.46 Mt) but only dominated by 2 companies (53%), hence lesser diversity
- Very small capacity of IF plants

### Rengali (Odisha)

- High DRI capacity (3.04 Mt) but not many plants (7)
- Bigger cluster radius of 18 km, hence lesser plant density
- Only 1 listed company

### Kendrikela (Odisha)

- Lowest DRI capacity (0.52 Mt)
- Only 1 plant in the cluster covered under PAT scheme
- No listed company

### Durgapur (Bardhaman)

- Second-lowest DRI capacity (0.6 Mt)
- No plants under PAT scheme

*Source: Authors' analysis*

Note: Blue indicates clusters suitable for survey and previously covered by CEEW; green indicates clusters covered for survey under this report; grey indicates clusters not suitable for survey.


# 3. Survey findings and cluster profile

Following the stakeholder-driven prioritisation of emerging clusters, we conducted detailed surveys across Odisha and Karnataka between September and October 2024. As outlined in Chapter 2, the Odisha surveys covered the Jharsuguda and Sundargarh clusters, whereas in Karnataka, the focus remained solely on the Bellary cluster. This chapter presents the findings from these surveys while also integrating insights from our previous surveys in Raipur (Siltara and Urla), Raigarh (Punjipatra), and Bellary (Hospet) in 2023, wherever relevant, to enable comparison and inform the evaluation framework.

# 3.1 Survey methodology

## Description of sampling approach

The survey employed a hybrid sampling approach that integrated convenience and snowball sampling techniques to select and involve sponge iron plants. The process commenced with site visits to plants that had expressed interest in participating. During these interactions, relationships were fostered with plant managers, who were subsequently requested to suggest and connect the survey team with additional plants in the surrounding area. This strategy expanded the scope of engagement, building trust and enthusiasm among participants and enhancing the overall effectiveness of the sampling process.

We first approached industry associations or energy service companies (ESCOs) in the cluster to get access to the DRI clusters. In Odisha, the survey was supported by Power Tech Consultants (PTC n.d.), a BEE-approved ESCO based in the state. Power Tech Consultants leverages its existing network to engage sponge iron plants willing to participate, resulting in a convenience sample of eight plants–two in Jharsuguda and six in Sundargarh.

In Karnataka, the Karnataka Sponge Iron Manufacturers Association (KSIMA) (KSIMA n.d.) played a pivotal role by providing a comprehensive list of sponge iron units operating within the Bellary cluster. Initial outreach targeted plant owners and managers identified from this list, and those who agreed to participate formed the initial convenience sample. To expand the sample, these senior representatives were asked to nominate additional plants that might be interested in joining the study, thereby incorporating a snowball sampling technique. This combined methodology led to the successful surveying of seven plants across the Bellary cluster.

## Data collection approach

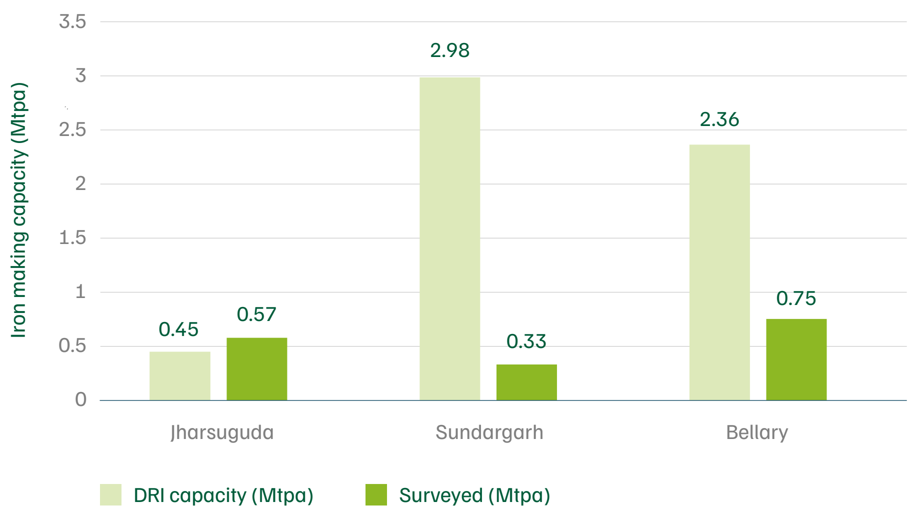
Primary data collection included site visits to the identified plants, during which structured interviews were the primary tool for gathering information. Each interview began with a concise explanation of the project's objectives to provide participants with context and clarity. Participants were assured that their data would remain confidential and would be utilised solely for research and to inform policy discussions on low-carbon DRI steel. The surveys primarily aimed to capture comprehensive insights into energy consumption trends, production processes, types of coal used, and prevailing energy-efficiency practices. Supplementary questions explored cluster-specific characteristics to identify opportunities and barriers to low-carbon transitions within the cluster. The detailed survey questionnaire is included in Annexure 2.

Our 2024 surveys covered 1.76 Mtpa—30% capacity—across Jharsuguda–Sundargarh and Bellary clusters.

## 3.2 Cluster characteristics and survey findings

Figure 8 and Table 4 present details of the surveyed clusters, including total capacity and the number of plants covered in the survey relative to the total capacity and number of plants in each cluster. The surveys conducted across Jharsuguda and Sundargarh in Odisha and Bellary in Karnataka together covered a total DRI capacity of 1.76 Mtpa out of an aggregate 5.79 Mtpa. In Jharsuguda, site visits were conducted at 2 out of 5 DRI plants, while in Sundargarh, 7 out of 40 DRI plants were surveyed in the Bonai and Kalunga areas. In Bellary, the survey covered 7 of the 26 DRI plants. Overall, the surveys captured approximately 30 per cent of the total DRI capacity across Jharsuguda, Sundargarh, and Bellary. It is worth noting that DRI capacities were estimated using datasets from 2021–22. Clusters in Odisha have seen significant capacity additions in the interim. For instance, while the dataset shows 0.45 Mt of capacity in Jharsuguda, the two plants surveyed alone accounted for 0.58 Mt during the survey. The surveyed plants included both single- and multiple-rotary kilns, with individual kiln sizes ranging from 75 tpd to 350 tpd.

Figure 8. Survey coverage compared to total cluster capacity




*Source: Authors' analysis*

Table 4. Our survey covers 15.6% of DRI plants in Odisha and 27 per cent in Karnataka

| Sr no | Place | No of plants surveyed | Total no of DRI plants in the cluster |
|---|---|---|---|
| 1 | **Jharsuguda** | 2 | 5 |
| 2 | **Sundargarh** | 7* | 40 |
| 3 | **Bellary** | 7 | 26 |

*Source: Authors' compilation of survey data*

*Note: Although six plants containing DRI and one standalone IF plant were surveyed in Sundargarh, data were not fully available for one plant and were therefore not used in developing the evaluation framework.

The findings from this survey are consistent with findings from prior surveys conducted in Chhattisgarh and Bellary in 2023. (Nitturu, et al. 2024) The assessments revealed that most of the surveyed units employed rotary kilns of Stelco-Lurgi/Republic Steel–National Lead (SL/RN) technology or variations of it. Table 5 integrates plant capacities across all five clusters covered in both surveys. These span a broad range of plant sizes, except in Sundargarh, where all plants had a uniform capacity of 200 tpd. Nonetheless, the choice of input materials varied across clusters, influenced by multiple factors, including costs and accessibility. The following sections detail the survey findings.

Table 5. Sample size of plant capacities surveyed to capture various energy efficiency measures

| Plant capacity (tpd) | Raigarh | Raipur | Bellary (2023) | Bellary (2024) | Sundargarh | Jharsuguda |
|---|---|---|---|---|---|---|
| **50** | - | - | 1 | - | - | - |
| **75** | - | - | - | 1 | - | - |
| **100** | - | 4 | 2 | 2 | - | - |
| **200** | 2 | 2 | 3 | - | 5 | - |
| **300** | 1 | 2 | - | 2 | - | - |
| **350** | - | - | - | 1 | - | - |
| **375** | - | - | 1 | - | - | - |
| **400** | 1 | - | 1 | - | - | - |
| **600** | | - | - | - | - | 1 |
| **>600** | 2 | 3 | - | 1 | | 1 |

*Source: Authors' analysis based on surveys conducted in 2023 and 2024; the 2023 survey is documented in Nitturu, Kartheek, Pratheek Sripathy, Rishabh Patidar, Sabarish Elango, Deepak Yadav, and Hemant Mallya. 2024. "Decarbonising Coal-Based Direct Reduced Iron Production: Surveying the Landscape in Steel Clusters of India." New Delhi: Council on Energy, Environment and Water, SED FUND.*

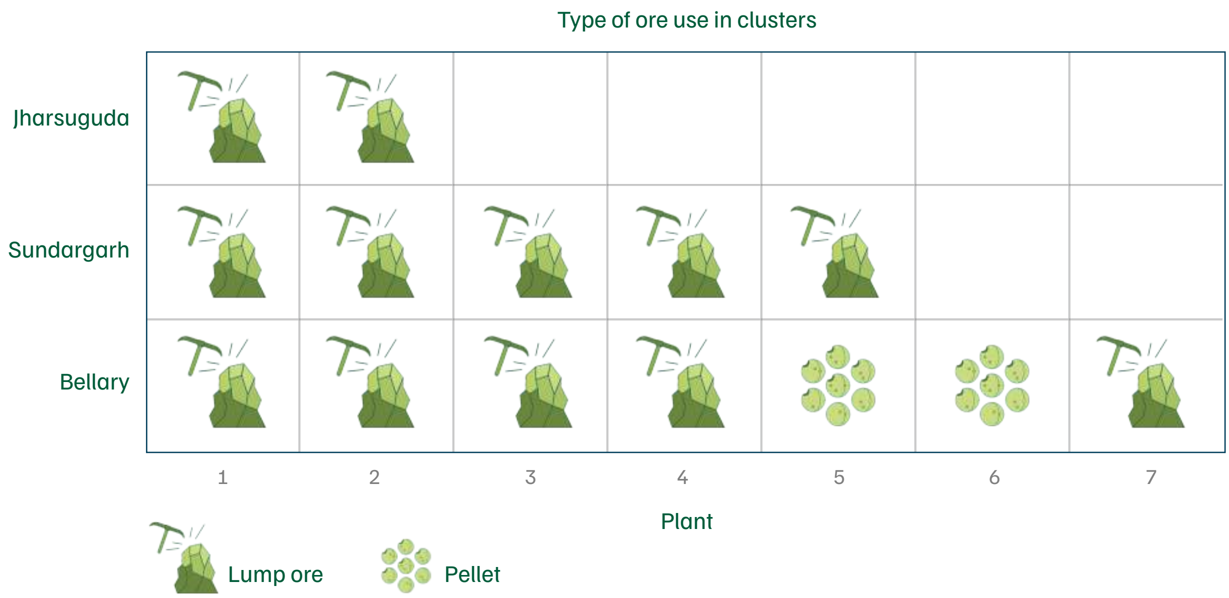
## Raw material consumption

Our survey indicates that pellets constitute only a small share of the raw material used across the DRI clusters. Figure 9 illustrates the variation in raw material use across the surveyed clusters. In Odisha, plants rely heavily on lump ore rather than pellets. One unit surveyed in Odisha had pellet-making capacity but reported selling pellets to units in Chhattisgarh rather than utilising them in its operations. The plant reported that lump ore prices were lower in Odisha, and selling pellets to Chhattisgarh was more profitable. As such, all plants in Odisha also reported reducing iron production during the survey period due to a cyclical slump in iron market prices.

Across India, pellet-making units had a total installed capacity of 106 Mtpa in FY 2022–23, with a capacity utilisation of 63 per cent (Verma et al. 2024). This reflects a lower demand for pellets within the steel sector. The Jharsuguda cluster had no pellet-making capacity, whereas Sundargarh had 0.6 Mtpa, according to our analysis of the database (JPC 2021 - 22). By comparison, the pellet consumption potential in Jharsuguda and Sundargarh is 0.62 Mtpa and 4.10 Mtpa, respectively, indicating that the existing pellet-making capacity falls below potential demand.

In the Bellary cluster, only two units used pellets as input, while all others utilised lump ore. The preference for lump ore was attributed to the high cost of pellets, even though pellets improve kiln operations and reduce maintenance downtime. Surveyed units reported pellet prices ranging from INR 8,000–10,000 per tonne, compared to INR 4,000–6,000 per tonne for lump ore. The Bellary cluster has a total pellet-making capacity of 6.8 Mtpa, excluding 16.4 Mtpa owned by JSW Steel Vijayanagar Works. The consumption potential among sponge iron units in the cluster is about 3.25 Mtpa of pellets, suggesting overcapacity but lower demand. Nevertheless, several plants reported using pellets in the past when costs were favourable and expressed a willingness to return to pellet use with improved access and cost competitiveness.

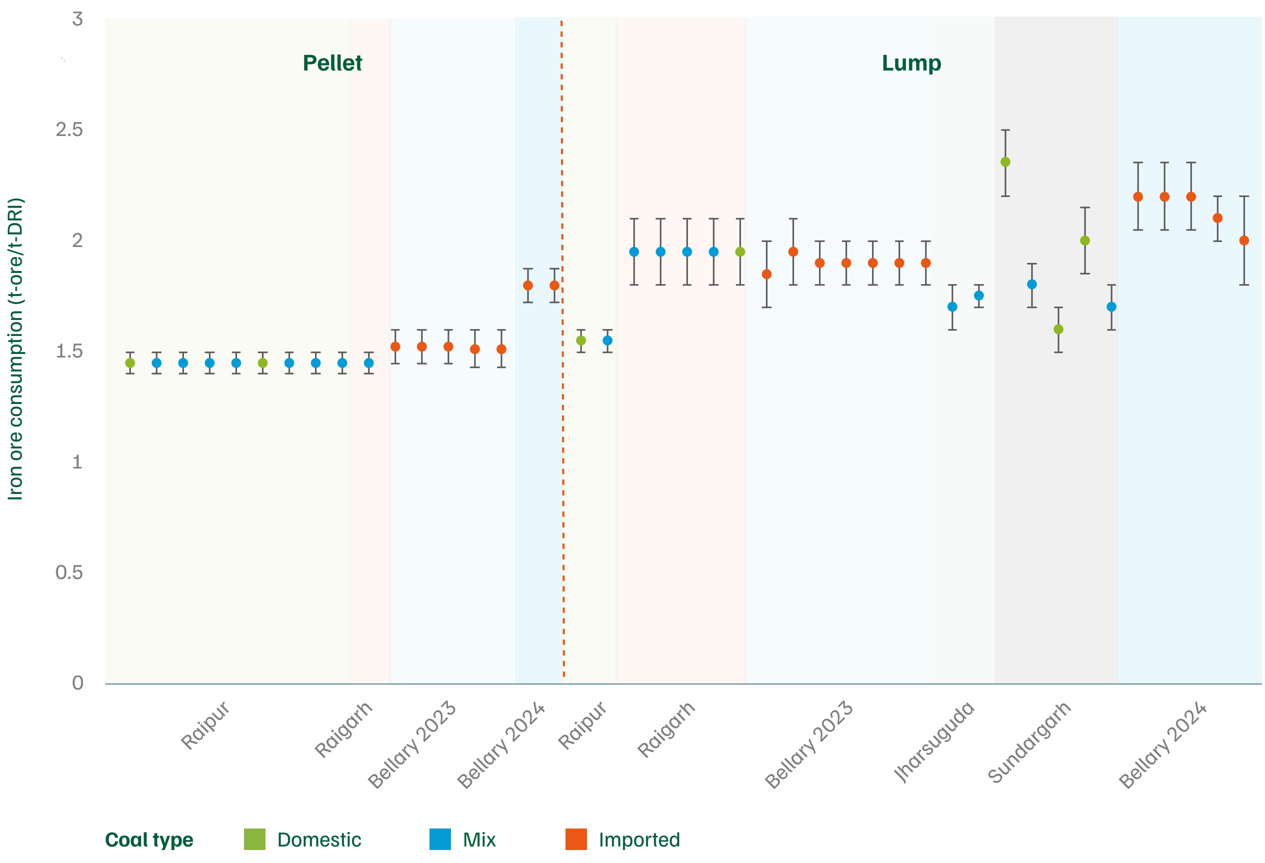
Figure 9. Pellets constitute a small share of the raw material used in DRI clusters




*Source: Authors' analysis*

Figure 10 integrates data from the 2023 DRI survey in Chhattisgarh and Bellary with findings from the current 2024 survey. The use of pellets in the kilns decreases ore use across clusters. On average, our survey indicates pellet consumption of 1.51 (1.45–1.57) t/t-DRI and lump ore consumption of 1.91 (1.79–2.03) t/t-DRI. Ore use also depends on the quality of the iron ore used in the kilns. Ores with a higher tumbler index[1] are preferred by the industry, as they contain fewer fines and thus result in lower wastage of ore (Singh and Jain 2015). In the 2024 survey, Bellary reported comparatively higher ore use, primarily due to the use of soft ore, resulting in 15–20 per cent wastage through fines and the breakage of lump ores into sizes unsuitable for rotary kilns. A significant accumulation of iron ore fines was found stored in the DRI plants in the survey in Bellary. Plants reported stricter environmental regulations and a quota-based system for transporting iron-ore fines as the primary reasons for this buildup. When permitted, fines were reportedly sold at INR 2,000 per tonne following clearance.

Figure 10. Use of lump ore increases iron ore consumption by 27% compared to pellet use



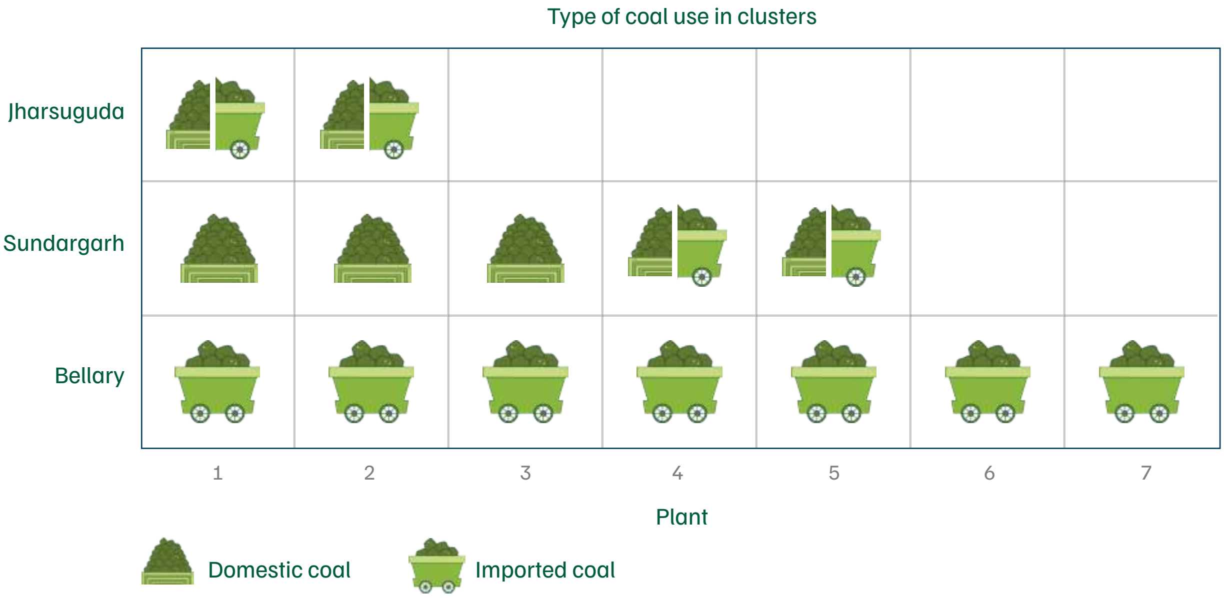

*Source: Authors' analysis*

1. The tumbler index measures the physical strength of iron ore, indicating its resistance to breaking and generating fine particles, particularly during handling and transportation.

## Coal utilisation

Similar to pellet and lump-ore use, coal utilisation is determined by several parameters, including the availability and access to domestic coal, the relative cost of domestic and imported coal, and the advantages of using low-ash coal as a blend. As depicted in Figure 11, all units in Bellary reported using imported Richard Bay grade 2 (RB2) coal from South Africa. Further, these units cited the superior quality of imported coal and limited access to domestic coal as the primary reasons for this preference. The Bellary cluster is located away from the coal-rich regions of India, and units have reported easier access to imported coal through nearby ports along the Konkan coast than to domestic coal from the coal-rich areas of Chhattisgarh and Odisha. In contrast, clusters in Odisha primarily use a blend of imported (RB2) and domestic coal, or in some cases, entirely domestic coal from the Talcher and Mahanadi coal fields. This disparity persists despite a notable cost difference between domestic and imported coal varieties. In Odisha, domestic coal was priced at INR 1,100–5,000 per tonne, depending on the coal grade, whereas in Bellary, imported coal was priced at INR 9,000–12,000 per tonne. It should be noted that the gross calorific value (GCV) of domestic coal ranged from 1,100 kCal/kg on the lower end to 5,000 kCal/kg on the higher side, while imported coal had a GCV of 5,000–6,000 kCal/kg.

Figure 11. The type of coal used depends on access and delivered costs in the cluster



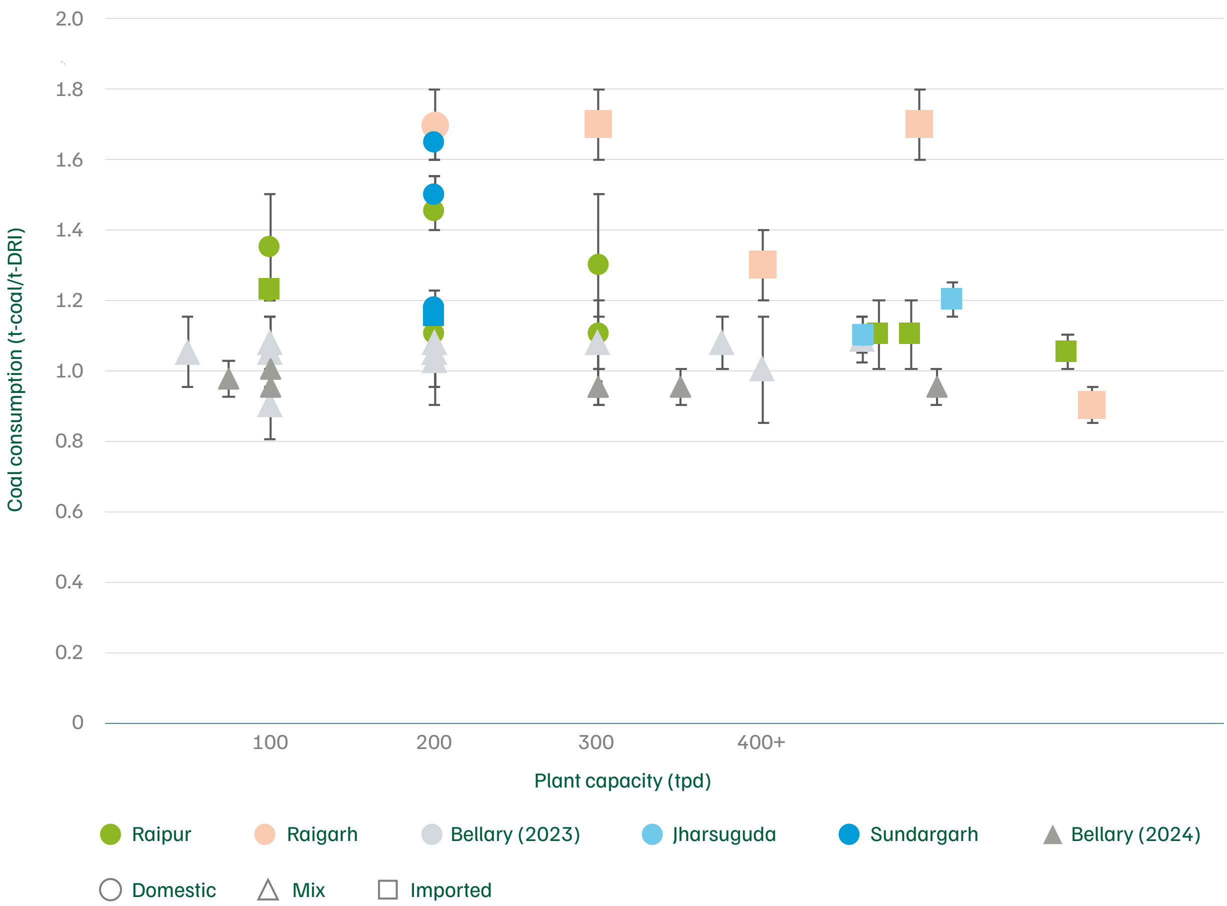

Domestic coal price: INR 1,100–5,000 per tonne depending on the grade of coal used in Odisha

Imported coal price: INR 9,000–12,000 per tonne reported in Bellary cluster

*Source: Authors' analysis*

Figure 12 tracks the coal consumption rate across plant capacities. The amount of coal consumed in a rotary kiln depends on many factors, primarily the type of coal and ore used, and the level of EE measures incorporated. For example, pre-heating of ore using waste heat recovery (WHR) can reduce energy consumption by up to 15 per cent, while the use of mullite lining in rotary kilns can reduce energy consumption by up to 1.5 per cent (Verma et al. 2024). The coal consumption per tonne of DRI produced in the case of imported coal use is notably lower than that of domestic and mixed coal use. This is attributed to the higher calorific value and lower ash content of imported coal. In contrast, domestic coal is characterised by high ash content and lower carbon content, with fixed carbon ranging from 50–60 per cent in imported coal and 28–32 per cent in domestic coal. Consequently, DRI plants in Bellary that use imported coal report lower coal consumption rates than other clusters. A few DRI plants in Raipur, Raigarh, and Jharsuguda, which use a mix of domestic and imported coal, consume higher amounts than Bellary. Across all coal categories and kiln sizes, Raigarh recorded the highest coal consumption, as its plants either use domestic coal or a mixture of domestic and imported coal.

## Figure 12. A significant discrepancy is noticed in the type and quantity of coal consumption across various clusters and kiln capacities




*Source: Authors' analysis*

Note: Plant sizes above 400 tpd are not proportional to the dimensions shown on the x-axis, to protect the proprietary information of the surveyed plants.

## Electricity consumption

Figure 13 illustrates the variation in power consumption for DRI production across various clusters and kiln sizes. Consistent with the trends observed in Figure 12, lower-capacity kilns exhibit greater variability in power intensity. This is primarily because lower-capacity kilns have reported facing financial challenges that limit the incorporation of EE measures, such as energy-efficient motors and pumps, which could otherwise reduce electricity consumption. On average, plants reported a power consumption rate of 60–70 kWh per tonne of DRI in the 2024 survey. Electricity consumption data for the entire steelmaking value chain are provided in Annexure 3.

Figure 13. Power consumption for DRI kiln ranges from 60–90 kWh/t-DRI


*Source: Authors' analysis*

Note: 1. Plant sizes above 400 tpd are not proportional to the dimensions shown on the x-axis, to protect the proprietary information of the surveyed plants.

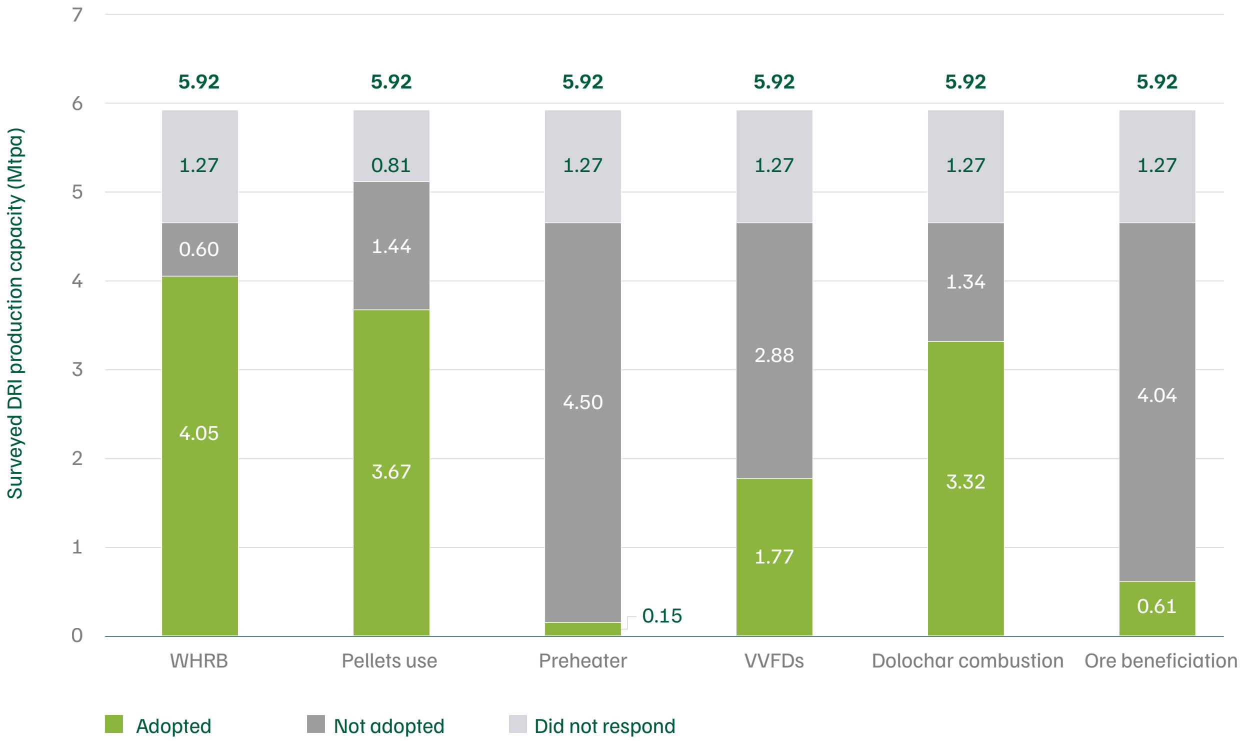
2. kWH: kilowatt hour

## Energy efficiency (EE)

The adoption of EE measures (see Annexure 4 for a detailed description) varies across the surveyed units. Figure 14 presents the uptake of EE measures implemented based on capacity across the five clusters surveyed in 2023 and 2024. Pellet use, WHRBs, and dolochar combustion were the most widely adopted measures in terms of capacity. In contrast, variable voltage frequency drives (VVFDs), efficient blowers, and mullite linings were reported to have been widely installed in the 2024 survey. However, VVFD installations remain low relative to the total capacity surveyed.

Ore preheating was present in only one plant in the Bellary cluster, while none of the plants surveyed in 2024 reported having ore beneficiation. Most plants have access to higher-grade ores, and the additional investment required to install beneficiation infrastructure has prevented its adoption. Waste heat recovery boilers remain the preferred EE measure for waste heat produced in kilns. Smaller kiln operators who face feasibility issues with WHRB installations tend to explore ore preheating as a measure to improve EE, which explains its low uptake in plants with higher capacity. Some smaller units also reported space constraints as a reason for not installing measures such as WHRBs and ore preheaters.

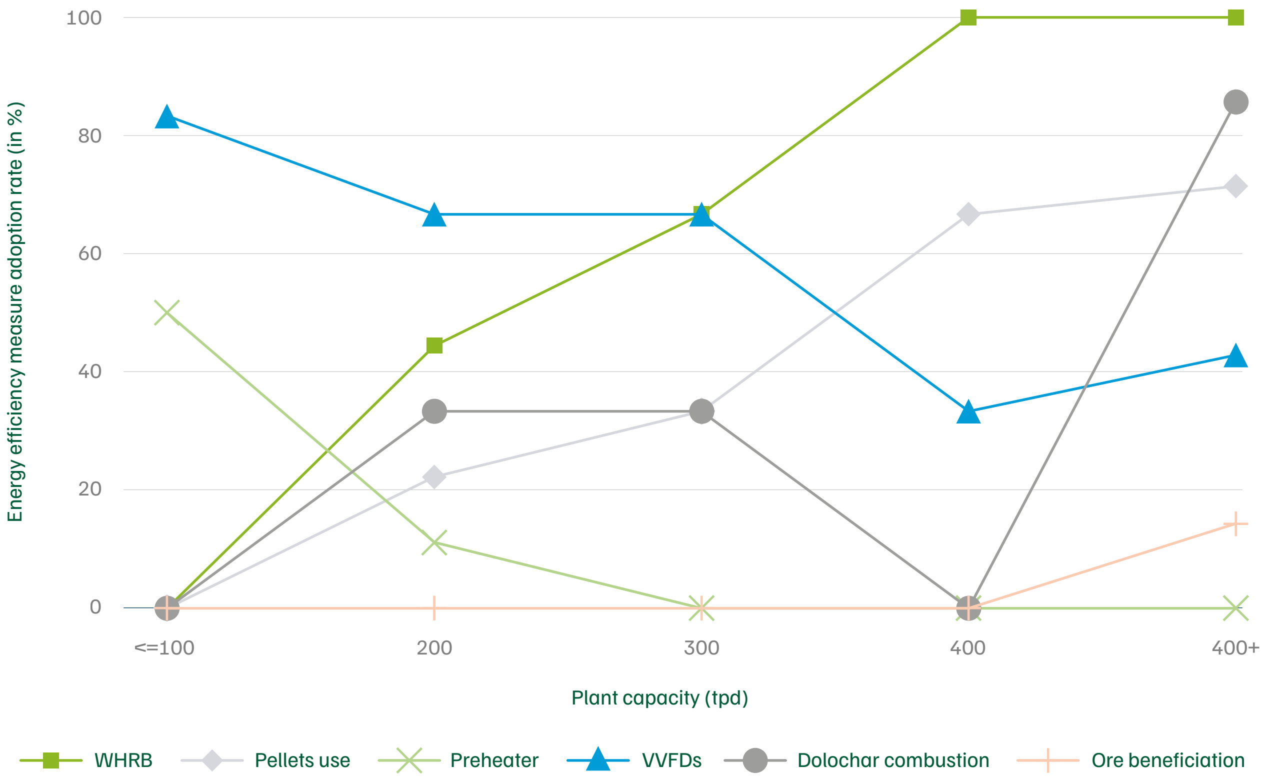
Figure 14. Pellet use, waste heat recovery boiler (WHRB), and dolochar combustion are the most adopted energy efficiency (EE) measures in the five clusters




*Source: Authors' analysis*

Figure 15 displays the relationship between plant capacity and the adoption of the various EE measures shown in Figure 14 based on the percentage of units adopting them. Adoption of pellet use, WHRBs, and dolochar combustion increases with plant capacity, with all units above 300 tpd having installed WHRBs. By contrast, VVFD uptake declines with increasing plant size. Ore preheating is mainly observed in units below 300 tpd, as larger plants typically adopt WHR systems. Ore beneficiation is typically not preferred by DRI units; there is only one unit that uses beneficiation.

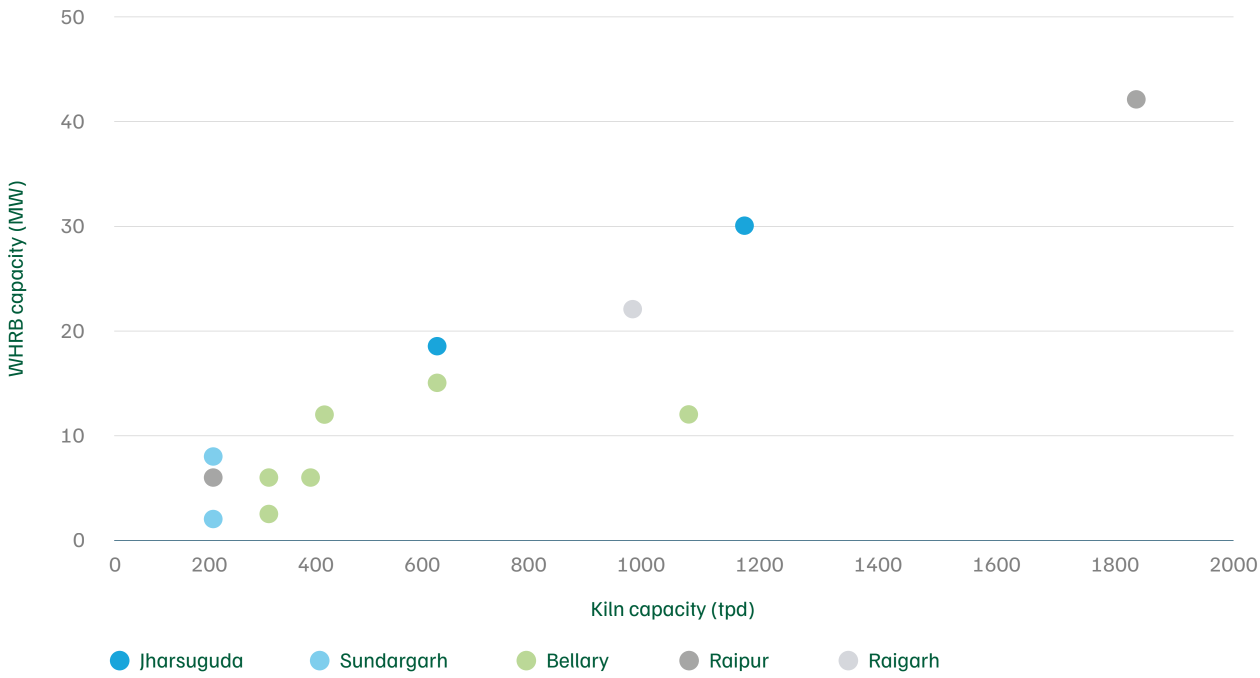
Figure 15. Adoption of EE measures usually increases with the plant capacities of the units surveyed, except for ore preheating and variable voltage frequency drives (VVFD)




*Source: Authors' analysis*

The capacity of WHRBs in iron production using rotary kilns is directly proportional to kiln capacity. Survey data from the 5 clusters indicate that approximately 2 MW of WHRB capacity can be theoretically installed for every 100 tpd of kiln capacity (Figure 16). However, data from the current survey reveal that some operational WHRB installations are inadequate relative to this. This gap is primarily driven by economic and regulatory barriers, including the high upfront capital costs of WHRB infrastructure, insufficient subsidies to offset installation costs, and the frameworks to facilitate power evacuation from such systems. Collectively, these challenges limit the sector's ability to fully utilise WHR potential, especially in smaller kilns. Conversely, a few plants reported WHRB capacities exceeding the theoretical limit, as they have not yet expanded their DRI capacity to align with the added WHR infrastructure.

Figure 16. Variation exists in WHRB capacity across different plant sizes




*Source: Authors' analysis*

## Power utilisation by source

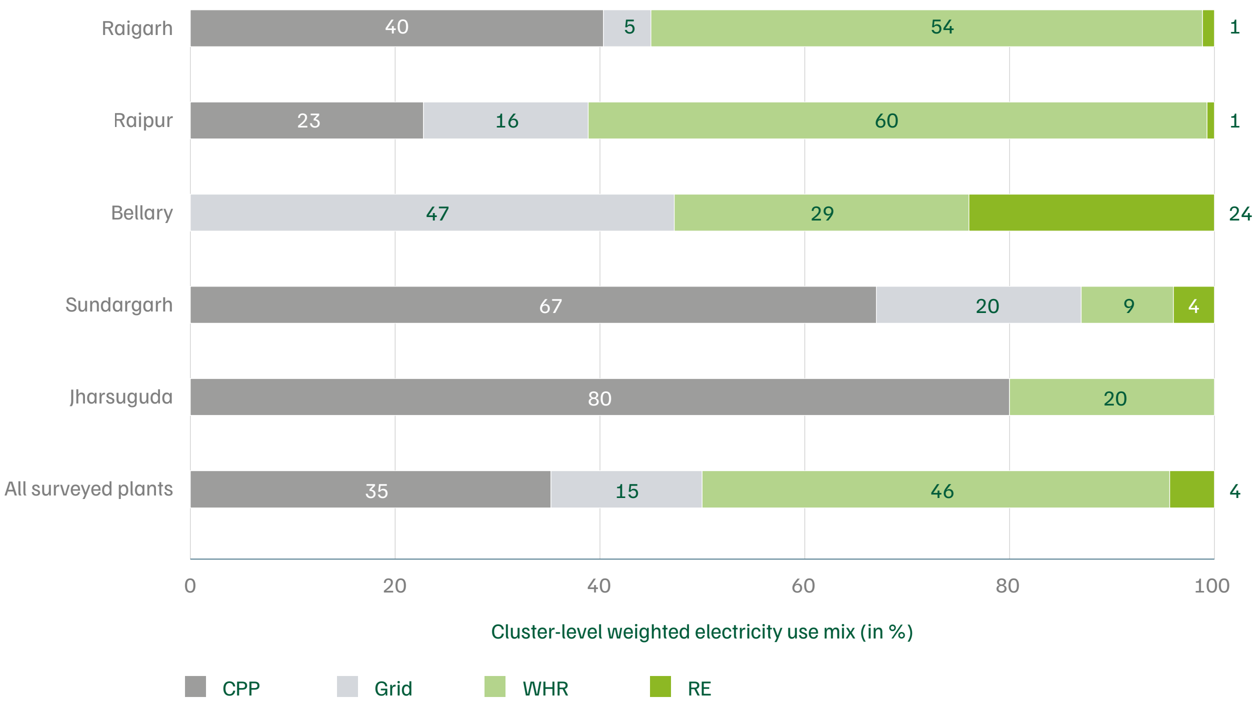
Figure 17 depicts the share of power consumption by source across the surveyed units. Percentages are averaged based on the capacities of the plants surveyed. We have classified power usage by four main types of sources:

- Captive power plant (CPP)
- Grid power
- Power from WHR
- RE (all types of RE, including captive, third-party power purchase agreements (PPAs), and RE through OA)

All surveyed units, except those in the Bellary cluster, rely on CPPs to meet their electricity requirements. Units in Odisha (Sundargarh and Jharsuguda) reported greater dependence on CPPs, primarily because domestic coal was available in the vicinity of the clusters. In contrast, units surveyed in Bellary primarily depend on grid power for their operations, citing limited access to domestic coal for captive power generation. Key reasons for not preferring CPPs among the surveyed units include challenges in securing domestic coal, a preference for lower-cost, incentivised WHRB systems, and limited financial capacity among smaller plants to support the high capital expenditure associated with CPP installation. Clusters in Chhattisgarh have plants with higher capacities and greater WHRB penetration. Both Raipur and Raigarh have a higher share of WHRBs, at 60 and 54 per cent, respectively, with CPPs being the next preferred power source, at 23 and 40 per cent, respectively. These clusters have a very low share of grid power compared to other clusters, as the average distribution company (discom) prices in Chhattisgarh are the highest among the surveyed states, at INR 8.61 per kWh of power.

Although many units expressed interest in purchasing RE, the current offtake is only around 4 per cent for all surveyed plants. High total capital expenditure (CAPEX) and a preference for WHR and captive power, which are available at lower prices per kWh, have led to low RE penetration. Thus, on average, WHRBs and CPPs are the main sources of power in the surveyed clusters, with an overall share of 46 per cent and 35 per cent, respectively. Grid power use accounted for the remaining 15 per cent of power consumption. Additionally, the analysis reflects that even in plants with WHRBs, the generated power is not completely utilised, owing to challenges with power utilisation and reluctance from discoms to buy power at a higher price.

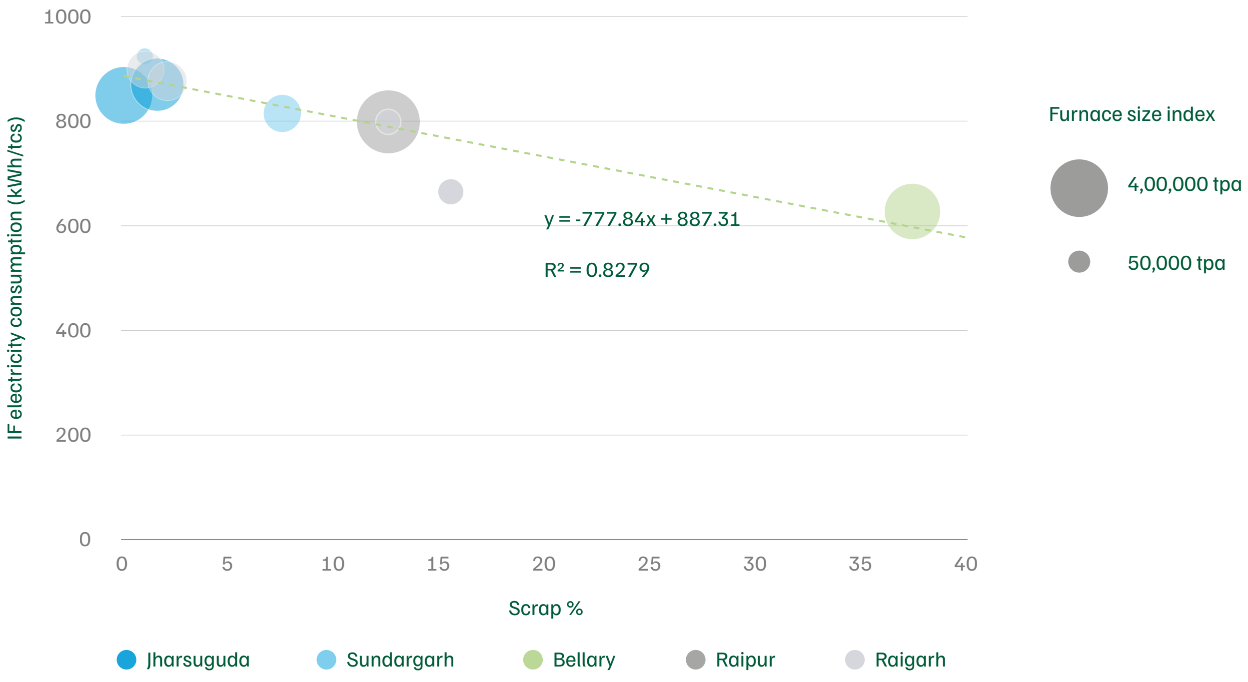
Figure 17. Captive and grid power are the key power sources in DRI clusters




*Source: Authors' analysis*

Figure 18 illustrates the relationship between electricity consumption and the percentage of scrap used as inputs in IFs across all five clusters. The analysis shows that increasing the proportion of scrap in the IFs leads to a reduction in electricity consumption. Based on data from both surveys, the relationship between power consumption and scrap integration in steelmaking can be derived from the slope of the curve plotting energy consumption in IFs against scrap share. The results indicate that a 5 per cent increase in scrap share reduces power consumption by 38.9 kWh per tonne of crude steel (kWh/tcs).

Figure 18. Electricity requirement in IFs decreases with an increase in scrap share




*Source: Authors' analysis*

## 3.3 Market and financial landscape: Demand for green steel, financial barriers, and access to credit

Across the three clusters, discussions were structured to explore the markets served by the surveyed units. This was done to determine whether any of these clusters or units were likely to be affected by emerging international regulations, such as the *Carbon Border Adjustment Mechanism*. None of the surveyed plants exported iron and steel products. Integrated plants utilised DRI internally in their IFs and rerolling mills, while standalone DRI plants served only domestic steel producers. Certain units also reported utilising DRI in their facilities located in other clusters or states.

Despite the growing global emphasis on low-carbon steel, the surveyed units showed a notably low level of awareness of green steel. When discussions were steered towards the concept and potential market appetite for low-carbon steel, only one senior representative from Sundargarh mentioned that their organisation was exploring the feasibility of establishing a green thermo-mechanically treated (TMT) unit in Goa. However, the rationale for selecting Goa, the underlying motivations, and the anticipated demand for green steel remained unclear.

### Financial barriers and access to credit

Discussions with plant representatives revealed a marked contrast in financial considerations between the Odisha and Karnataka clusters. In Odisha, most of the surveyed plants had self-financed the adoption of RE systems and the installation of EE measures. Regarding the need for financial support for the transition to low-carbon steel production, respondents expressed a strong preference for self-financing over debt-based financing.

In contrast, all surveyed units in the Bellary cluster cited several financial constraints. Many found the loan application cumbersome, citing extensive documentation, high collateral requirements, and prolonged approval timelines. Given that several plants located in the Bellary cluster were resuming operations after financial struggles, their immediate priority was achieving stability rather than investing in low-carbon transitions.

Further, our findings reveal a substantial gap in access to green financing for SMEs, despite the availability of tailored schemes administered by the Small Industries Development Bank of India (SIDBI), such as the *Green Investment and Financing for Transformation* (GIFT) and *Sustainable Production and Industrial Capacity Enhancement* (SPICE). The BEE has also introduced complementary mechanisms, including the *Partial Risk Sharing Facility for Energy Efficiency* (PRSF) (implemented with SIDBI and the World Bank) and the *Energy Efficiency Financing Platform* (EEFP), to encourage banks and financial institutions to support efficiency projects. Some commercial banks have additionally begun offering sustainability-linked loans, but adoption remains limited within the C-DRI sector.

## 3.4 Policy and institutional ecosystem: Awareness of decarbonisation initiatives and the role of industry associations

### Awareness of green steel and NCMs

Site visits and discussions underscored limited awareness of ongoing developments in green and low-carbon steel, as well as the proposed NCM framework, across the surveyed clusters. Only plants covered under the PAT scheme demonstrated familiarity with the BEE's role in emission reductions. These plants reported attending BEE-organised meetings and workshops, while others remained largely unaware of such initiatives. However, all surveyed plants reported compliance with local pollution regulations and were subject to regular inspections and audits.

Cluster characterisation provides the basis for developing detailed emission profiles.

### Industry associations and institutional support

Engagement with industry associations varied significantly across regions. In Odisha, plant representatives noted minimal interaction with the Odisha Sponge Iron Manufacturers' Association (OSIMA), with several noting a lack of updates and an absence of communication from the association in months. Discussions with PTC corroborated that OSIMA is currently defunct, with its activities suspended.

In contrast, KSIMA remains active, with a designated office in Bellary. It maintains an updated database of sponge iron plants, including their capacities, coal consumption, and production levels. As part of its engagement, KSIMA facilitated member participation in a BEE workshop on EE for the DRI sector in October 2024, highlighting its role in supporting industry-level capacity-building initiatives.

## Training and capacity building

In Odisha, only the plants covered under the PAT scheme reported participating in meetings and workshops focused on emission reduction and improving EE. Beyond these, most respondents had not attended cluster- or state-level training programmes. In Bellary, BEE conducted a training in October 2024 on emission reduction and improving EE for members of KSIMA. Besides these training workshops, the primary sources of information regarding market trends, emerging technologies, and other sectoral developments were local energy auditors, technology providers, and, in some cases, ESCOs.


Image: CEEW

# 4. Cluster emissions and mitigation pathways

Chapter 3 details the key findings from the survey conducted across the three clusters studied, supplemented by insights from our previous survey (Nitturu et al. 2024). This chapter builds on that data to develop insights into the transition pathways that inform the evaluation framework for cluster-level decarbonisation. We first develop an emissions inventory for the entire cluster based on the pre-cluster analysis (Chapter 2) and survey data. Subsequently, we identify the energy transition pathways that can enable each cluster to achieve net-zero emissions based on the emissions inventory and evaluate the marginal abatement cost (MAC) based on our previous research (Elango et al. 2023). Finally, we develop estimates for the capital investment requirements and evaluate changes in operational expenditure across various clusters. These results and insights underpin the evaluation framework detailed in Chapter 5.

## 4.1 Baseline emissions inventory for the clusters

While the survey primarily focused on DRI units, the emissions inventory developed here accounts for all stages of steel production within cluster boundaries, including DRI plants, IFs, EAFs, rerolling mills, and pellet plants. The parameters considered for building the emissions inventory are discussed in detail in Annexure 4. Baseline emissions for DRI, IFs, EAFs, and rerolling units across the clusters were estimated by extrapolating fuel and electricity consumption rates reported in the survey for the clusters as a whole and using emissions intensity data from the survey findings. This involved using baseline values for emissions intensities for domestic coal, imported coal, and captive and grid power, as detailed in Annexure 4.

The overall emissions from a cluster depend on the emissions intensity of coal and electricity used, as well as the overall capacity of DRI and steelmaking operations. Table 6 lists the DRI and steel production capacities across clusters, which significantly impact the total coal and electricity consumption in the cluster. Based on the electricity mix discussed in Chapter 3, we also estimate the weighted-average power emissions intensity for each cluster. These factors are expected to significantly impact the total emissions and emissions intensity of steel in a cluster. As illustrated in Figure 17, the emission intensity of power varies significantly between clusters, primarily due to the percentages of power being used. Clusters with higher CPP use have a higher intensity of electricity-related emissions.

Table 6. Emissions inventory for the cluster is based on the entire value chain of steel production

| Parameters | Units | Jharsuguda | Sundargarh | Bellary | Raipur | Raigarh |
|---|---|---|---|---|---|---|
| **Pellet capacity** | Mtpa | 0.00 | 0.60 | 6.80 | 3.90 | 2.90 |
| **Coal consumption** | Mtpa | 0.59 | 3.95 | 2.27 | 4.08 | 5.08 |
| **Electricity consumption** | GWh | 488 | 1,289 | 746 | 2,490 | 4,142 |
| **Electricity intensity** | kg $CO_2$/kWh | 1.04 | 1.04 | 0.39 | 0.43 | 0.56 |

*Source: Authors' analysis*

*Note: GWh–gigawatt-hours*

Figure 19 depicts the total emissions across clusters based on the stages of steel production. Overall, clusters with larger DRI capacities exhibit higher emissions. The use of coal in the DRI process results in the highest emissions overall, followed by IFs, which primarily rely on electricity. In DRI production, coal-related emissions range from 1.8–2.36 $tCO_2$/t-DRI produced, depending on the type of coal and ore used and the EE measures adopted. The share of emissions from crude steelmaking in EAF and IF units, as well as from finished steel production in rolling mills, is significantly lower than that from rotary kilns. Pellet-making emissions average around 0.09 tonnes of $CO_2$ per tonne produced (with a range of 0.03–0.15 $tCO_2$/t-pellet) (KIOCL 2022–23; Lv et al. 2019; Shaik et al. 2024) and have a very low contribution to the overall emissions from the cluster.

Across clusters, Raigarh records the highest emissions overall, followed by Raipur and Sundargarh. As discussed in Chapter 3, the Raigarh cluster has higher coal consumption per tonne of DRI than Raipur, even though their overall DRI capacities are comparable. Additionally, both Raigarh and Raipur have higher capacities of IF and EAF plants, which add to their overall emissions. The Sundargarh cluster shows higher emissions despite its lower steelmaking and DRI capacities compared to the Chhattisgarh clusters, primarily due to its higher electricity emissions intensity and greater reliance on domestic coal. In contrast, the Bellary cluster has very low steelmaking capacity and, as a result, uses imported coal for DRI production. It has the highest pellet production capacity (6.80 Mtpa) among all clusters, yet it accounts for only about 0.61 Mtpa in emissions. These factors keep the overall emissions in the Bellary cluster lower, at 4.98 Mtpa. The Jharsuguda cluster, with the smallest DRI capacity (0.45 Mtpa) among all surveyed clusters, records high electricity emissions intensity (1.04 kg $CO_2$/kWh) and coal emissions intensity due to its reliance on domestic coal. Thus, despite its smaller scale, Jharsuguda's emissions are disproportionately high relative to its production capacity, highlighting how regional variations in energy mix can significantly impact overall emissions profiles. The lack of pellet usage additionally increases the emissions intensity of DRI clusters in Odisha.

The variations across clusters in terms of DRI, steelmaking, and pellet production capacities underscore the need for customised decarbonisation strategies that reflect regional differences in resource availability, technological infrastructure, and production configurations. For instance, clusters with high electricity-emissions intensity should prioritise RE integration, while those with large DRI capacities might focus on alternative fuel use or improved EE. Clusters with significant steelmaking capacity can benefit from purchasing WHR systems from DRI units and incorporating higher percentages of scrap metal in the steelmaking process to reduce overall carbon emissions. These cluster-specific opportunities are detailed in Chapter 6.

Figure 19. DRI process accounts for the highest share of total emissions from a steel cluster


*Source: Authors' analysis*

## 4.2 Emissions mitigation pathways for the steel clusters

This section discusses the pathways for mitigating emissions across the steel clusters. As illustrated in Figure 20, various possible decarbonisation options have been evaluated based on our previous research (Elango et al. 2023). In summary, this study considers various decarbonisation levers, including ME (pelletisation and scrap use), EE (use of WHR systems), firm and dispatchable renewable energy (FDRE) to offset captive and grid electricity, alternative fuels (use of higher-grade imported coal instead of domestic coal), CCS, and offsets to achieve net-zero emissions from the clusters.

Figure 20. Decarbonisation levers that can be applied to DRI clusters

| | | |
|---|---|---|
|  | 7<br>Energy efficiency technologies | • DRI char for WHR power<br>• Kiln flue gas WHR power<br>• Efficient blowers for kilns<br>• VVFDs for shell air fans<br>• Scrap pretreatment for IF<br>• Ore preheating using flue gas<br>• Mullite-based kiln lining |
|  | 2<br>Material efficiency measures | • Increase of scrap utilisation in IF<br>• Use of pellets |
|  | 1<br>Renewable energy | • Coal-based CPP/grid to RE |
|  | 2<br>Alternate fuels | • Higher quality of imported coal use in DRI kilns<br>• Biomass, hydrogen and other alternate fuel injection in DRI kilns |
|  | 3<br>Carbon management technologies | • CCS<br>• CCU<br>• Carbon offsets |

*Source: Authors' analysis*

- **Pelletisation**: Replacing lump ore with pellets reduces coal consumption in rotary kilns, decreases ore consumption, and improves operational efficiency (Nitturu et al. 2024). To account for net emissions reduction from pelletisation, emissions from pellet making are subtracted from the reduction achieved at the DRI stage. However, further research is required to identify pathways for mitigating pellet-making emissions. Current global R&D efforts in this area remain limited, with only a few initiatives underway–for instance, the HYBRIT pellet plant, which uses bio-oil to decarbonise the pellet-making process (LKAB 2020). As such, in this analysis, we assume that emissions from combustion in pellet plants are mitigated through CCUS, while emissions from electricity use are offset through FDRE.

- **WHR systems**: Waste heat recovery installations recover waste heat from kiln exhaust gases to generate power, thereby displacing grid or captive electricity. Within this assessment, WHR is considered a low-hanging option for offsetting grid or captive thermal power consumption in clusters. The residual power requirement in a cluster after a 100 per cent WHRB installation is then met through FDRE integration. Table 7 summarises the existing WHR capacity and the maximum extent to which WHR can meet the power requirement across the clusters. Power demand varies across clusters depending on the composition of DRI, IF, EAF, and rerolling capacities. Clusters with high DRI capacities, such as Sundargarh and Bellary, can fulfil 88 per cent and over 100 per cent of their power requirements, respectively, through WHR. In contrast, clusters with larger steelmaking capacities can only offset part of their power requirements through WHR and will require a higher quantity of FDRE to achieve net-zero emissions from electricity use.

Table 7. Bellary can generate surplus waste heat recovery energy compared to what the cluster requires

| | Units | Jharsuguda | Sundargarh | Bellary | Raipur | Raigarh |
|---|---|---|---|---|---|---|
| **Total power required in the cluster** | GWh | 488 | 1289 | 746 | 2490 | 4142 |
| | MW | 60 | 162 | 114 | 307 | 506 |
| **WHR power already installed in the cluster** | GWh | 68 | 113 | 90 | 323 | 553 |
| | MW | 9 | 14 | 11 | 41 | 70 |
| **RE power already installed in the cluster** | GWh | 0 | 43 | 75 | 56 | 69 |
| | MW | 0 | 5 | 9 | 7 | 8 |
| **New WHR capacity that can be installed** | GWh | 101 | 1,018 | 807 | 968 | 763 |
| | MW | 13 | 129 | 94 | 122 | 96 |
| **FDRE requirement** | GWh | 319 | 114 | - | 1,144 | 2,757 |
| | MW | 38 | 14 | - | 137 | 331 |

*Source: Authors' analysis*

- **RE**: Solar and wind power can be deployed to meet the clusters' residual power requirements after the WHR power installation. In this analysis, FDRE is considered to supply the remaining power requirement that cannot be met through WHR. Emissions reductions achieved from adopting FDRE are estimated by calculating the emissions mitigated through the replacement of existing power sources. The RE capacity requirements are indicated in Table 7. Clusters with greater electricity demand, particularly those with higher steelmaking capacity, have greater potential for emission reductions through FDRE.

- **Increasing scrap utilisation**: Increasing scrap use can reduce emissions in steel production by (i) replacing DRI required to produce steel and (ii) lowering the electricity needed to produce crude steel in an IF, as illustrated in Figure 18. In this analysis, we calculate emission reductions for a 5 per cent increase in scrap utilisation in IFs. The assumed increment is intentionally modest, reflecting prevailing constraints on domestic scrap availability, quality, and cost, which currently limit large-scale substitution.

- **Alternative fuel use**: Emissions reductions from replacing domestic coal, or a mix of domestic and imported coal, with 100 per cent imported coal are estimated based on the corresponding decrease in coal consumption (Elango et al. 2023). The highest reduction in emissions from alternative fuel use occurs in the Odisha clusters, where domestic coal use is high. In contrast, the Bellary cluster shows no potential for emission reductions, as it already uses 100 per cent imported coal.

- **CCUS**: For residual emissions, we considered the application of carbon capture and utilisation (CCU) or carbon capture and storage (CCS). However, as CCU is significantly more expensive than CCS, the remaining emissions in the cluster are designated to be removed using CCS with an 85 per cent carbon capture efficiency (Verma et al. 2024), with the residual emissions being designated for offsets (we have not evaluated the cost of offsets in this study). Decarbonisation of DRI through a rotary kiln without radically changing the process will necessitate the need for CCUS. However, CCS will not play an immediate role in reducing emissions due to significant costs, a lack of incentives and the absence of a required ecosystem to deploy these projects. As per Bakshi et al. (2023), it might take up to 18 years to implement CCS in the clusters. It is therefore crucial to initiate the pre-appraisal phase for CCS now to ensure its deployment by 2040.

Emission-reduction estimates from all the measures are compiled in Table 8. Mitigation potentials correspond to 100 per cent uptake of the specific decarbonisation measure, except for scrap utilisation, where scrap uptake is 5 per cent in addition to the base case. The emission-reduction potential of various decarbonisation levers varies significantly across clusters, highlighting the need for cluster-specific policy interventions. Waste heat recovery contributes modestly to overall reductions, ranging from 4 per cent in Raigarh to 14 per cent in Sundargarh. Renewable energy adoption plays a slightly larger role in clusters such as Raigarh (15 per cent) and Jharsuguda (24 per cent), but has no impact in Bellary, where WHR alone meets 100 per cent of power demand. The relatively higher emission-reduction potential in Raigarh and Jharsuguda stems from their greater steelmaking capacities, which translate into higher electricity demand.

Across five industrial clusters, CCUS contributes 38–78% of total emissions mitigation, with Bellary exhibiting the highest reliance at 78%.

Material efficiency through pellet use shows a limited overall impact, with only Sundargarh achieving a 6 per cent reduction, primarily because it's a cluster with 88 per cent lump ore use. In contrast, the substitution of domestic coal with imported coal drives significant reductions in Sundargarh (26 per cent) and Raipur (17 per cent), while Bellary–already reliant on imported coal—sees no benefit from this measure.

Regardless, all clusters will rely heavily on CCUS as a decarbonisation lever to achieve net-zero emissions, with mitigation potential ranging from 38–78 per cent across clusters. The Bellary cluster exhibits the highest reliance on CCUS (78 per cent), given its minimal potential for reduction through RE and alternative fuel use. In contrast, Jharsuguda requires only a 38 per cent reduction through CCUS, benefiting from significant contributions from RE (24 per cent) and imported fuel use (16 per cent). Residual emissions, accounting for 7–14 per cent across clusters and resulting from the 85 per cent capture efficiency of CCUS technology, will need to be addressed through carbon offsets.

Table 8. CCUS dominates as the most prominent mitigation measure in the steel clusters to achieve net zero

| Cluster | Units | Raigarh | Raipur | Sundargarh | Bellary | Jharsuguda |
|---|---|---|---|---|---|---|
| **Cluster baseline emissions** | Mtpa | 10.66 | 7.75 | 7.29 | 4.96 | 1.40 |
| **EE** | Mtpa | −0.43 | −0.40 | −1.03 | −0.25 | −0.11 |
| **RE** | Mtpa | −1.55 | −0.48 | −0.15 | −0.00 | −0.33 |
| **Increase scrap use** | Mtpa | −0.22 | −0.26 | −0.18 | −0.04 | −0.06 |
| **Pellet use** | Mtpa | −0.22 | −0.01 | −0.46 | −0.11 | −0.05 |
| **Imported coal use** | Mtpa | −1.47 | −1.33 | −1.91 | −0.00 | −0.23 |
| **CCUS** | Mtpa | −5.76 | −4.49 | −3.02 | −3.88 | −0.53 |
| **Residual emissions to be reduced through offsets** | Mtpa | −1.02 | −0.79 | −0.53 | −0.68 | −0.09 |

*Source: Authors' analysis*

## 4.3 Marginal abatement cost curve and investment sizing transition in steel clusters

For each identified mitigation measure, we estimate the MAC using the methodology established in our earlier assessment (Elango et al. 2023). Annexure 4 summarises the key assumptions used for estimating MAC. The resulting MAC for each measure is presented in Figure 21, with detailed calculations provided in Annexure 4.

Figure 21 illustrates the consolidated MAC for all mitigation measures across all five clusters considered in the assessment. The MAC curve is colour-coded by cluster name and is highly sensitive to the assumptions indicated in Annexure 4. For example, we have indicated the MAC for the Bellary cluster in blue. Generally, the cost of mitigation varies across clusters depending on the cost of incumbent fuels and energy sources, as well as the cost of each decarbonisation measure. The MAC values for each decarbonisation lever assessed in this study are discussed as follows.

Waste heat recovery and scrap utilisation save costs; all other levers cost, especially CCUS and fuel switching.

- **EE using WHR**: Implementing WHR yields a negative MAC for all clusters, as WHR-generated power is cheaper than existing power costs. The MAC for EE in Bellary is especially lower because it relies on grid power, which is more expensive than CPP.

- **ME by increasing scrap utilisation**: A 5 per cent increase in scrap utilisation also results in negative MAC values, though less negative than those of WHR (detailed assumptions and calculations are shown in Annexure 4). While scrap procurement costs exceed those of DRI, the quantity of scrap required per tonne of crude steel is lower than the amount of DRI required per tonne of crude steel (Elango et al. 2023). Additionally, increasing scrap percentage in steelmaking reduces the electricity required per tonne of crude steel produced, as seen in Figure 18. Together, these two factors yield a negative MAC for increased scrap utilisation. However, if the price difference between scrap and DRI increases, the MAC for scrap utilisation can then become positive. The variation of negative scrap MAC values across clusters stems from differences in electricity costs, which depend on the share of electricity drawn from various sources and the cost of grid power in each state. For example, Raipur, which has a higher share of grid power than Raigarh, records lower MAC values. The MAC values also vary due to differences in scrap procurement costs across clusters, which reflect regional differences in scrap demand and supply. However, for this analysis, we have applied uniform prices based on average scrap rates in Indian metros, as these differences are marginal, with a standard deviation of 6 per cent (Ayron Mart n.d.).

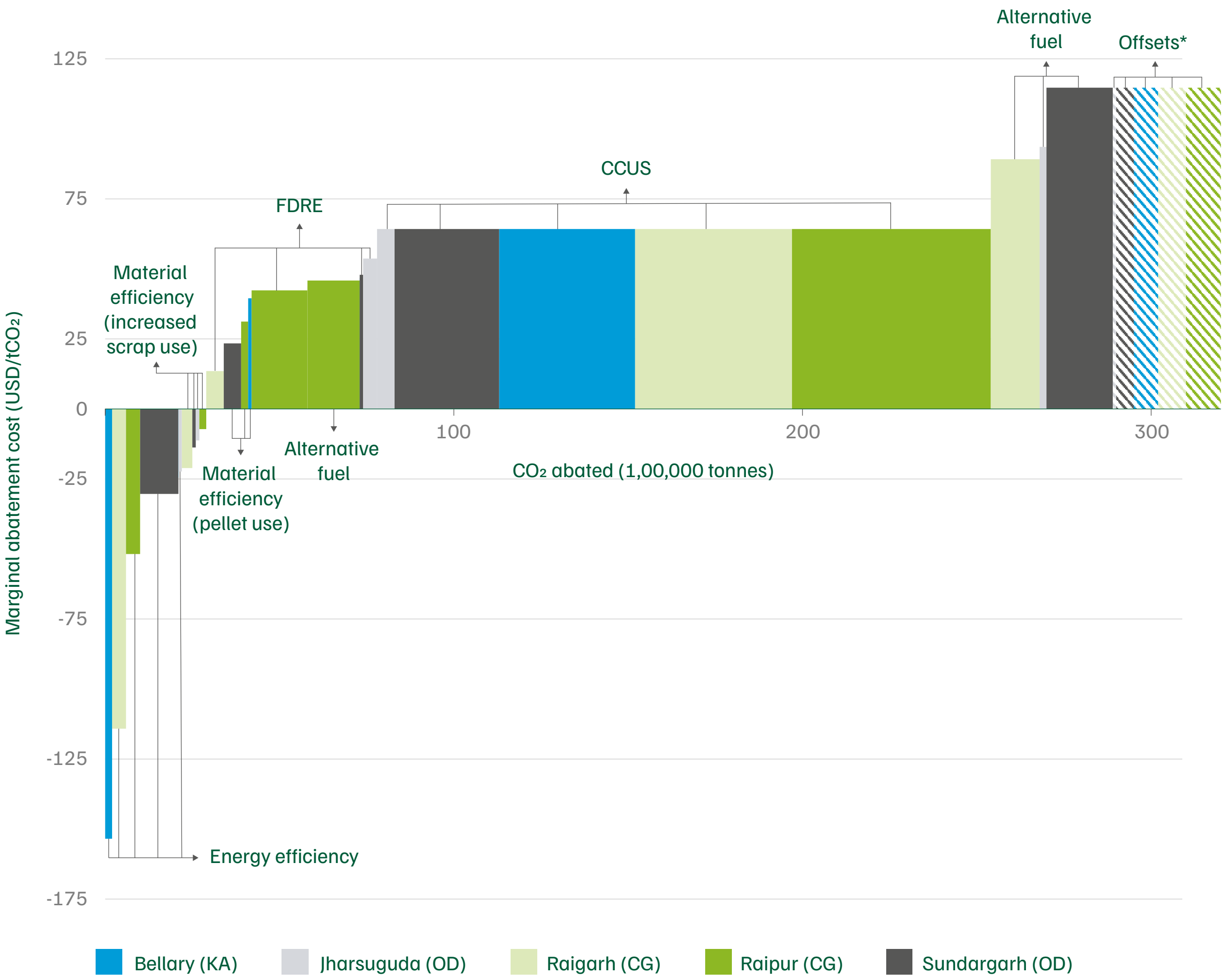
- **RE/FDRE**: Adoption of FDRE results in a positive MAC, as captive power remains cheaper and RE requirements are higher for the FDRE requirements. The ranges for RE MAC depend on the existing share of CPPs, grid power, and RE in the cluster.

- **ME through pelletisation**: The MAC values for pelletisation depend on the cost of iron ore and the fines used to make pellets, as well as the emission reductions achieved, which in turn vary with the type of coal used. Using 100 per cent pellets by setting up pellet-making units results in a lower MAC value than FDRE, except in Raipur, where 98 per cent pelletisation already yields nominal emission reductions.

- **Imported coal use**: The implementation of imported fuel use in the clusters is relatively more expensive than other measures due to the higher cost of imported fuel.

- **CCS**: Carbon capture and storage exhibit uniform MAC values across clusters, reflecting uniform underlying assumptions. It also remains one of the most expensive decarbonisation measures.

Figure 21. Marginal abatement cost (MACs) for all the decarbonisation levers in the five clusters




*Source: Authors' analysis*

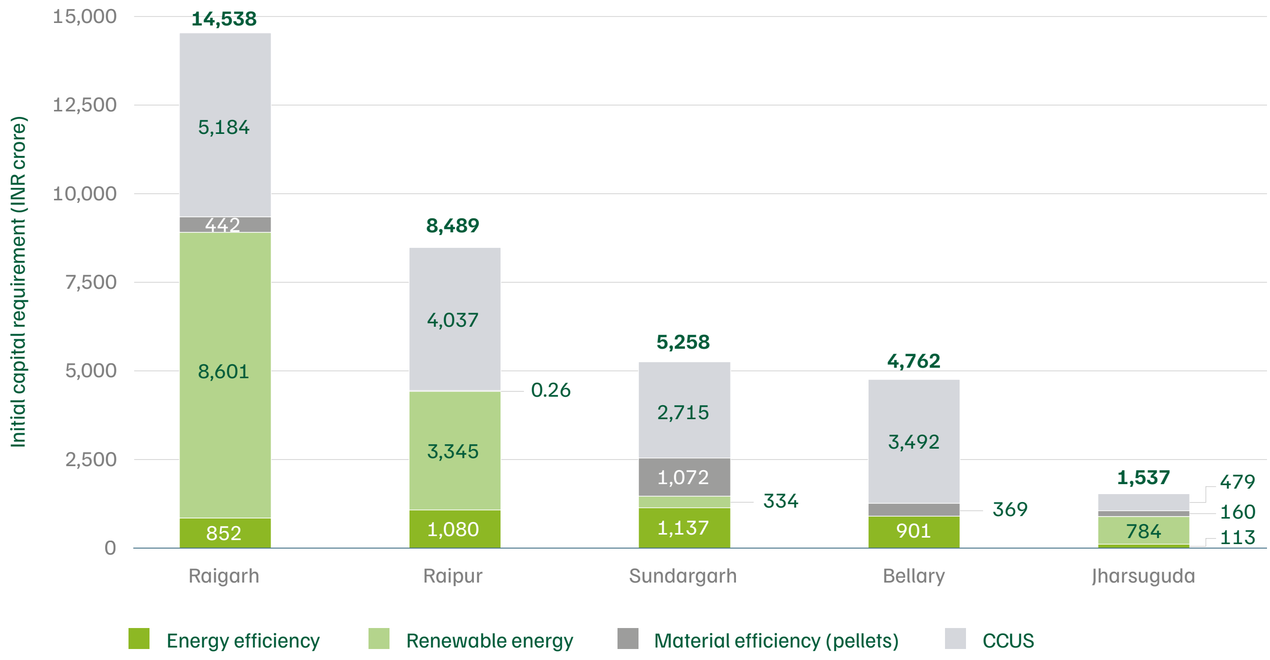
Note: The MAC for offsets is only representational as an option for carbon mitigation without considering the cost of mitigation.

It is important to recognise that not all the decarbonisation measures listed are ready for immediate uptake. In the short term (within the next three years), WHR systems can be implemented. Additionally, RE, scrap utilisation, pelletisation, and imported coal use can begin in the short to medium term (three to five years). However, deploying CCUS will take considerable time to become operational and should be viewed as a long-term measure (beyond 10 years).

Figure 22 illustrates the CAPEX required to implement the identified decarbonisation measures across all clusters. All cost-related assumptions are detailed in Annexure 4. Capital expenditure is particularly high across the clusters for FDRE and CCS. While we have included CAPEX estimates for RE and CCUS, it is important to note that neither necessarily requires steel plants to bear the entire investment themselves. Both may be provided by external developers – RE developers or CCUS operators – on a tariff basis. The usage of scrap and imported fuel has no CAPEX requirements, while implementing 100 per cent pelletisation and WHRB requires relatively lower CAPEX than FDRE and CCUS. The Sundargarh cluster records the highest WHR-related costs, requiring an additional 129 MW of new WHR capacity compared to other clusters. In contrast, the Raigarh cluster, which has a higher steelmaking capacity, requires 331 MW of FDRE, as seen in Table 7. This substantially increases Raigarh's RE CAPEX to INR 8,263 crore. Similarly, the Raipur cluster requires 137 MW of FDRE, increasing its RE-related CAPEX to INR 3,509 crore.

Carbon capture and storage represents the largest capital investment across all clusters except Raigarh, where both Raigarh (INR 5,186 crore) and Raipur (INR 4,045 crore) require particularly high investments. It should be noted that these CCS figures include only capture-related CAPEX, estimated at INR 900 crore per tonne of $CO_2$ captured (Mukherjee and Chatterjee 2022), while transport and storage are accounted for under operating expenses (OPEX).

## Figure 22. The initial capital required for cluster decarbonisation initiatives is high for CCUS and RE deployment




*Source: Authors' analysis*

Figure 23 illustrates the OPEX requirements across clusters, derived by disaggregating MAC into its respective CAPEX and OPEX components and then computing the total OPEX required based on the total emissions mitigated by each measure. Clusters in Chhattisgarh (Raipur and Raigarh) and Sundargarh exhibit higher OPEX due to their larger emissions base than those in Bellary and Jharsuguda. However, the composition of OPEX varies across clusters. In Raipur and Raigarh, CCUS dominates, followed by alternative fuels and FDRE, whereas in Sundargarh, alternative fuels are the major driver, followed by CCUS. This is primarily because Sundargarh has a large DRI capacity that remains heavily reliant on domestic coal.

Across individual measures, some record negative OPEX values, while others record positive values. Negative OPEX values in this context indicate cost savings achieved through the adoption of certain decarbonisation measures, primarily EE (WHRBs), increased scrap utilisation, FDRE (in Chhattisgarh), and pelletisation (in Odisha and Bellary), relative to the status quo. For instance, WHR offsets the need to procure more expensive captive or grid power; WHRBs provide the greatest savings, particularly in clusters with higher DRI capacity and greater dependence on grid power, such as Raipur, where electricity tariffs are among the highest across states.

As shown in Table 7, clusters in Chhattisgarh require higher levels of FDRE deployment. However, the OPEX of RE in these clusters is negative, as high discom tariffs (INR 8.61 per kWh) and comparatively low OA charges (INR 1.15 per kWh) make FDRE more cost-effective than existing electricity sources. In contrast, Odisha faces lower discom tariffs (INR 6.76 per kWh) but significantly higher OA charges (INR 3.38 per kWh). This pricing differential results in RE-related OPEX savings of approximately INR 518 crore in Raigarh and INR 395 crore in Raipur. Despite these savings, FDRE costs remain driven by CAPEX, making the overall cost of FDRE deployment positive across all clusters, as reflected in the MAC values in Figure 21. The OPEX is positive in Odisha. Sundargarh, which can meet most of its electricity demand through WHRB, shows a modest RE-related OPEX of INR 3 crore, while Jharsuguda's FDRE OPEX stands at INR 46 crore. Bellary, which can fulfil nearly all its power needs through WHRBs, incurs no FDRE-related OPEX.

For scrap utilisation and alternative fuels, the entire MAC is reflected as OPEX, since these measures require no upfront CAPEX. Increasing scrap utilisation results in cost savings, with the level of cost savings depending on IF capacities and electricity costs within the cluster. Raigarh, which has a higher EAF capacity (for which we have not considered scrap utilisation), records lower savings than Raipur. Clusters that can implement alternative fuels to a greater extent, such as Sundargarh, show a particularly high OPEX component for alternative fuels, exceeding even that of CCS. This is largely due to the cost variance between cheaper domestic coal and more expensive imported coal, as well as the amount of imported coal required to mitigate emissions. Consequently, switching to a different variety of coal is neither a cost-effective nor sustainable measure to reduce emissions in the long term, as indicated in Figure 21. The OPEX component of CCUS is uniform across clusters, while cost variations stem from the share of emissions that are delegated to CCS, as seen in Table 8.

## Figure 23. CCUS and adopting imported coal use have the highest operating expenses amongst measures


Source: Authors' analysis

The overall OPEX estimates are nonetheless largely driven by CCUS and alternative fuel use, even though WHRBs across all clusters and FDRE in Chhattisgarh offer substantial cost savings. The OPEX, along with other findings in this chapter, underscores the need for a structured and comparative framework to prioritise and sequence decarbonisation interventions at the cluster level. The next chapter builds on this data by introducing an evaluation framework that facilitates systematic comparison and evaluation across clusters, further supporting the development of targeted policies that can enable cluster-wise decarbonisation.


High imported fuel and carbon capture costs challenge net-zero pathway viability.


Image: CEEW

# 5. Evaluation framework for cluster-level transition in the steel sector

The evaluation framework for decarbonisation in DRI-based clusters provides a structured approach to evaluating and guiding the transition towards low-carbon steel production. It integrates two key dimensions: annualised decarbonisation cost and readiness, which together provide a comprehensive understanding of a cluster's ability to reduce carbon emissions and its preparedness to implement decarbonisation strategies. The framework also enables comparisons across clusters based on these two dimensions.

## 5.1 Evaluation framework for decarbonisation: Annualised decarbonisation cost and readiness indicators

Clusters can comprise numerous small-capacity or standalone DRI plants or a smaller number of larger integrated steel facilities. Emissions intensity varies across these clusters depending on a range of factors. In smaller plants, it could be the use of poor-quality coal and technical limitations in adopting energy-efficient equipment, such as WHRBs. In larger plants, a higher emissions intensity could result from a broader scope for installing EE technologies beyond WHRBs, expanding RE penetration, etc. In both cases, further emission reductions can be achieved through increased pellet use, substitution with higher-quality coal, and the deployment of CCUS.

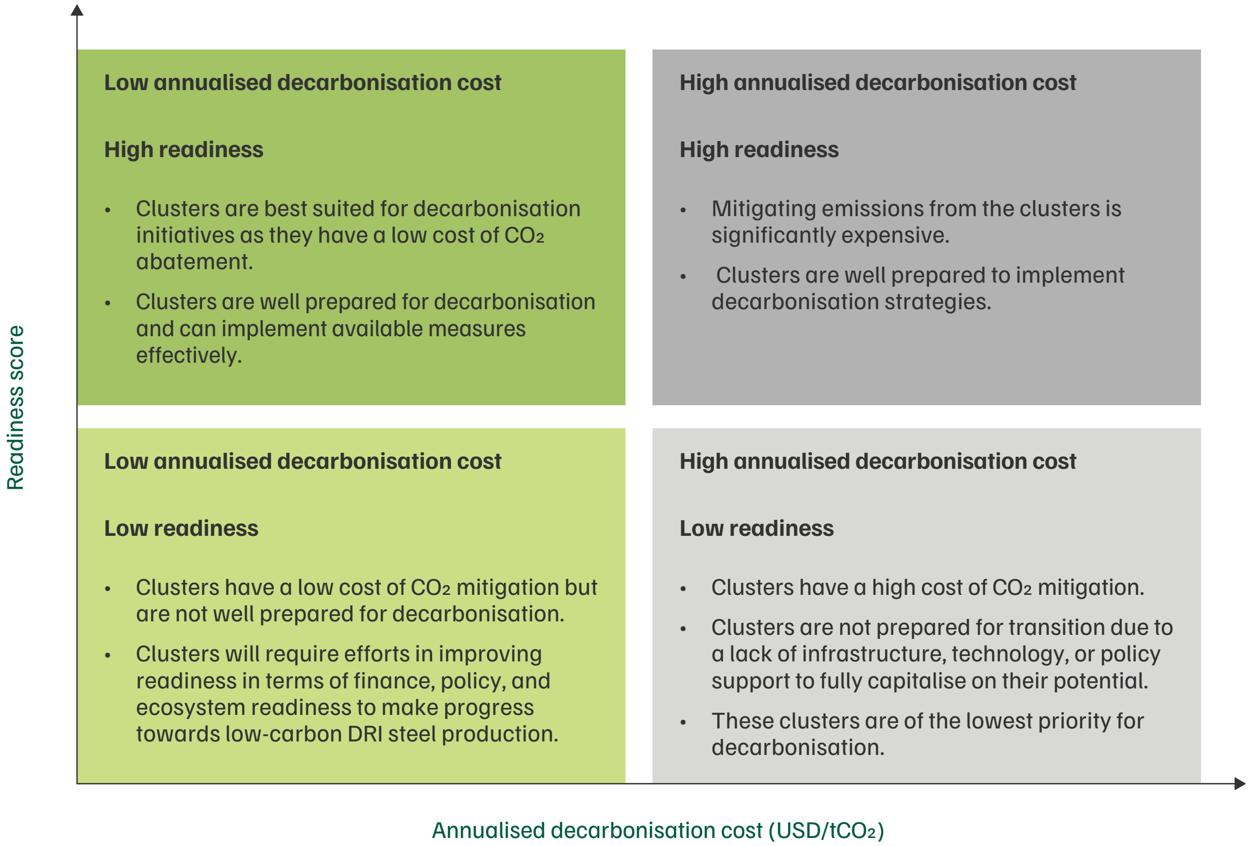
This section details the two key components of the evaluation framework: annualised decarbonisation cost and readiness. Annualised decarbonisation cost represents a steel cluster's capacity to reduce emissions through various mitigation measures and the investment required to achieve significant carbon emission reductions, as determined by its overall emissions. It evaluates the scope for decarbonisation through increased use of pellets (ME-P) and scrap (ME-S), EE, RE, substitution of imported for domestic coal/alternate fuel (AF), CCUS, and carbon offsets.

Readiness reflects a cluster's preparedness to decarbonise. It accounts for factors such as the presence of ESCOs and pellet-making units, awareness of green steel, NCMs, and related developments, availability of alternative fuels (e.g., NG), and access to and connectivity with port infrastructure. Based on these definitions, clusters can be categorised into four groups, as indicated in Figure 24.

- Low annualised decarbonisation cost and high readiness
- High annualised decarbonisation cost and high readiness
- Low annualised decarbonisation cost and low readiness
- High annualised decarbonisation cost and low readiness

Annualised cost shows mitigation and investment needs; readiness reflects implementation conditions.

Figure 24. Categories of clusters explained based on annualised decarbonisation cost and readiness levels




*Source: Authors' illustration*

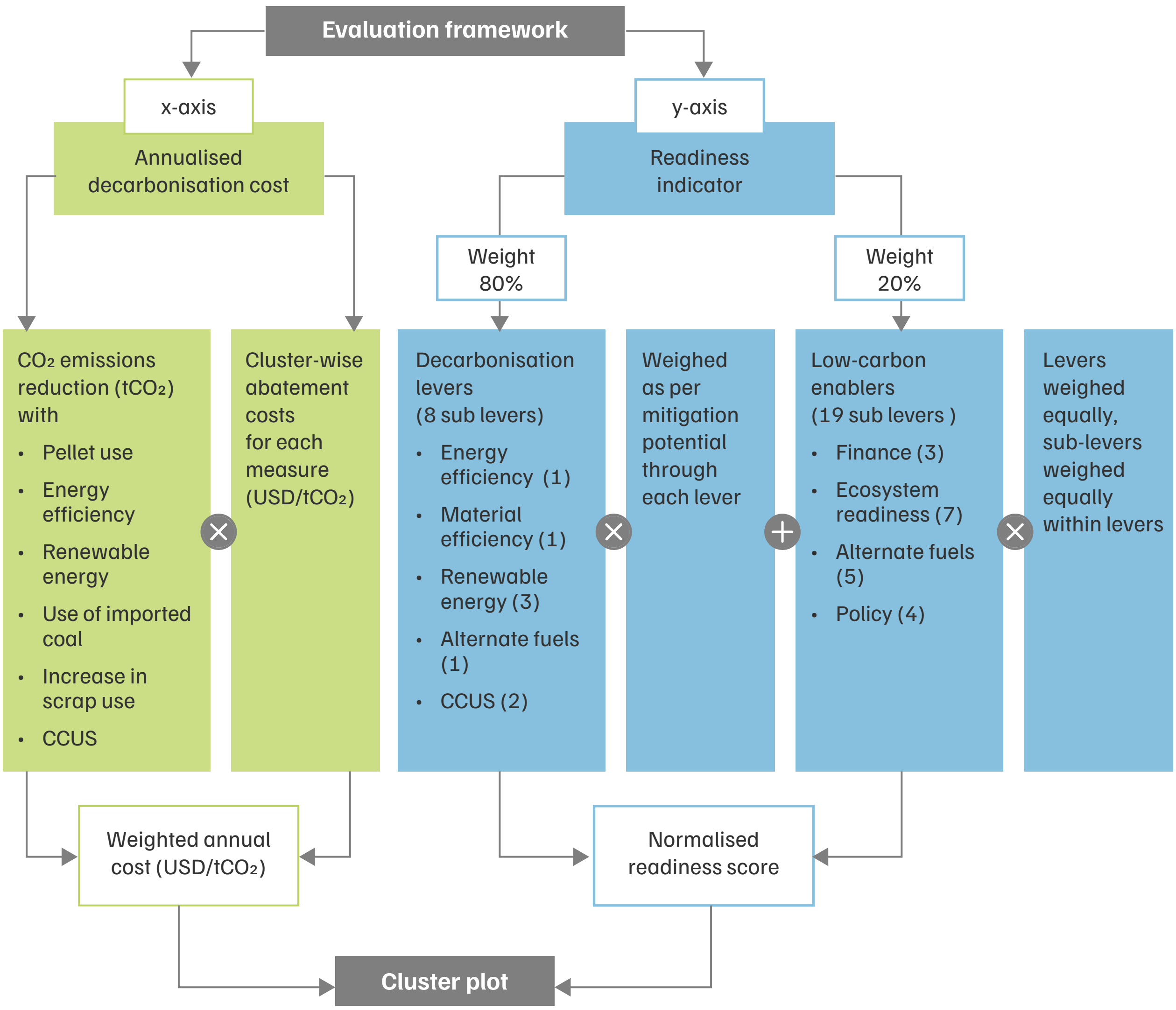
## 5.2 Methodology

The evaluation framework serves as a decision-support tool for systematically comparing decarbonisation opportunities across clusters by evaluating two key dimensions: decarbonisation cost and readiness. Clusters are plotted on a matrix, with the x-axis representing the annualised decarbonisation cost (cost per tonne of $CO_2$ of transition required per year, obtained from MAC curves developed in Chapter 4) and the y-axis representing the readiness indicator (decarbonisation levers and enablers of transition). Figure 25 illustrates this framework, enabling key stakeholders to identify clusters where decarbonisation interventions can achieve high or low impact and face higher or lower barriers to execution.

## Annualised decarbonisation cost

The decarbonisation indicator of a steel cluster can be represented either in monetary terms or based on total emissions. While total emissions serve as a decent indicator of emissions mitigation potential, they do not effectively capture the associated costs. Consequently, presenting the decarbonisation index in monetary terms provides a more accurate reflection of the efforts required to achieve net-zero emissions within the cluster. To compare clusters more effectively, costs are further expressed per unit of emissions mitigated, highlighting the relative ease of decarbonisation across clusters. In this report, the x-axis monetary value represents the sum product of the cost of $CO_2$ mitigation across various decarbonisation levers and the corresponding extent of abatement achievable for each, as derived from the MAC curve indicated in Figure 21. This cost is then normalised by the emissions mitigated in each cluster. The annualised decarbonisation cost thus indicates the annual monetary outlay (in USD/tonne) to achieve net-zero emissions in the cluster.

Figure 25. The evaluation framework considers the annualised decarbonisation cost and readiness of each cluster for comparison




*Source: Authors' illustration*

## Readiness indicators

Readiness indicators, as defined earlier, use multiple levers and sub-levers to compare clusters. They are broadly divided into two categories:

- Decarbonisation levers
- Low-carbon enablers

The decarbonisation levers comprise 5 levers and 8 sub-levers, while the low-carbon enablers indicator comprises 4 levers and 19 sub-levers. Each lever is scored either quantitatively or qualitatively and normalised to a 0–1 scale, following the method adopted by NITI Aayog (Pandey et al. 2022). These are then aggregated to compute a composite readiness score. To maintain uniformity, each cluster is normalised against maximum and minimum scores wherever quantitative inputs are considered. The following is a description of the levers under the readiness indicator:

**Decarbonisation levers**: These represent indicators that can aid in reducing emissions under the levers identified in the annualised decarbonisation cost.
These include:

- EE (1 sub-lever)
- ME (1 sub-lever)
- RE (3 sub-levers)
- CCUS (2 sub-levers)
- Alternative fuels (1 sub-lever)

Decarbonisation levers are more critical to achieving emission reduction than low-carbon enablers and, therefore, are assigned an 80 per cent weightage in the overall readiness score. The weights attached to each lever correspond to the share of emissions mitigation potential for each lever for that cluster and are equally divided among sub-levers. For example, if CCUS can reduce 50 per cent of the emissions in a cluster, then the weights allocated to CCUS sub-levers are derived as follows:

- Total weight for decarbonisation levers: 80 per cent
- CCUS share of decarbonisation potential: 40 per cent (50 per cent of 80 per cent)
- Sub-lever allocation: 40 per cent divided equally between the 2 CCUS sub-levers (e.g., CCU and CCS potential), resulting in 20 per cent weight per sub-lever

In total, there are eight sub-levers under these five levers. Scoring for each sub-lever is based either on absolute values derived from the survey or secondary data, or on binary values depending on the indicator evaluated, as described in Figure 26. For example, under the CCUS lever, two indicators are used. The first is CCU potential, which is assessed using the increase in delivered cost of green hydrogen in the cluster due to OA charges as a proxy. For this indicator, the analysis considers CCU products that use green hydrogen as a feedstock. This varies across clusters and is therefore assessed using relative scoring. The second indicator is CCS potential, which is based on the presence of carbon storage formations, such as saline aquifers or basalt, within the cluster. This is scored as a binary indicator: clusters with identified storage formations (e.g., Raipur, which has saline aquifers) are assigned a score of 1, while those without such formations (e.g., Bellary, which lacks both saline aquifers and basalt formations) are assigned a score of 0. The nature of each rating (binary or relative) is indicated in Figure 26, after the name of the lever in italics. Further details on the rating for each lever and sub-lever are provided in Annexure 5.

Figure 26. Decarbonisation levers are weighted by mitigation potential in the cluster

**Decarbonisation levers**

**Energy efficiency**

- Presence of ESCOs within and near the steel cluster (*binary*)

**Material efficiency**

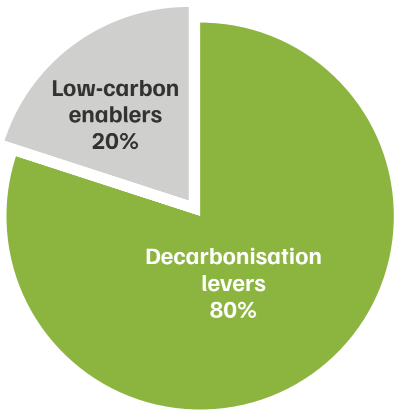
- Presence of pellet-making units in the cluster (*relative*)

**Alternate fuels**

- Access and connectivity with port infrastructure for imported coal through railways (*binary*)

**Renewable energy**

- The state has adopted or issued a draft for Green Open Access Rules (*binary*)
- Delivered cost of RE (via solar intra-state and inter-state) through OA charges (*relative*)
- Delivered cost of RE (via wind energy) through OA charges (*relative*)




**Carbon capture, utilisation and storage potential**

- CCU potential in the cluster based on green hydrogen potential in the region (*relative*)
- CCS potential in the cluster (geological storage availability: basalt, saline aquifers) (*binary*)

*Source: Authors' analysis*

**Low-carbon enablers**: The remaining readiness indicator comprises low-carbon enablers, with a total weight of 20 per cent. These enablers contain systemic, institutional, financial, and policy-related factors that create an enabling environment for the deployment of decarbonisation technologies. While they do not directly reduce emissions, they are essential for unlocking the feasibility and scalability of mitigation measures. Given that these enablers are parameters that, in most cases, do not entail any major financial implications, they are collectively assigned only 20 per cent of the weightage in the overall readiness scores. The low-carbon enablers category includes 4 main levers and 19 sub-levers. Each lever is allocated an equal weight of 5 per cent (20 per cent divided equally across four levers), and each sub-lever under a given lever is further allocated an equal weight of the 5 per cent weight allocated. For example, the sub-lever 'presence of a natural gas pipeline in the cluster' under the alternate fuels lever is weighted as follows:

- Total weight for low-carbon enablers: 20 per cent
- Alternative fuels' share of low-carbon enablers: 5 per cent (20 per cent divided equally among 4 levers)
- Sub-lever allocation: 1 per cent (5 per cent divided equally among the 5 alternate fuels sub-levers, resulting in 1 per cent per sub-lever)

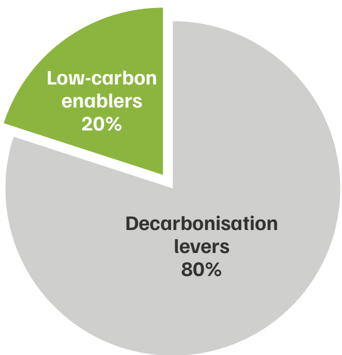
Figure 27 illustrates the 19 sub-levers for each lever and the scoring type used (binary or relative). The sum of all weighted 27 sub-levers yields the total readiness score for low-carbon enablers. The scoring method (binary or relative) is indicated in italics after each lever in Figure 27, and detailed descriptions of all levers and sub-levers are provided in Annexure 5.

Figure 27. Sub-levers under low-carbon enablers are equally weighted under each lever

**Low-carbon enablers**

**Finance**

- Finance – access to finance i.e. presence of SIDBI branch in the cluster (*binary*)
- Bankability – share of the number of non-standalone DRI units in the cluster (*relative*)
- Availability of low-interest loans and interest subvention in the cluster (*binary*)




**Alternate fuels**

- Presence of natural gas pipelines in the cluster (*binary*)
- Delivered cost of natural gas in the state (*relative*)
- Creation of state-level green hydrogen policy (*binary*)
- State-level support for green hydrogen (USD/kg) (*relative*)
- Increase in delivered cost of green hydrogen due to OA (*relative*)

**Ecosystem readiness**

- Awareness of green steel and other related developments (like Green Steel Roadmap, national carbon markets, etc.) in the cluster (*binary*)
- Status of association in the cluster (*binary*)
- Training and workshops on low-carbon technologies for the DRI sector on a cluster level (*binary*)
- Share of non-standalone DRI capacity of the cluster (*relative*)
- Presence of anchor steel plant in the cluster (*relative*)
- DRI capacity covered under PAT scheme in the cluster (*relative*)
- Steelmaking capacity covered under PAT in the cluster (*relative*)
- Finished steelmaking capacity under PAT in the cluster (*relative*)

**Policy support**

- Taxonomy of green steel definition (*binary*)
- Green steel procurement policy of the central government (*binary*)
- Green steel procurement policy of the state government (*binary*)
- Monitoring, reporting, and verification mechanism for green steel certification (*binary*)

*Source: Authors' analysis*

The individual readiness indicator scores are calculated for each of the five clusters. For each of the 27 indicators, based on weight, the scores range from 0–1. A cluster is scored 0 if it performs lowest on a given indicator and 1 if it scores the highest. Clusters falling between the highest and lowest are scored between 0 and 1 based on their proximity to the maximum score. The corresponding score is reversed for a negative indicator. This methodology is based on the NITI Aayog's ranking methodology for states in its *State Energy and Climate Index* report (Pandey et al. 2022) and is commonly referred to as min–max normalisation. The normalisation method for the indicators is further explained as follows:

For positive indicators, higher values indicate better performance. The formula used for normalisation is:

$$\text{Cluster's score for the indicator} = \frac{(\text{Cluster's actual value} - \text{Lowest value})}{(\text{Highest value} - \text{Lowest value})}$$

For negative indicators, lower values imply better performance. The formula used for normalisation is:

$$\text{Cluster's score for the indicator} = \frac{(\text{Highest value} - \text{Cluster's actual value})}{(\text{Highest value} - \text{Lowest value})}$$

For example, consider the readiness indicator, which measures the ratio of pellet capacity to DRI capacity in each cluster. The input values are as follows:

- Bellary: **2.10 (Highest value)**
- Raipur: 0.91
- Raigarh: 0.61
- Sundargarh: 0.18
- Jharsuguda: **0.00 (Lowest value)**

Since this is a positive indicator (higher values reflect better readiness), we apply min–max normalisation using the following formula to calculate normalised scores:

$$\text{Cluster's score for the indicator} = \frac{(\text{Cluster's actual value} - \text{Lowest value})}{(\text{Highest value} - \text{Lowest value})}$$

For example, the score for Raipur is calculated as:

$$\text{Raipur( Pellet score)} = \frac{(0.91-0)}{(2.1-0)} = 0.43$$

Applying the same formula across all clusters, we obtain the following normalised scores:

- Bellary = 1.00
- Raipur = 0.43
- Raigarh = 0.29
- Sundargarh = 0.08
- Jharsuguda = 0.00

The normalised scores are then multiplied by their respective weights to derive the overall readiness scores for each cluster. This method is particularly useful because it allows for the inclusion of additional clusters as new survey data become available. As more clusters are incorporated, the model's comparative strength and robustness improve, enhancing its utility for broader policy planning and targeted interventions at the cluster level.

## 5.3 Decarbonisation costs and readiness score computation

This section discusses the computation of the annualised decarbonisation costs and readiness scores, and analyses the results of the calculations that informs the development of the evaluation framework.

### Decarbonisation costs calculations and results

The annualised decarbonisation costs for all clusters are estimated using two key parameters:

- **Emissions mitigation potential (A)**: The total emissions in each cluster and the mitigation potential through each measure, as tabulated in Table 8 (Chapter 4).
- **Cost of emissions mitigation (B)**: Abatement costs for various decarbonisation measures across each cluster, measured in USD/t$CO_2$ abated. These are estimated using survey and secondary data, tabulated in Annexure 4 and further illustrated in Figure 21.

The weighted average of each measure's emissions mitigation potential (A) within a cluster, and its respective abatement cost (B), yields the annualised decarbonisation cost. Across clusters, costs exceed 40 USD per tonne of $CO_2$ mitigated, driven by the higher share of CCS, followed by alternative fuel use. Implementing CCUS as a mitigation measure substantially inflates annual costs in all clusters. Since there are no examples of CCUS implementation in India, this technology is unlikely to be adopted in the near term. The Ministry of Steel report (Verma et al. 2024) similarly identifies CCUS as a long-term measure, expected to be deployed only after 2030, once all other readily implementable measures have been adopted, particularly low-hanging options such as WHRBs and RE. Consequently, we have developed a separate cluster plot for all mitigation pathways, excluding CCUS, to evaluate cluster performance using readily available measures.

Excluding CCUS lowers annual costs to under 10 USD/t$CO_2$ but drastically cuts mitigation potential from 32 to 11 Mtpa.

## Readiness indicator results

Framework guides policy to boost readiness and lower decarbonisation costs across clusters.

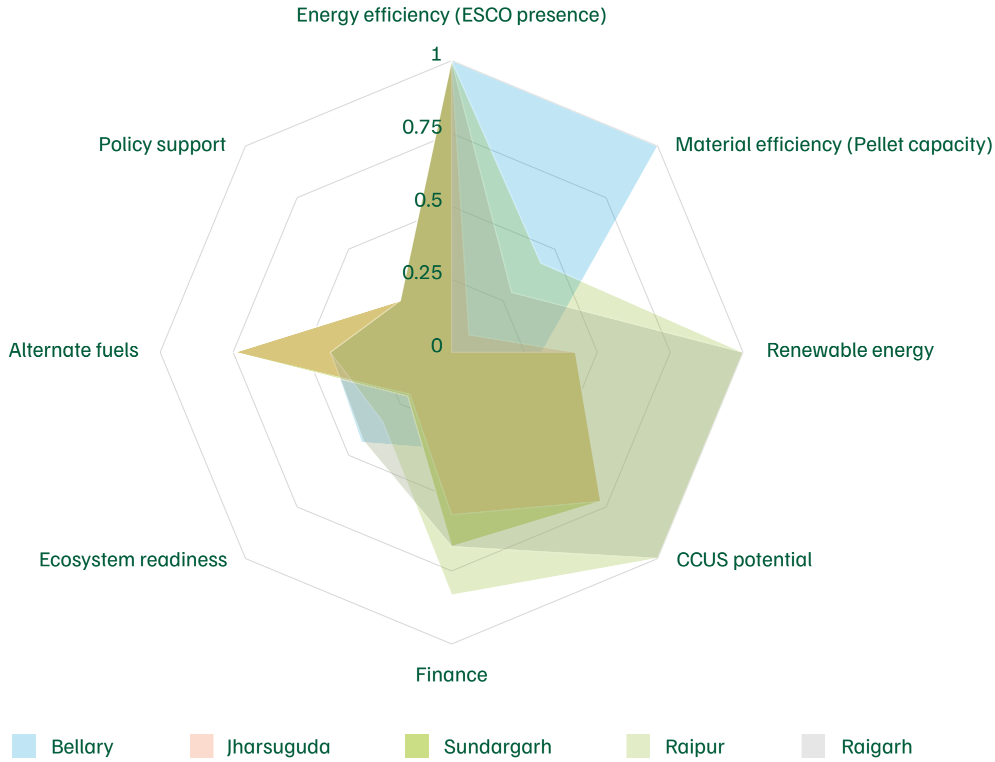
Figure 28 presents the cluster-wise relative readiness scores for all eight readiness levers. According to our survey findings, ESCOs are present in all states (BEE 2024). It is important to actively engage with them to identify and implement EE projects and avail benefits from state and central programmes, such as those offered through the Ministry of Micro, Small, and Medium Enterprises (MoMSME) and BEE. On ME, the Bellary cluster has greater pellet-making capacity than its internal demand, while Raipur has sufficient capacity to meet 91 per cent of its total requirement. In contrast, Raigarh and the clusters in Odisha have lower pellet-making capacity, indicating limited readiness to implement pelletisation as a decarbonisation lever. On RE, Chhattisgarh and Karnataka have incorporated the *Green Open Access Rules*, whereas in Odisha, the rules remain under draft. Chhattisgarh also has the lowest landed OA tariff for both solar (inter- and intra-state) and wind energy, boosting its RE-related readiness score.

As noted in Chapter 4, CCUS represents a major pathway for decarbonisation across clusters. The presence of saline aquifers in Chhattisgarh and Odisha can aid decarbonisation in clusters located in these states. Bellary, which lacks any CCS potential, scores low on the readiness score. Green hydrogen can be utilised for producing various value-added fuels and chemicals (Sripathy et al. 2025). Accordingly, for CCU readiness, we have used OA charges on green hydrogen to calculate cluster scores. Similar to RE, clusters in Chhattisgarh perform the best on this metric owing to lower OA charges, while Bellary, with higher charges, scores lower.

Chhattisgarh and Odisha are more conducive to finance than Bellary, primarily due to a higher proportion of non-standalone units and the presence of financing institutions, such as SIDBI branches, in the area. However, all clusters display limited readiness in ecosystem development, marked by low awareness of low-carbon steel, minimal training initiatives, and limited coverage under the PAT scheme. In terms of alternative fuel readiness, Odisha has state-level policy and support for green hydrogen; hence, it performs well. Chhattisgarh, however, faces a high delivered cost for NG, which reduces its readiness.

Both central and state governments can develop policies to support the decarbonisation of the steel industry. Currently, we have identified the taxonomy for green steel, green public procurement (GPP), and MRV frameworks as key policy tools influencing decarbonisation within clusters. These policy tools affect all clusters equally, as three out of the four sub-levers under the policy lever are managed by the central government. The fourth sub-level, a GPP programme, has not yet been developed by any state.

Figure 28. Cluster-wise relative readiness scores for all eight readiness levers



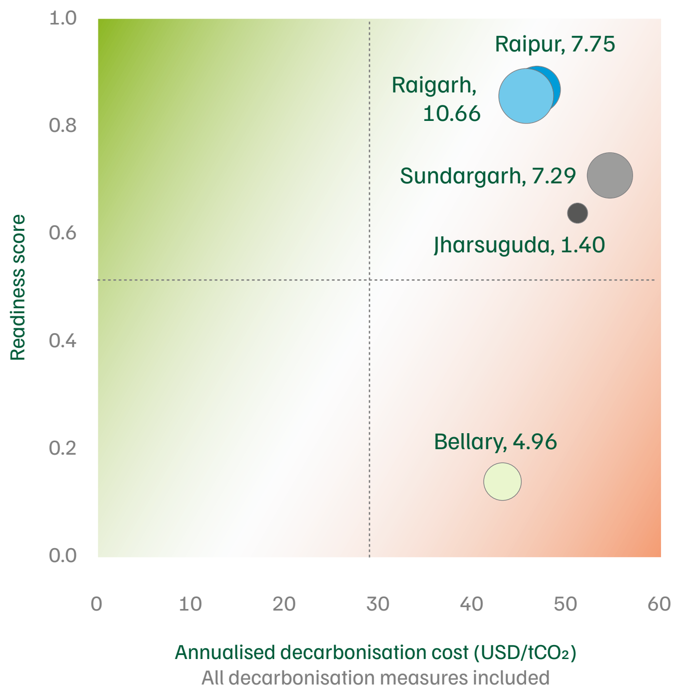

*Source: Authors' analysis*

## 5.4 Cluster plots

Cluster plots are created by plotting readiness indicators on the y-axis, with values ranging from 0–1. The normalised readiness indicator scores are weighted as described in Section 5.2 to yield an overall readiness score between 0 and 1. The annualised decarbonisation costs are normalised per tonne of emissions mitigated and plotted on the x-axis of the cluster plot, representing the relative ease of decarbonisation across clusters.

Figure 29 presents the cluster rankings based on their annualised decarbonisation costs and readiness indicators. With the exception of Bellary, all clusters exhibit high readiness and high annualised decarbonisation costs, primarily due to the cost of implementing CCUS and alternative fuels, as well as the potential for CCS deployment in these regions. Bellary demonstrates low readiness, primarily because of a lack of CCS potential and the high cost of green hydrogen, which is used as a proxy for CCU readiness. However, Bellary also has a lower annualised decarbonisation cost, as WHR alone can meet its power demand. Moreover, the cluster already uses 100 per cent imported coal, leaving no scope for additional RE or alternative fuel interventions that might otherwise increase decarbonisation costs. Sundargarh and Jharsuguda have comparatively higher costs due to the need for a higher proportion of alternative fuels. Overall, achieving net-zero emissions across all clusters will require decarbonisation costs of over 30 USD/t$CO_2$, indicating a high cost of decarbonisation.

Figure 29. Raigarh, Raipur, and Sundargarh clusters have relatively high potential and readiness indicator scores compared to other clusters



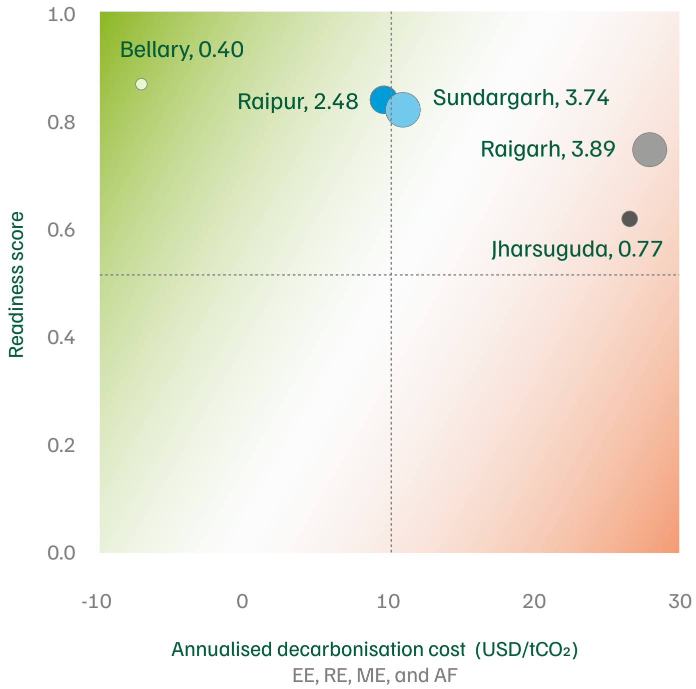

*Source: Authors' analysis*

Note: The size of the bubble corresponds to the emission-reduction potential.

A limitation of this plot and cluster comparison is that CCUS, as a single measure, is responsible for a significant portion of the emission reductions in the clusters if they are to achieve net zero immediately. Consequently, it disproportionately influences both readiness and decarbonisation costs. As shown in Table 8, CCUS dominates the overall decarbonisation cost across all clusters. Additionally, because of the high weight assigned to CCUS within the decarbonisation levers–which represent 80 per cent of the weight in the readiness indicators–clusters in Odisha and Chhattisgarh have readiness scores above 0.5, while Bellary scores below 0.2. The latter is largely due to the cluster receiving zero weight for alternative fuel and RE, as it already uses imported coal and can meet its entire electricity demand through WHR alone, eliminating the need for additional RE deployment. It is hence necessary to independently evaluate the cluster plots without CCUS, as the technology is not yet ready for deployment compared to the other decarbonisation measures.

Removing CCUS from the readiness and decarbonisation cost calculations yields an alternative cluster plot, as shown in Figure 30. In this scenario, the extent of emission reductions decreases significantly without CCUS (as seen in the bubble sizes of the clusters in the Figure 30). Overall, the decarbonisation costs now range from–10 to 30 USD/t$CO_2$, while the readiness scores for each cluster range between 0.6 and 0.9. The Bellary cluster scores higher at 0.9, as EE and ME carry higher weights in this case. Bellary also benefits from ESCOs and a higher pellet capacity, which enhance its readiness. Without CCUS, decarbonisation costs largely shift towards alternative fuel use. The Bellary cluster now shows a negative decarbonisation cost, driven by substantial savings from WHR. In contrast, Sundargarh becomes a high-cost cluster because it must replace its domestic coal (88 per cent) with imported coal, which is an expensive intervention. Clusters in Chhattisgarh are less dependent on alternative fuels, resulting in a decarbonisation cost of 10 USD/t$CO_2$.

Figure 30. For easily implementable options, such as renewable energy, material efficiency, energy efficiency, and alternate fuels, all clusters have high readiness scores, but the clusters in Odisha have high decarbonisation costs




*Source: Authors' analysis*

Note: The size of the bubble corresponds to the emission-reduction potential.

Switching to higher-calorific imported coal can reduce emissions; however, it remains highly sensitive to price fluctuations between the types of coal considered. The MAC values for the clusters inflate as the cost difference between imported and domestic coal increases, compounded by the volume of coal used. Our survey found domestic coal prices ranging from INR 1,000–5,000 per tonne, while imported coal costs ranged from INR 9,000–12,000 per tonne. For clusters that depend more on domestic coal, this significantly inflates annualised decarbonisation costs. This is particularly evident in Sundargarh, which has a large DRI capacity and 100 per cent domestic coal use. This makes the coal switch an expensive proposition despite its emission-reduction benefits. Moreover, relying on imported coal raises concerns around national energy security and contradicts the Ministry of Coal's efforts to promote domestic production and reduce import dependence. Recognising this, Figure 31 presents readiness and decarbonisation costs, excluding alternative fuels and CCUS, to better isolate the results of 'low-hanging' interventions, including WHR, scrap, pelletisation, and FDRE.

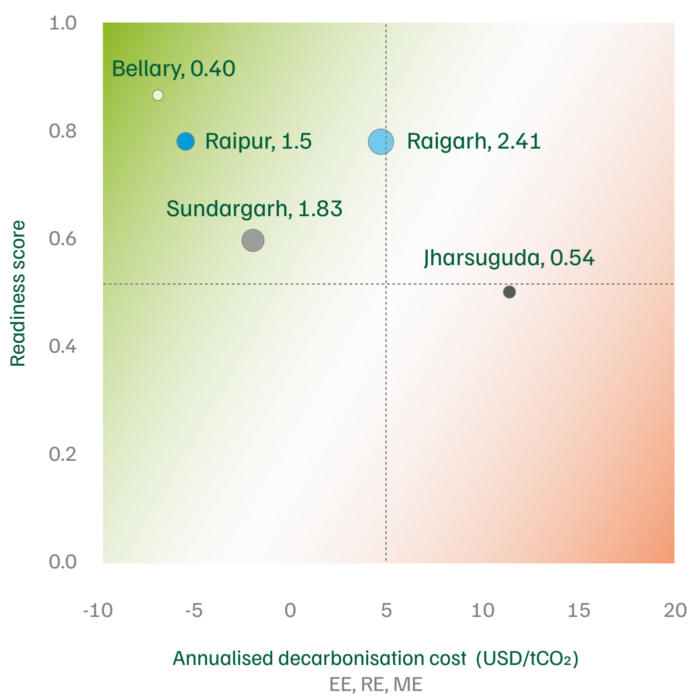
In this scenario, the emissions mitigated from clusters decline further, and all clusters except Jharsuguda transition to the low-cost, high-readiness quadrant. Bellary emerges as the most suitable cluster, but with only 0.4 Mtpa of emission reduction achieved. The relative positioning of clusters in terms of cost and readiness is explained as follows:

From the MAC values, it is evident that WHR and scrap utilisation result in cost savings. Pelletisation, as a measure, has a limited impact in Raipur due to its already high pellet usage but incurs additional costs in Raigarh, Sundargarh, and, to some extent, Bellary.

The FDRE requirement is 0 MW in Bellary, and Sundargarh requires only 14 MW of additional FDRE capacity, since WHRBs can meet 88 per cent of its power needs. Raipur, which relies more on grid power, has the lowest OA charges among all clusters across states, resulting in significantly lower MAC values for FDRE. All these factors led only Jharsuguda and Raigarh to record positive MAC values, primarily driven by FDRE and pelletisation.

In terms of readiness, scores depend on both the relative scores of the indicator and the weights described in Section 5.2. All clusters score above or equal to 0.5 on readiness, with Bellary the highest at 0.87 and Jharsuguda the lowest at 0.50. In the case of Bellary, the absence of RE-related emission-reduction measures shifts most indicator weight to EE and ME levers, where the cluster scores well due to strong ESCO presence and pellet-making capacity that exceeds local DRI demand. Jharsuguda, by contrast, has no pellet capacity and thus scores poorly on ME readiness. Other clusters also underperform on ME indicators because of Bellary's higher pellet capacity (Annexure 3). Clusters in Chhattisgarh benefit from lower OA charges for both solar and wind, improving their readiness scores relative to Odisha. In contrast, Jharsuguda allocates 49 per cent of its weight to RE indicators—an area in which it performs poorly—contributing to its lower overall readiness score.

Figure 31. Without CCUS and alternate fuel use, firm and dispatchable renewable energy and WHR influence costs for decarbonisation




*Source: Authors' analysis*

Note: The size of the bubble corresponds to the emission-reduction potential.

The evaluation framework developed in this study could be devised in several ways. For instance, the weights assigned to readiness indicators can be recalibrated, and the total costs of cluster decarbonisation could be used in place of per-capita costs (Annexure 6 presents the results using this approach). Another approach is to plot total emissions mitigated on the x-axis rather than costs. Although these alternative approaches were explored and assessed, the model presented here was ultimately selected as the most accurate representation of both readiness and decarbonisation potential.

It is also important to note that the current version of the model has been applied to only five clusters. However, it is better suited for evaluation across a larger number of clusters. With a limited sample size, readiness scores remain relative–meaning a cluster could receive a score of zero despite being sufficiently prepared, simply due to the narrow comparison base.

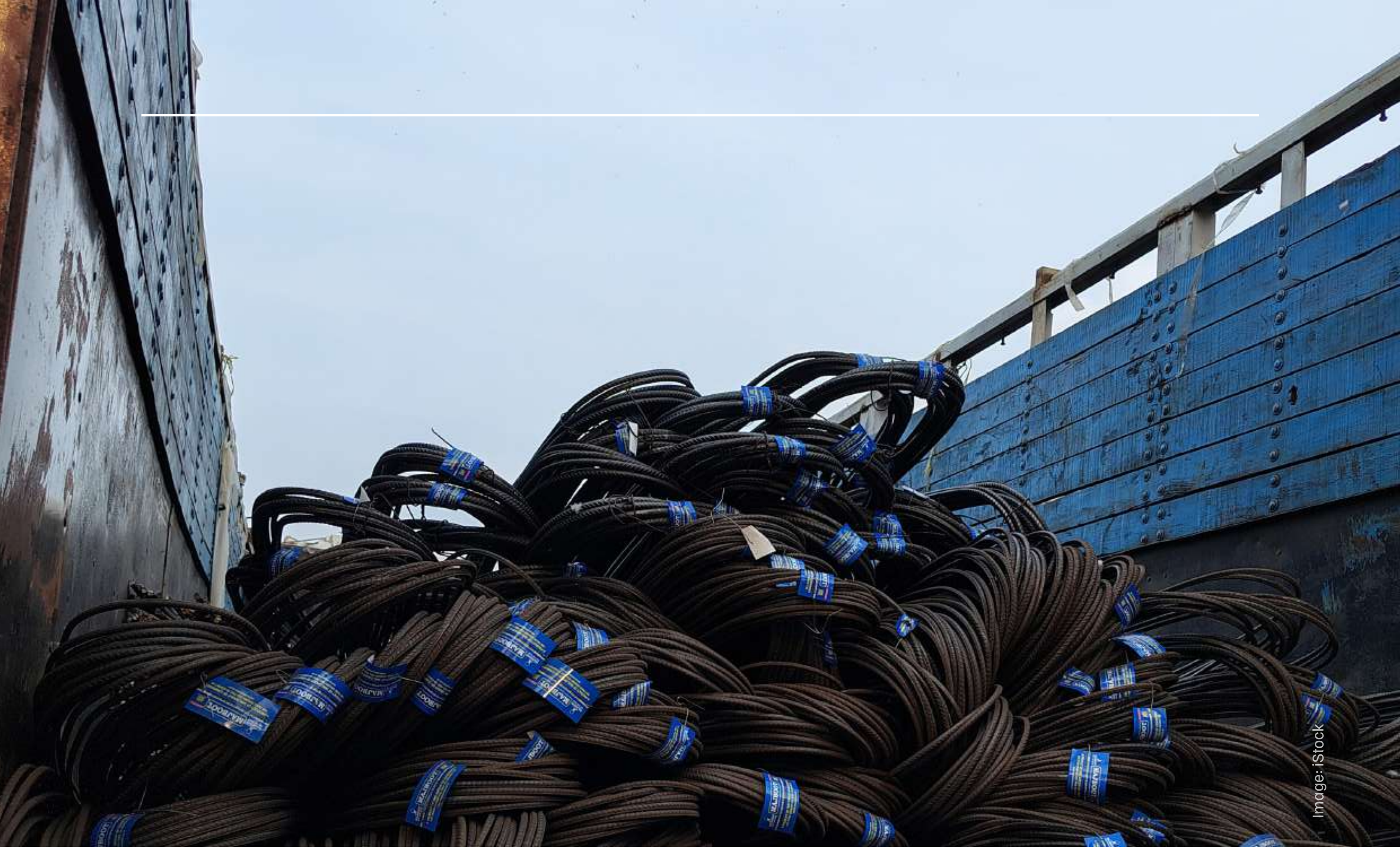


Image: iStock

# 6. Recommendations

Decarbonising the DRI sector requires a structured, phased approach to address barriers and unlock opportunities across clusters. By adopting the evaluation framework developed in this study, stakeholders can assess each cluster's readiness and decarbonisation cost to enable interventions that reduce emissions while enhancing sustainability. This chapter presents a stepwise strategy that begins with raising policy awareness and improving data disclosure, advances to policy support, leadership, and the simultaneous implementation of decarbonisation levers—such as EE, ME through pellet-plant integration, RE, and culminates in scaling solutions through demonstrations. The recommendations are categorised into cross-cutting and cluster-specific recommendations. The cross-cutting recommendations lay the foundation for sectoral progress, while cluster-specific recommendations address the distinct needs of each cluster, ensuring that interventions are both targeted and effective in relieving operational issues and driving a low-carbon transition.

## 6.1 Cross-cutting recommendations for all DRI clusters

The cross-cutting recommendations in this section are organised according to the order in which specific interventions should be implemented. They are grouped into three broad categories based on the type of recommendation:

- Ecosystem enablers (three recommendations) under readiness indicators
- Decarbonisation levers, comprising targeted interventions for EE (one recommendation), ME (one recommendation), and RE (four recommendations)
- Pilot demonstration (one recommendation)

## Ecosystem enablers

The first set of interventions—the ecosystem enablers category under the readiness indicators (see Tables 9–11)—focuses on creating a supportive environment across all DRI clusters by addressing systemic barriers and institutional gaps. These actions serve as precursors and are essential for the successful implementation of the decarbonisation lever–related policies discussed later. They include:

1. Supporting SMEs through policy literacy (Table 9)
2. Improving data disclosure and reporting in DRI clusters (Table 10)
3. Implementing cluster-level decarbonisation accelerators (Table 11)

Each recommendation is presented in a structured format, identifying the key implementing agencies, supporting stakeholders, current barriers (state of play), and proposed solutions.

### Table 9. Improving policy literacy among steel units through targeted communication and outreach

| Field | Details |
|---|---|
| **Recommendation** | Support SMEs through policy literacy |
| **Category** | Grant |
| **Implementing agency/ Anchor organisation** | SIMA, state sponge iron associations |
| **Other stakeholders** | DRI SMEs, MoS, BEE, philanthropies |
| **State of play** | **Limited awareness and missed opportunities**<br>Plant visits and surveys across DRI clusters in Odisha and Karnataka revealed knowledge gaps among SMEs regarding recent policy and regulatory developments, particularly the Green Steel Roadmap and the NCM. Several SME representatives demonstrated limited familiarity with these frameworks, and discussions often required preliminary clarification of terms such as 'low carbon' or 'green steel' before meaningful discussions and surveys could be initiated. This lack of awareness not only impedes SMEs' ability to respond to emerging compliance requirements but also prevents them from capitalising on energy-saving opportunities and financial incentives embedded within these policies. |

| Field | Details |
| --- | --- |
| **Proposed solution** | **Reaching the last mile: A communication strategy for the DRI sector**<br><br>To address this disconnect, we propose a multi-pronged approach that leverages the convening power of DRI associations to raise awareness about green steel policies through four key channels:<br>• A central portal for information dissemination<br>• The SIMA DRI conference<br>• Cluster-level workshops<br>• Improved communication strategies<br><br>The Udyam portal should be leveraged as a central digital platform for disseminating information on any support measures or policy mechanisms developed by the MoS for SMEs in the steel sector. The MoS should update the platform with relevant decarbonisation policies, financing options, and regulatory guidance to ensure accessibility, especially for smaller units.<br><br>A core initiative under this approach could be the International DRI Conference, convened by SIMA. Representing over 80 DRI plants nationwide, SIMA is well-positioned to disseminate critical information on the evolving policy landscape, highlight support mechanisms, and demonstrate the operational and financial benefits of regulatory alignment, including emission reductions and access to concessional financing.<br><br>Along with dedicated sessions to unpack complex policy frameworks and make them accessible to the broader DRI sector, it is equally important to reach out to the many smaller DRI units that are not fully affiliated with national or state-level associations. These workshops may be conducted at the cluster level and, in the case of smaller clusters such as Jharsuguda, could be organised at nearby clusters, such as Kalunga. This could involve a series of workshops convened by think tanks, featuring interactive sessions and discussions with officials from district industrial centres, BEE, SIDBI, and other leading agencies. The workshops should be planned and structured to remain concise while directly addressing the plants' existing knowledge gaps and challenges. Simultaneously, these sessions must ensure that the information shared reaches general managers and senior plant representatives, and is not limited to owners alone.<br><br>Lastly, to ensure continuous engagement beyond in-person events, regulatory updates and circulars could be disseminated through dedicated messaging app groups or channels tailored to engage DRI plant owners and senior managers. These messages can be supplemented with short, jargon-free videos (1–2 minutes) and infographics summarising key policy developments, compliance procedures, and available financial incentives. To further enhance understanding, virtual Q&A sessions can be organised as needed, driven by the specific queries or challenges raised by SMEs, ensuring timely responses.<br><br>Beyond raising awareness, such an approach can also foster peer-to-peer (P2P) learning, encouraging SMEs to share experiences, replicate successful practices, and explore available incentives. Expanding this approach through events and outreach can improve policy literacy across the sector, enhancing both the resilience and competitiveness of India's DRI sector in its transition towards low-carbon growth. |

*Source: Authors' analysis*

Table 10. Improving emissions data disclosure and digital readiness in the DRI sector

| Field | Details |
|---|---|
| **Recommendation** | Improve data disclosure and reporting in DRI units |
| **Category** | Policy/regulatory |
| **Implementing agency/Anchor organisation** | BEE |
| **Other stakeholders** | MoS, artificial intelligence/machine learning startups |
| **State of play** | **Emerging compliance architecture and carbon market readiness**<br><br>Over the past two years, the steel sector has witnessed momentum around decarbonisation, driven by initiatives such as the *Green Steel Roadmap*, the *National Green Hydrogen Mission*, and the introduction of the Taxonomy of Green Steel. Most recently, the BEE has taken steps to operationalise the NCM by setting initial targets for heavy industries, such as steel, cement, and aluminium. These developments have been accompanied by the rollout of standardised project application templates and a structured compliance mechanism, including the appointment of accredited verification agencies. |
| **Proposed solution** | **Standardised reporting and public disclosure**<br><br>As the NCM evolves and the steel industry is brought under its scope, there is a strong case for introducing standardised emissions reporting formats for the secondary steel sector, particularly DRI producers. Such data disclosure formats would form the backbone of a system to capture emissions intensity across various production processes, including energy use, ME, and power generation.<br><br>This could include exploring how AI and data analytics startups can be engaged to develop smart data platforms that enable automated emissions tracking, flag anomalies, and provide real-time insights on potential carbon savings or enhance compliance. Such platforms could also serve as third-party enablers for smaller DRI units that lack internal MRV capacity, thereby improving overall readiness for market participation. Over time, such tools could be integrated into the national emissions registry, thereby ensuring a scalable, technology-driven data disclosure framework for the steel sector.<br><br>The disclosed data should be publicly accessible and updated annually. This measure alone can encourage industries to cut emissions (Meadows 2008). Further, this measure can guide philanthropies and government bodies in targeting specific clusters and enabling industry benchmarking. Data disclosures will also allow companies to understand where they stand relative to their peers. This could encourage P2P learning, knowledge exchange, and the adoption of best practices, resulting in operational improvements and sector-wide efficiency gains. |

*Source: Authors' analysis*

Table 11. Establishing cluster-level decarbonisation accelerators through local leadership and energy service companies (ESCO) partnerships

| Field | Details |
|---|---|
| **Recommendation** | Implement cluster-level DRI decarbonisation accelerator |
| **Category** | Capacity-building/Programmatic support |
| **Implementing agency/Anchor organisation** | Philanthropies, state sponge iron associations |
| **Other stakeholders** | DRI SMEs, state-designated ESCOs, think tanks |
| **State of play** | **Structural and resource constraints faced by associations**<br><br>State-level sponge iron associations face significant constraints due to their reliance on membership-based models. Their focus includes immediate operational challenges, including regulatory compliance, local conflicts, and survival concerns, relegating decarbonisation and emission reduction to a secondary priority. This lack of resources and clear mandates hinders their ability to drive the adoption of EE and RE among DRI SMEs. |
| **Proposed solution** | **Activate champions and ESCOs for cluster-level impact**<br><br>To foster leadership within associations, a donor-funded programme could be designed to identify two to three SME CEOs ('sustainability champions') from each state-level sponge iron association. Selected for their leadership potential, these champions would be required to collaborate with state-level ESCOs to drive decarbonisation initiatives at the cluster level.<br>As mandated by the BEE, ESCOs would conduct energy audits, implement EE and RE interventions, and verify the resulting savings, ensuring measurable cost and energy reductions. Identified sustainability champions would be responsible for coordinating SME participation, fostering engagement and recognising the top-performing SMEs through rewards and incentives.<br><br>Philanthropic support would be essential to facilitate capacity-building, equipping champions to advocate effectively without straining association resources. This initiative could integrate decarbonisation with improved EE, addressing associations' survival concerns while cultivating a culture of proactive engagement in the sector's low-carbon transition. Over time, it could lay the foundation for institutional change, positioning state-level associations as key drivers of industrial decarbonisation in India. |

*Source: Authors' analysis*

## Decarbonisation levers

While the ecosystem enablers establish the foundational infrastructure and supportive environment necessary for transformation, the decarbonisation levers represent the core technical interventions that directly reduce emissions intensity across DRI operations. These targeted solutions focus on three critical areas of 'low-hanging options' where immediate, measurable impact can be realised by improving EE, ME, and RE integration.

**1. Energy efficiency**

The following sets of recommendations aim to address the decarbonisation levers discussed in Chapter 4, beginning with those related to EE, primarily to increase WHRB penetration in the DRI clusters, as detailed in Table 12. Waste heat recovery represents the lowest-hanging fruit in the steel decarbonisation pathway, and efforts should be made to increase its penetration.

Table 12. Enabling WHR systems for small DRI units

| Field | Details |
|---|---|
| **Recommendation** | Enable WHR systems for small DRI plants |
| **Category** | Administrative coordination/Regulatory |
| **Implementing agency/Anchor organisation** | BEE, SIDBI, National Institute of Secondary Steel Technology |
| **Other stakeholders** | WHRB technology providers, industry associations, SME units |
| **State of play** | **Limited WHRB adoption among small-scale DRI units**<br><br>Survey findings indicate that WHRB adoption increases with plant capacity, with all units above 300 tpd reporting operational systems. On average, approximately 2 MW of WHRB capacity can be installed for every 100 tpd of kiln capacity. However, many existing installations fall short of this potential, particularly in smaller plants, where WHRB systems are often underutilised or inadequately sized relative to kiln capacity.<br><br>This shortfall is primarily driven by the financial challenges faced by small DRI plants (typically under 200 tpd). The capital cost of WHRB systems—around INR 14 crore per MW—represents a considerable financial barrier. Although WHRBs offer significant potential to enhance EE and reduce operating costs, limited access to finance continues to restrict widespread adoption, especially in smaller plants. Further, existing financing schemes, such as SIDBI's GIFT and SPICE, remain underutilised, primarily due to limited awareness, high collateral requirements, and complex application procedures. As a result, several smaller DRI plants continue to rely on less efficient processes, undermining efforts to reduce emissions. |
| **Proposed solution** | **Demand aggregation for accelerated uptake of WHRB systems for small DRI plants**<br><br>To address this challenge, MoS could explore a demand aggregation mechanism for WHRB systems through a centralised procurement platform or agency. This approach can leverage economies of scale to reduce capital costs and simplify procurement for smaller units that often lack negotiation leverage or procurement expertise. |

**2. Material efficiency**

The use of pellets reduces emissions in the DRI sector; however, pellet-making units generate their own emissions and currently remain outside emissions accounting frameworks. Table 13 highlights the need to integrate pellet plants into the forthcoming NCM and strengthen data collection on emissions and substitution potential.

Table 13. Integrating pellet plants into emissions frameworks and market mechanisms

| Field | Details |
|---|---|
| **Recommendation** | Account for and reduce pellet plants' emissions |
| **Category** | Policy |
| **Implementing agency/Anchor organisation** | BEE |
| **Other stakeholders** | MoS, Pellet Manufacturers Association of India, pellet plant operators |
| **State of play** | **Pellet plants remain outside the emissions framework**<br><br>Pellet manufacturing units, which play a critical role in the DRI production value chain, remain outside the scope of existing regulatory mechanisms, such as the CCTS, despite their significant contribution to emissions. Moreover, the removal of export duties on pellets —originally intended to stimulate production and international trade—has had unintended consequences. In FY2023–24, approximately 12.24 Mt of pellets were exported out of the 47 Mt produced by non-integrated steel producers. Assuming ISP-based pellet production is used internally, only 34.76 Mt remained available for the rest of the industry, including DRI units (JPC 2023–24). However, C-DRI production during the same period stood at 33.34 Mtpa, which would have required around 45.84 Mtpa of pellets to meet demand fully. Thus, lower pellet availability increases pellet prices for DRI producers, many of whom reported price sensitivity as a key factor limiting pellet uptake in our survey. |
| **Proposed solution** | **Integrate standalone pellet plants into emissions accounting and market mechanisms**<br><br>To address this issue, standalone pellet manufacturing units should be brought within the ambit of the proposed NCM, thereby recognising both their emissions profile and their potential to support emission reductions in downstream DRI production. While the contribution of pellet use to emission reduction is reflected in the emissions intensity of DRI production, the actual emissions intensity of pellet production itself remains unaccounted for, creating a potential leakage in the system. The first step in this process could involve collecting and disseminating data and evidence quantifying the dual role of pellets: their own emissions footprint and their comparative advantage in reducing emissions when substituting for lump ore in DRI plants. These insights could be presented through policy briefs and targeted consultations with key stakeholders, including the BEE, MoS, and PMAI. The aim would be to establish a more integrated and holistic emissions accounting framework within the secondary steel sector. |

*Source: Authors' analysis*

**3. Renewable energy**

Tables 14 to 17 present recommendations to enhance the adoption of RE in secondary steel industries (SSIs). These include:

- Reallocating CPP power (Table 14)
- Rationalising cross-subsidy and additional surcharges for RE accessed via OA (Table 15)
- Aggregating demand through cluster-level coordination and streamlined approval processes (Table 16)
- Facilitating RE procurement through measures such as behind-the-meter (BTM), P2P, and group captive models (Table 17), which can lower transaction costs and boost participation by smaller units

## Table 14. Reallocating captive coal power plants to enable RE integration in steel clusters

| Field | Details |
|---|---|
| **Recommendation** | **Reallocate the existing captive coal power plant's power to market or discoms** |
| **Category** | Policy |
| **Implementing agency/Anchor organisation** | MoP, state energy departments, discoms, GENCOs |
| **Other stakeholders** | NTPC, state GENCOs, steel plant operators |
| **State of play** | Captive power plants currently play a major role in meeting the electricity needs of steel clusters. As per our survey, approximately 35 per cent of the total electricity demand in the surveyed units is met through CPPs, with clusters in Odisha showing an even higher dependence. Meanwhile, India plans to add 80 GW of coal-based power capacity by 2030–31 (PIB 2024b). A portion of this projected capacity could be offset by reallocating existing CPPs power in steel clusters. |
| **Proposed solution** | To support the transition of CPP-based units away from coal, state governments and their respective energy departments should facilitate the offloading of CPP-generated power to the grid or the market . This would create space for RE integration at the plant level while minimising the risk of stranded power assets.<br>A pilot initiative should be undertaken to assess the feasibility of this mechanism. Insights from such a pilot could inform the development of a policy framework under the MoP and state energy departments to further reduce reliance on CPP-based power from steel units. |

*Source: Authors' analysis*

Table 15. Rationalising cross-subsidy and additional surcharges to improve RE adoption without harming grid stability

| Field | Details |
|---|---|
| **Recommendation** | **Rationalise cross-subsidy and additional surcharge in the states** |
| **Category** | Policy |
| **Implementing agency/Anchor organisation** | State electricity regulatory commissions (SERCs) |
| **Other stakeholders** | Central Electricity Regulatory Commission (CERC), state energy departments, discoms, commercial and industrial (C&I) consumers |
| **State of play** | At present, units procure CPP power at INR 3.72 per kWh (Elango et al. 2023) and grid power at INR 6.76–8.61 per kWh. Units seeking to access RE through OA must also incur several charges, including cross-subsidy surcharges (CSSs) ranging from INR 0.42 per kWh in Odisha to INR 1.95 per kWh in Karnataka. While Chhattisgarh and Odisha currently do not levy additional surcharges (CSERC 2024; OERC 2024), Karnataka levies a surcharge of INR 0.96 per kWh (KERC 2023). Nonetheless, Odisha offers notable regulatory exemptions under its *Renewable Energy Policy, 2022*. For example, industries procuring RE through Grid Corporation of Odisha (GRIDCO ) -- acting as a demand aggregator, are exempt from CSSs and receive additional concessions on wheeling and transmission charges. Karnataka has also initiated CSS rationalisation under its latest tariff orders (KERCb 2024). However, these differences across states create uneven playing fields and limit the broader uptake of RE through OA. Therefore, to encourage C&I consumers to adopt RE via OA, it is essential that states incorporate best practices from one another. |
| **Proposed solution** | To make third-party RE amenable to units that use grid power and are willing to switch to RE instead of CPP, state electricity regulatory commissions should rationalise cross-subsidy charges and any additional surcharges on steel plants adopting RE through OA for units migrating from grid power. Additionally, states should also align with *green energy open access rules* (GOAR 2022), which mandate the removal of all charges other than transmission, wheeling, CSS, and standby charges wherever applicable. To avoid revenue losses for discoms, reforms should be accompanied by robust resource adequacy planning and tariff rebasing mechanisms, in line with the *National Tariff Policy, 2016*. These measures would lower the effective landed cost of RE, enabling wider adoption across steel clusters without compromising grid stability. States could also draw lessons from best practices—such as Tamil Nadu and Gujarat's approaches to evaluating and planning for additional surcharges, and Karnataka's gradual CSS reduction—to design fair and balanced frameworks (KERC 2024). |

*Source: Authors' analysis*

Table 16. Aggregating RE demand and streamlining approvals through a single-window system

| Field | Details |
|---|---|
| **Recommendation** | **RE demand aggregation and single-window clearance for steel clusters implementing RE** |
| **Category** | Administrative coordination/Regulatory |
| **Implementing agency/Anchor organisation** | Steel units, MoS, state energy departments |
| **Other stakeholders** | SECI, state RE development agencies, state sponge iron associations |
| **State of play** | Clusters in Chhattisgarh require significant FDRE deployment—340 MW in Raigarh and 144 MW in Raipur. Aggregating RE demand rather than having individual units add capacity could reduce the cost of RE procurement. The SECI currently aggregates RE but charges a trading margin of INR 0.07 per kWh (SECI 2021). Meanwhile, MSMEs also face compliance and approval hurdles. Gujarat's *Survey of Villages and Mapping with Improvised Technology in Village Areas* (SVAMITVA) model offers a strong policy example: it digitally maps land parcels and implements a 'no denial policy' for transmission implemented through the *Akshay Urja Setu* portal under Gujarat Urja Vikas Nigam Limited (GUVNL), ensuring easier grid access for RE developers. |
| **Proposed solution** | State sponge iron associations could collaborate with renewable energy implementing agencies (REIAs), such as the Gujarat Energy Development Agency, to evaluate the feasibility of cluster-level demand aggregation through competitive bidding. Steel associations can coordinate aggregation efforts to reduce tariffs and achieve scale. In parallel, the MoS can develop a digital single-window platform for SSIs, integrating best practices from Gujarat's SVAMITVA scheme and the *Akshay Urja Setu* portal of GUVNL. This system should provide guidance on RE procurement models (captive, OA, community RE, etc.), streamline regulatory approvals and tracking, map land and transmission availability, and facilitate linking with RE developers and financiers. |

*Source: Authors' analysis*

Table 17. Enabling behind the meter (BTM), peer to peer (P2P), and group captive RE procurement to improve RE penetration

| Field | Details |
|---|---|
| **Recommendation** | **Explore the feasibility of BTM, P2P, and group captive RE procurement in steel clusters** |
| **Category** | Administrative coordination/Regulatory |
| **Implementing agency/Anchor organisation** | State energy departments, SERCs, state sponge iron associations |
| **Other stakeholders** | Discoms, RE developers, MoP, CERC |
| **State of play** | Many steel units surveyed expressed strong interest in installing RE systems, but face multiple hurdles related to power evacuation, land availability, and affordable grid access. Steel clusters are often located near other industries, providing opportunities to trade excess power generated within the cluster, bypassing grid power or CPP. Peer-to-peer energy trading between prosumers and customers in steel clusters can be another avenue to waive OA or discom charges. Group captive RE installations can also promote RE uptake in clusters for SSI units in industrial areas that face space constraints preventing on-site RE installations |
| **Proposed solution** | State energy departments should evaluate the feasibility of BTM RE procurement to bypass discom charges and reduce RE costs for the units. This model should also be extended to DRI units in the cluster that have issues evacuating power generated by WHR, particularly in Bellary, where it can produce more than 100 per cent of the power required in the cluster when it implements 100 per cent WHR.<br><br>The Chhattisgarh and Odisha state energy departments should enable P2P energy trading platforms between prosumers and customers in the cluster to waive RE-related OA or discom charges, similar to the policies in Delhi and Karnataka (KERCa 2024; DERC 2024; UPERC 2023). This can help units consume RE power with a lower tariff rate than RE procured through OA.<br><br>Further, state policies should proactively encourage group captive RE adoption by simplifying eligibility norms, enabling PPAs, and introducing a single-window clearance system to boost approvals. |

*Source: Authors' analysis*

## Pilot implementation based on this set of recommendations:

The last cross-cutting recommendation for all clusters is to demonstrate decarbonisation and act as a catalyst for the adoption of low-carbon technologies in the DRI sector.

Table 18. Establishing a model cluster-level DRI plant to demonstrate low-carbon pathways

| Field | Details |
|---|---|
| **Recommendation** | **Demonstrate decarbonisation at the unit level to build trust** |
| **Category** | Grant, administrative coordination/regulatory |
| **Implementing agency/Anchor organisation** | MoS, SMEs |
| **Other stakeholders** | Financial institutions, SRTMI, technology companies, and think tanks |
| **State of play** | **Lack of practical demonstrations**<br><br>Along with associations, DRI SMEs face considerable challenges in adopting low-carbon production practices, largely due to the lack of practical, financially viable, and scalable demonstrations tailored to their operational and financial contexts. Without live demonstrations showcasing decarbonisation strategies, such as EE, gas-based DRI, and RE integration, SMEs find it difficult to assess the operational and financial feasibility of such transitions. This lack of clarity reinforces their dependence on emissions-intensive, coal-based, and inefficient processes, ultimately delaying meaningful adoption. |
| **Proposed solution** | **Establish a cluster-level model DRI plant**<br><br>To address this challenge, it is recommended to establish a model DRI SME at the cluster level, designed to demonstrate low-carbon interventions with a focus on operational viability. Led by a think tank and co-funded by industry, financial institutions (such as SIDBI), technology providers, and SMEs themselves, this model plant would integrate EE measures, gas-based DRI processes, and RE adoption, offering a replicable and context-specific pathway for decarbonisation.<br><br>The model DRI plant could serve as a learning hub, providing hands-on exposure to actual operational costs, energy savings, and implementation challenges through site visits and technical workshops. By documenting and sharing key metrics—such as reduced energy costs and lower emissions intensity—the model would de-risk the adoption of low-carbon technologies for SMEs in the cluster, building trust and confidence in their feasibility.<br><br>An initial pilot in a low-cost, high-readiness cluster would leverage existing industrial networks and ecosystems. Insights from the demonstration could be disseminated through exposure visits, workshops, and stakeholder engagements to encourage broader uptake. Serving as a proof of concept, the model plant would not only inform future policy frameworks but also equip SMEs with practical, actionable knowledge to support cost-effective, low-carbon transitions. Learnings from the model plant could be documented and used to refine future pilots, shape supportive policies, and build a stronger case for financing low-carbon transitions across the DRI sector. The Steel Research and Technology Mission of India (SRTMI) can be leveraged to guide R&D efforts and share information about the pilot study across all clusters.<br><br>In parallel, the MoS should assess the feasibility of a pilot group-captive gas-based DRI model, in which either multiple steel producers within a cluster co-invest and jointly operate a large-scale gas-based DRI facility, or the gas-based DRI plant operates as a service to DRI producers in the cluster. This arrangement could potentially achieve economies of scale, distribute investment risks among multiple stakeholders, and enable pooled procurement of NG. The MoS should coordinate with the Ministry of Petroleum and Natural Gas to assess and facilitate the provision of affordable gas for such group-captive projects. |

*Source: Authors' analysis*

## 6.2 Cluster-specific recommendations

While the ecosystem-level and lever-based recommendations apply across India's DRI landscape, the evaluation framework highlights variations in cluster readiness and decarbonisation costs. Each cluster can therefore take targeted actions to advance its low-carbon transition. The following section outlines key focus areas for each cluster, with recommendations structured based on levers for decarbonisation and ecosystem enablers. We also provide recommendations for one key cluster (Bellary, Sundargarh, and Raipur) within the three states (Karnataka, Odisha, and Chhattisgarh) covered in the report. Other clusters across these states are covered in Annexure 7.

### Bellary

Bellary already relies on imported coal and has significant installed pelletisation capacity within the district. It is also the only cluster among those studied with strong potential for both wind and solar energy. Its current energy demand can be met entirely through WHR, avoiding the need for RE deployment to achieve emission cuts. However, the cluster is dominated by a high number of standalone DRI units, which face challenges in accessing finance and policy support. The recommendations for Bellary, provided in Table 19, focus on leveraging its EE potential, enhancing pellet uptake, improving access to NG and green hydrogen, addressing financing and regulatory barriers, and exploring a pilot programme to demonstrate CCUS in the cluster.

Table 19. Specific recommendations for the Bellary cluster

| Lever | Recommendations |
|---|---|
| EE | **Enable purchase of WHR power by IFs within the cluster**: The Bellary cluster has a WHR potential of 102 MW, assuming all DRI units adopt the measures outlined in Table 12. This exceeds the cluster's current power requirement of 94 MW. Achieving 100 per cent WHR utilisation could reduce $CO_2$ emissions by 0.25 Mtpa, resulting in a 6 per cent decrease in the cluster's total emissions. Therefore, Gulbarga Electricity Supply Company Limited (GESCOM) should allow other industries, in addition to IFs within the cluster, to purchase the WHR power generated by DRI units. The WHR power should be available at an affordable price to end consumers to encourage a switch from grid electricity to WHR power.<br><br>**Offtake WHR power at viable costs and incentivise WHR projects**: If surplus WHR electricity is available in the cluster, GESCOM should purchase it at viable prices for DRI plants. If discoms are unwilling to offtake WHR power at viable prices, additional incentives should be provided to encourage WHR system installations among DRI units. |
| ME | **Incentivise pellet uptake in the DRI industry**: Bellary has a pellet-making capacity of 6.8 Mtpa (excluding JSW's 16.4 Mtpa), sufficient to sustain its 2.36 Mtpa of DRI capacity. Plants have reported switching between pellets and lump ore based on cost considerations; only two of seven surveyed plants were using pellets during the survey. From our analysis, implementing 100 per cent pellet utilisation in Bellary could reduce $CO_2$ emissions by 0.11 Mtpa, about 2 per cent of the total cluster emissions. To enable this, the state government, through the Department of Mines and Geology, should ensure competitive pellet prices by granting pellet producers access to iron ore mines and reducing input costs through slurry pipeline development. Additionally, pellet unit emissions should be accounted for, as per Table 13, both to assess benefits from pelletisation and to nudge pellet-making units to reduce emissions. |

| Lever | Recommendations |
|---|---|
| **Alternate fuels** | **Provide access to NG at affordable prices**: Bellary's DRI plants are primarily dependent on imported coal from South Africa. As such, none of the surveyed plants have access to NG through pipelines, which could be a key enabler in the transition from solid-based rotary kilns to vertical shafts for producing gas-based DRI. The MoS should address this gap by aggregating NG demand from the cluster, thereby facilitating the connection of the NG pipeline (which passes through the district but is 70 km from the cluster) via spur lines. Further, once demand for NG is established in the cluster, the MoS can facilitate long-term contracts that enable low-priced NG imports.<br><br>**Develop state-level green hydrogen policy and incentivise its uptake in the steel sector**: Green hydrogen can be a key fuel in transitioning the cluster to a low-carbon emissions cluster. The Karnataka government, through Karnataka Renewable Energy Development Limited (KREDL), should launch a state-level green hydrogen policy to promote its use and accessibility in the cluster. Drawing on best practices from steel-producing states such as Odisha, which offer significant support for green hydrogen production, Karnataka should also implement competitive support pricing and incentives to accelerate uptake in the steel sector. The state should also reduce OA charges for green hydrogen projects. |
| **Finance** | **Establish an SIDBI branch in the cluster**: The Bellary cluster hosts a large number of standalone DRI units but lacks an SIDBI branch within the district, a key institution that provides financial support to MSMEs nationwide. Therefore, SIDBI should establish a branch in the district to improve access to low-interest financing for DRI plants in the cluster.<br><br>**Develop tailored financing solutions for standalone DRI players**: Since 88 per cent of DRI units in Bellary are standalone (accounting for 61 per cent of total capacity), tailored green finance schemes are crucial. The Small Industries Development Bank of India should design dedicated instruments, including interest subventions and risk-sharing mechanisms, to improve affordability and access to capital for SMEs adopting EE and RE technologies. |
| **CCUS** | **Support pilot and research, development, and demonstration (RD&D) programmes for CCUS in the cluster**: While Bellary itself lacks CCS potential within the cluster, basalt formations located 250–300 km away would eventually support decarbonisation in the cluster. However, these basalt formations have not yet been characterised. Therefore, the MoP should prioritise the assessment of basalts near the Bellary cluster under the upcoming CCUS mission, while the MoS, through its upcoming *National Mission for Green Steel*, should support RD&D-related activities that can aid in plugging the gaps related to CCS. |

*Source: Authors' analysis*

## Sundargarh

The Sundargarh cluster is among the fastest-growing DRI clusters in India. It has a high WHR potential of 129 MW, similar to Bellary, and requires only 14 MW of FDRE. The cluster primarily uses lump ore and domestic coal, offering significant potential for decarbonisation. Unlike Karnataka and Chhattisgarh, Odisha lacks an active industry association to coordinate low-carbon initiatives. The following recommendations for Sundargarh aim to accelerate the uptake of EE and RE solutions, encourage investments in pelletisation, enable alternative fuels such as NG, and revive OSIMA to support a coordinated low-carbon transition.

Table 20. Cluster-specific decarbonisation recommendations for Sundargarh

| Lever | Recommendations |
|---|---|
| **EE** | **Enable purchase of WHR power by IFs within the cluster**: The Sundargarh cluster has a WHR potential of 129 MW, capable of meeting 79 per cent of the cluster's steel industry power demand, while reducing 1.03 Mtpa of emissions, equivalent to 14 per cent of the total cluster emissions. The large demand for WHR capacity in the cluster can be addressed using the policies mentioned in Table 12. To further incentivise WHR adoption, the Western Electricity Supply Company of Odisha Limited (WESCO) should allow IFs in the cluster to purchase WHR power from DRI units. The WHR power should be available at an affordable price to encourage end consumers to switch from grid electricity to WHR power. |
| **ME** | **Incentivise pellet uptake in the DRI industry**: Sundargarh has a pellet-making capacity of 0.6 Mtpa, with a demand of 4.1 Mtpa to achieve 100 per cent adoption. None of the surveyed plants in Odisha were using pellets. Substituting lump ore with pellets can mitigate 0.46 Mtpa of emissions in Sundargarh, representing 6 per cent of the cluster's total emissions. The MoS, Ministry of Mines, and the Department of Steel and Mines in Odisha, in conjunction with the recommendations in Table 13, should incentivise investments in pellet plants within the cluster and ensure competitive pellet pricing for the industry to maximise their uptake in the sponge iron sector. Granting pellet plants access to captive iron ore mines and developing slurry pipelines can further reduce input costs. |
| **Alternate fuels** | **Aggregate NG demand to promote completion of ongoing NG pipeline projects for NG access and reduce the delivered cost of NG in Odisha**: The Sundargarh cluster is expected to gain access to NG through the Jagdishpur–Haldia–Bokaro–Dhamra pipeline, currently under construction by Gas Authority of India Limited (GAIL). The MoS should aggregate NG demand within the cluster to expedite completion of the pipeline spur. Ensuring timely gas availability will be critical to encourage industries to shift from coal-based rotary kilns to vertical-shaft gas-based DRI technology.<br><br>**Reduce the delivered cost of NG**: The delivered cost of NG in Odisha remains higher than in Karnataka, primarily due to differences in state taxes. While Karnataka levies USD 1.48 per metric million British thermal unit (MMBtu), Odisha charges USD 4.44, resulting in an 18.6 per cent higher NG price in Odisha. To encourage the adoption of gas-based DRI, which is less carbon-intensive but has a higher OPEX than non-coking coal, the Odisha government should consider reducing the VAT on NG. |
| **Eco-system** | **Revive defunct OSIMA**: Unlike Chhattisgarh and Karnataka, the sponge iron association in Odisha is inactive. Reviving OSIMA to coordinate decarbonisation efforts could help accelerate the state's transition to low-carbon steelmaking. |

*Source: Authors' analysis*

## Raipur

Raipur is one of the largest DRI-producing clusters in the country. It has high pellet usage, an active industry association, and a large number of steelmaking units alongside DRI facilities. As a result, the cluster requires approximately 137 MW of FDRE. While Raipur has high solar potential, it lacks viable wind resources. A key challenge for the cluster is leveraging its relatively low OA charges to scale RE penetration while simultaneously improving access to NG and, perhaps, in the longer term, green hydrogen. The recommendations in Table 21 prioritise expanding WHRB use, enabling RE and green hydrogen uptake, and supporting standalone DRI units through targeted financial and regulatory interventions.

### Table 21. Cluster-specific decarbonisation recommendations for Raipur

| Lever | Recommendations |
| --- | --- |
| **EE** | **Enable purchase of WHR power by IFs within the cluster**: The Raipur cluster has a WHR potential of 122 MW, which can fulfil 39 per cent of the cluster's existing power requirement and reduce 0.4 Mtpa (5 per cent) of total cluster emissions. This potential can be met by implementing the recommendations outlined in Table 12. Subsequently, the Chhattisgarh State Power Distribution Company Limited (CSPDCL) should enable other industries, such as IFs, to purchase WHR power from DRI units. The WHR power should be available at an affordable price to end consumers to encourage the switch from grid electricity to WHR power. The state government and the MoS should provide incentives for smaller DRI plants to install WHRBs, as utilising WHRBs can have a very short payback period owing to their negative MAC values. |
| **RE** | **Support RE installations in the cluster**: The Raipur cluster has high solar energy potential but lacks wind potential. It requires 137 MW of FDRE, in addition to WHRB capacity, to meet cluster-wide power requirements. Chhattisgarh has the lowest OA charges for solar, at INR 0.7 per kWh, when compared to INR 2.52 in Bellary and INR 3.04 in Sundargarh (Annexure 3). Incentives for captive RE and RE procurement through OA can further enable Raipur's transition to a low-carbon cluster. The policy recommendations listed in Table 16 (on-demand aggregation) and Table 17 (on procurement plans) can be leveraged to expand RE installations in Raipur. Chhattisgarh's energy department should actively support RE development by facilitating pooled demand aggregation and enabling simplified single-window approvals for solar installations across the cluster. |
| **Alternate fuels** | **Aggregate demand for NG in the cluster**: The Raipur cluster is expected to be connected through the under-construction Mumbai–Nagpur–Jharsuguda pipeline. The MoS should aggregate NG demand across the cluster to justify spur-line investments and accelerate the completion of the pipeline by GAIL. Ensuring gas availability at competitive prices will be critical to nudging the steel industry towards adopting vertical-shaft gas-based DRI over coal-based rotary kilns, thereby lowering the cluster's emissions intensity.<br><br>**Reduce the delivered cost of NG**: The delivered cost of NG in Chhattisgarh is significantly higher than in Karnataka and Odisha, primarily due to differences in state taxes. While Karnataka levies USD 1.48 per MMBtu and Odisha USD 4.44, Chhattisgarh imposes a much higher charge of USD 7.68, making gas prices in the state 39 per cent higher than in Karnataka. This poses significant challenges to using NG instead of coal DRI. The Chhattisgarh government should reduce VAT to make gas-based DRI more cost-competitive. Lowering taxes would also boost gas consumption, balancing lost revenue due to the tax decrease. |

| Lever | Recommendations |
|---|---|
| | **Develop state-level green hydrogen policy**: Green hydrogen can be a key fuel in transitioning Raipur to a low-carbon steel cluster. The Chhattisgarh government should develop and launch a dedicated state-level green hydrogen policy to promote the use and access of green hydrogen in the cluster. Additionally, a few states already offer significant support to green hydrogen projects. Chhattisgarh should also implement competitive support pricing and incentives to accelerate uptake in the steel sector (Pal et al. 2025). |
| **Finance** | Raipur has an equal number of standalone and integrated DRI units, which hinders financing access, especially for smaller standalone units, and additionally increases the cost to finances. Financial institutions should develop dedicated financial schemes for these operators, which could reduce financing costs for the DRI industry. Another method is to improve access to existing schemes, such as the *Partial Risk Sharing Facility for Energy Efficiency* (PRSF) offered by SIDBI. |
| **CCUS** | Raipur has significant potential for CCS through identified saline aquifer formations in and around the cluster. To capitalise on this, the MoS, through the forthcoming *National Mission for Green Steel*, should prioritise pilot demonstrations and R&D initiatives to advance CCS deployment in the region. These efforts would help assess viability, build confidence, and lay the foundation for achieving net-zero emissions in the cluster over the long term. |

*Source: Authors' analysis*

## 6.3 Path forward and conclusions

A cluster-based approach to decarbonisation enables targeted interventions and builds synergies that effectively reduce emissions. However, the success of this approach depends on the robustness and granularity of the underlying data. Expanding the model to include more clusters, increasing the number of plants assessed within each cluster, and refining datasets over time will enhance its accuracy in guiding policy decisions and industrial investments.

As additional clusters are mapped and analysed, the evaluation framework introduced in this report can be further calibrated to improve existing indicators and incorporate new ones to better assess a cluster's readiness and decarbonisation costs. This framework can also be adapted for other energy- and emissions-intensive sectors, such as cement, paper, and glass, providing a scalable approach to industrial decarbonisation. By embedding cluster-level diagnostics within broader industrial and energy policy frameworks, India can accelerate emission reductions across multiple sectors to meet its decarbonisation goals.

Many of the challenges identified in the report, and the proposed solutions, are not new; they reflect systemic issues that continue to hinder decarbonisation efforts. Addressing these challenges will require not only technical and financial interventions but also continued facilitation, capacity-building, and institutional support for industrial stakeholders throughout the transition process.

Research institutions and philanthropies can play a critical role in bridging these gaps by working directly with central and state governments, industry bodies, financiers, and industrial units to implement recommendations on the ground, monitor outcomes, document and disseminate learnings, and replicate successful models across clusters and sectors. Ultimately, sustained cross-sectoral collaboration, robust monitoring systems, and policy continuity will be essential to ensure the long-term success of India's industrial decarbonisation journey.

# Acronyms

| | |
|---|---|
| BEE | Bureau of Energy Efficiency |
| BF–BOF | blast furnace–basic oxygen furnace |
| BTM | behind-the-meter |
| C&I | commercial and industrial |
| CAGR | compound annual growth rate |
| CAPEX | capital expenditure |
| CCS | carbon capture and storage |
| CCTS | *Carbon Credit Trading Scheme* |
| CCU | carbon capture and utilisation |
| CCUS | carbon capture, utilisation, and storage |
| C-DRI | coal-based direct reduced iron |
| CERC | Central Electricity Regulatory Commission |
| $CO_2$ | carbon dioxide |
| CPP | captive power plant |
| CREDA | Chhattisgarh State Renewable Energy Development Agency |
| CSPDCL | Chhattisgarh State Power Distribution Company Limited |
| CSS | cross-subsidy surcharge |
| discom | distribution company |
| DCs | designated consumers |
| DRI | direct reduced iron |
| EAF | electric arc furnace |
| EE | energy efficiency |
| EEFP | *Energy Efficiency Financing Platform* |
| ESCO | energy service company |
| FDRE | firm, dispatchable renewable energy |
| GAIL | Gas Authority of India Limited |
| GCV | gross calorific value |
| GDP | gross domestic product |
| GENCO | generation company |
| GEOAR | *Green Energy Open Access Rules* |
| GESCOM | Gulbarga Electricity Supply Company Limited |
| GHG | greenhouse gas |
| GIFT | *Green Investment and Financing for Transformation* |
| GPP | green public procurement |
| GRIDCO | Grid Corporation of Odisha |
| GUVNL | Gujarat Urja Vikas Nigam Limited |
| GWh | gigawatt-hours |
| IF | induction furnace |
| INR | Indian rupee |
| ISP | integrated steel plant |
| KREDL | Karnataka Renewable Energy Development Limited |
| KSIMA | Karnataka Sponge Iron Manufacturers Association |
| kWh | kilowatt-hour |
| MAC | marginal abatement cost |
| ME | material efficiency |
| MNRE | Ministry of New and Renewable Energy |
| MoPNG | Ministry of Petroleum and Natural Gas |
| MoM | Ministry of Mines |
| MoMSME | Ministry of Micro, Small and Medium Enterprises |
| MoP | Ministry of Power |
| MoS | Ministry of Steel |
| MRV | monitoring, reporting, and verification |
| MSMEs | micro, small, and medium enterprises |

| | |
|---|---|
| Mt | million tonnes |
| MW | megawatts |
| NCM | National Carbon Market |
| NG | natural gas |
| NMGS | *National Mission for Green Steel* |
| OA | Open access |
| OPEX | Operating expenses |
| OSIMA | Odisha Sponge Iron Manufacturers' Association |
| PAT | *Perform, Achieve, and Trade* |
| PPA | power purchase agreement |
| PRSF | *Partial Risk Sharing Facility for Energy Efficiency* |
| P2P | peer-to-peer |
| R&D | research and development |
| RD&D | research, development, and demonstration |
| RE | renewable energy |
| REIAs | renewable energy implementing agencies |
| SAMEEEKSHA | *Small and Medium Enterprises: Energy Efficiency Knowledge Sharing* |
| SEC | specific energy consumption |
| SECI | Solar Energy Corporation of India |
| SERC | state electricity regulatory commission |
| SIDBI | Small Industries Development Bank of India |
| SIMA | Sponge Iron Manufacturers Association |
| SL/RN | Stelco-Lurgi/Republic Steel–National Lead |
| SME | small and medium enterprises |
| SPICE | *Sustainable Production and Industrial Capacity Enhancement* |
| SSI | secondary steel industry |
| SVAMITVA | *Survey of Villages and Mapping with Improvised Technology in Village Areas* |
| $tCO_2$ | tonne of carbon dioxide |
| tcs | tonne of crude steel |
| t-DRI | tonne of direct reduced iron |
| TMT | thermo-mechanically treated |
| USD | United States dollar |
| VAT | value-added tax |
| VVFD | variable voltage and frequency drive |
| WESCO | Western Electricity Supply Company of Odisha Limited |
| WHR | waste heat recovery |
| WHRB | waste heat recovery boiler |

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