Annexure

Advancing India's Green Steel Transition: Leveraging Industrial Clusters to Decarbonise Small and Medium Enterprises

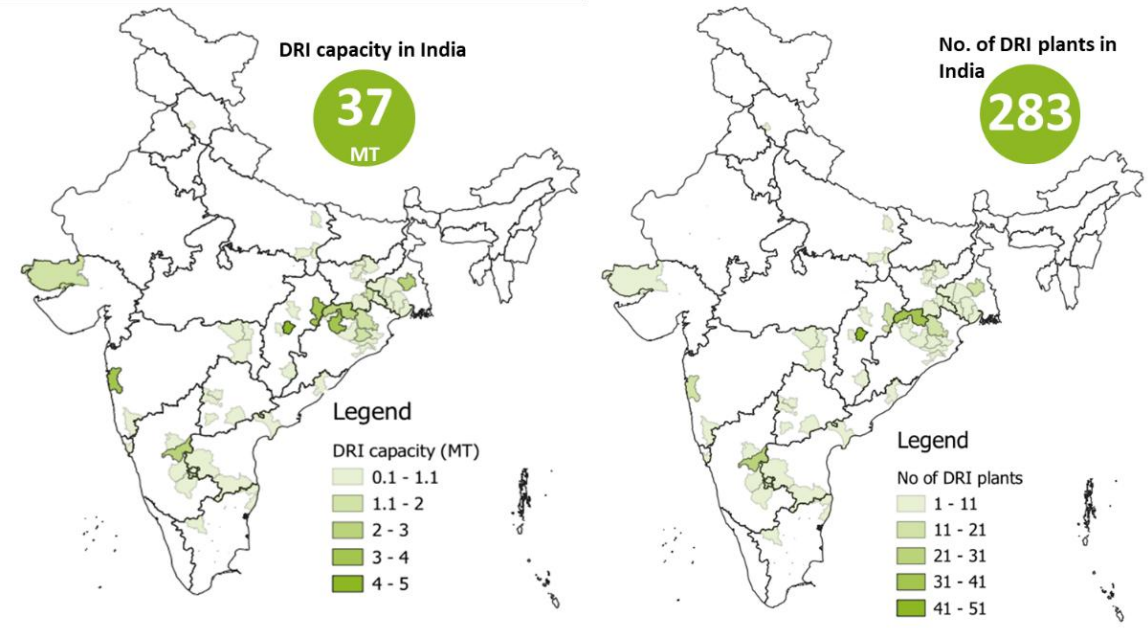
Karthik Shetty, Smita Chakravarty, Deepak Yadav, Suresh Kotla, Shweta Srinivasan and Pranav Dadhich

Annexure 1

1. District-level mapping and analysis of steel clusters in India.

The first step in analysing DRI clusters is to identify the presence of units across Indian districts, based on their production capacity and the number of units. In 2021–22, India had a total sponge iron production capacity of 37 Mtpa distributed across 283 plants, concentrated in the coal- and iron-rich states of Odisha, Jharkhand, Chhattisgarh, West Bengal and Karnataka, as seen in Figure A 1

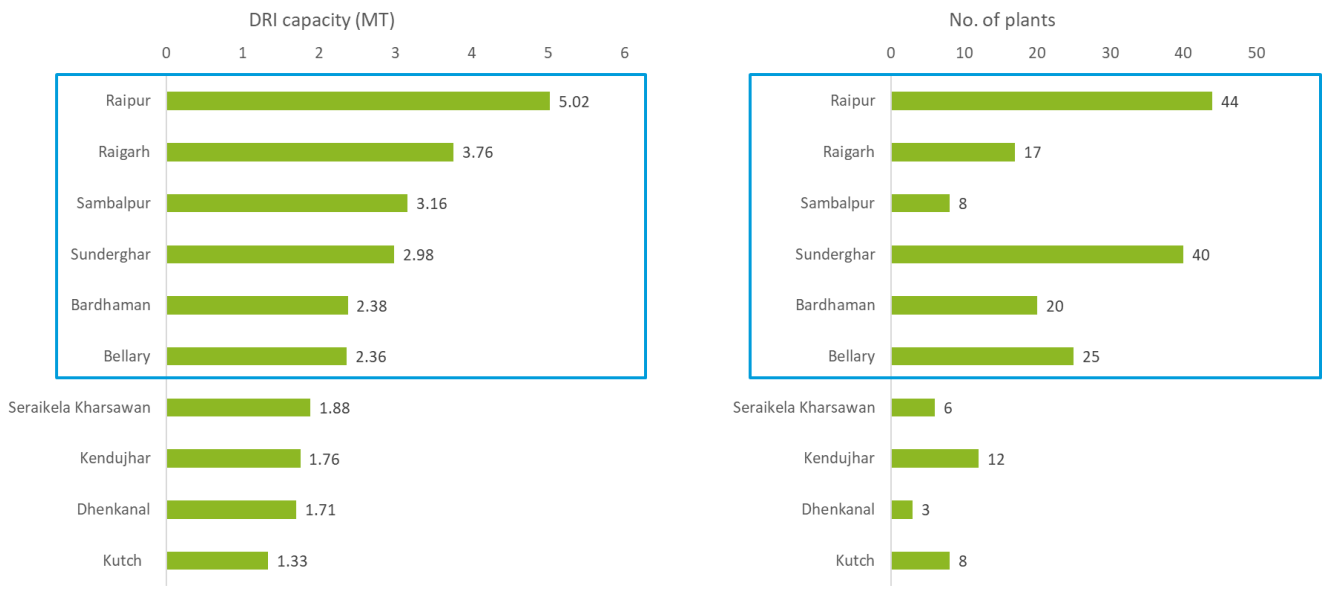
Figure A 1. India's DRI production capacity stands at 37 Mtpa, distributed across 283 plants (2021 -22)



Source: Authors' analysis

Figure A 2 shows the distribution of DRI capacity across the top districts. Of the 52 districts in India with DRI units, only 10 have a capacity exceeding 1 Mtpa, and together these account for 72 per cent of the country's total capacity.

Figure A 2. Out of 52 districts that have the presence of sponge iron plants, only 10 districts have a capacity greater than 1 Mtpa.



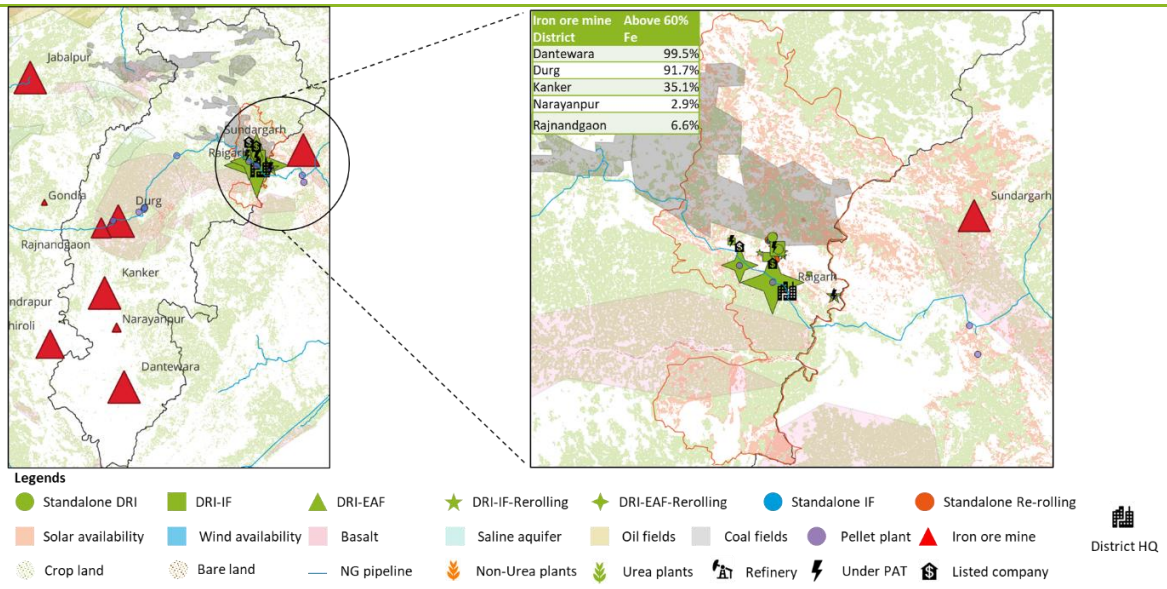
Source: Authors' analysis

2. Cluster pre-analysis across select districts (Raigarh, Paschim Bardhaman and Sambalpur)

2.1 Raigarh district

The Raigarh cluster, located on the Chhattisgarh-Odisha border next to Sundargarh district, is one of the prominent sponge iron-producing regions in India. It has a high concentration of Direct Reduced Iron (DRI) plants, contributing significantly to India's secondary steel production with 3.76 Mt capacity and 16 plants. Raigarh also has a high EAF capacity compared to other clusters. Although the cluster does not have any iron ore, it is located close to the Barbil-Koira iron ore belt in Odisha, which is a major supplier of high-grade hematite ore. Raigarh cluster also has a presence of larger plants that are listed companies, which can act as anchor plants. Unlike clusters in Raipur, Raigarh is located in areas containing coal reserves. It also has biomass and solar potential. However, there is no wind potential in the cluster. Raigarh also has access to saline aquifers to tap into CCS.

Figure A 3. Raigarh cluster is located iron ore-rich region of Chhattisgarh.

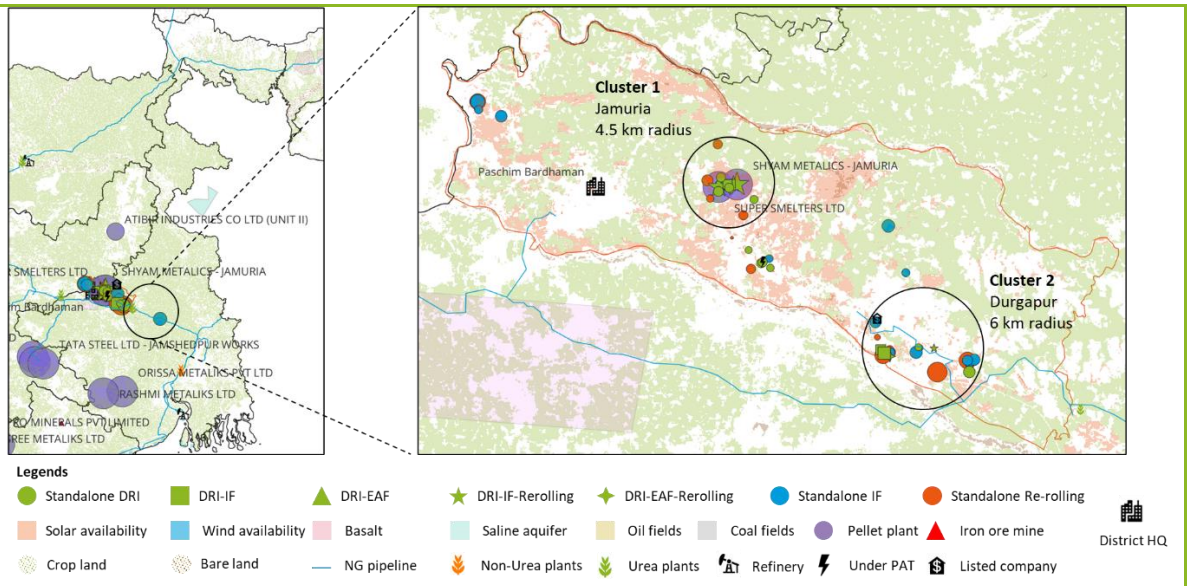


Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and Climate 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

2.2 Paschim Bardhaman (West Bengal)

There are two clusters, Paschim Bardhaman (West Bengal) – Jamuria and Durgapur, with a radius of 4.5 km and 6 km, respectively. West Bengal as a state doesn't have any iron ore mines or reported iron ore reserves (Government of India, Ministry of Mines 2024), and is dependent on ore from states in the vicinity, i.e. Jharkhand and Odisha. Both these clusters have less than 10 DRI units and less than 2 Mtpa of DRI capacity each. The clusters in West Bengal have just one listed company and one PAT-covered plant in the entire district. Both the clusters in West Bengal are, however, located in areas of coal reserves and benefit from their proximity. These clusters additionally have Solar and biomass potential. However, there is no wind and CCUS potential in the clusters.

Figure A 4. The two clusters in Paschim Bardhaman (West Bengal) – Jamuria and Durgapur clusters have fewer units as compared to clusters in Odisha and Chhattisgarh.

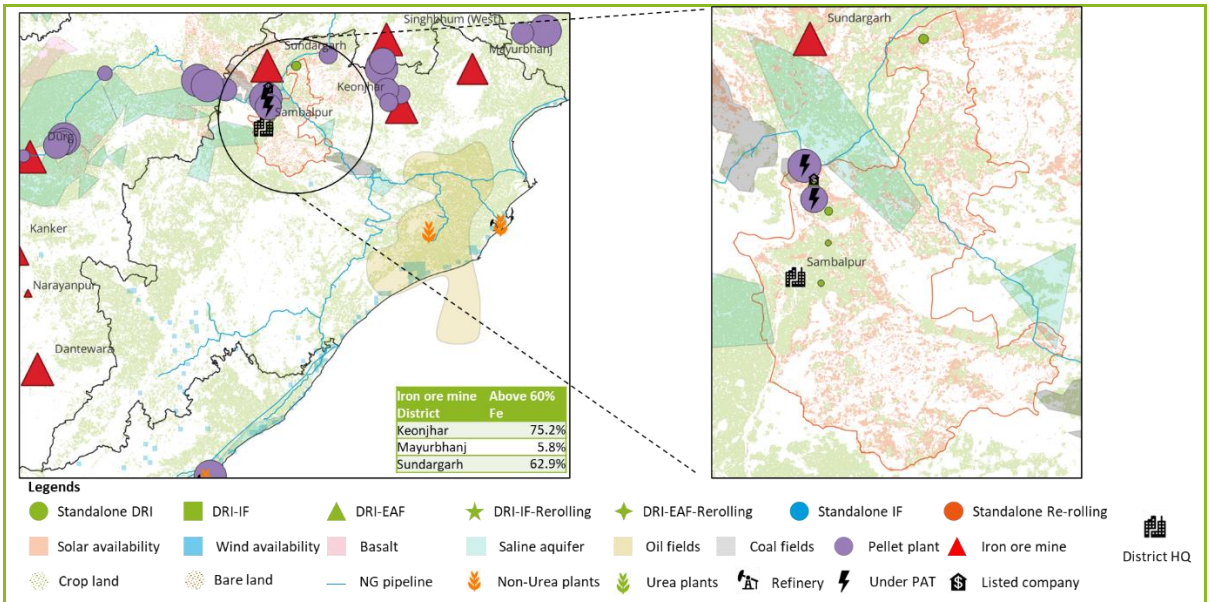


Source: *Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and 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*

2.3 Sambalpur district

Rengali cluster in Sambalpur district is another DRI cluster in Odisha, which has a high DRI capacity; however, it has only seven DRI units. Further, it has just two IF plants and one rolling mill. The cluster in Sambalpur is relatively farther away from the iron ore deposits in Odisha, which is primarily located in Keonjhar and Sundargarh. There is CCUS potential in Sambalpur because of the presence of Saline aquifers. Sambalpur additionally has solar and biomass presence but no wind potential

Figure A 5. Sambalpur cluster has higher capacity but has fewer number of DRI units.

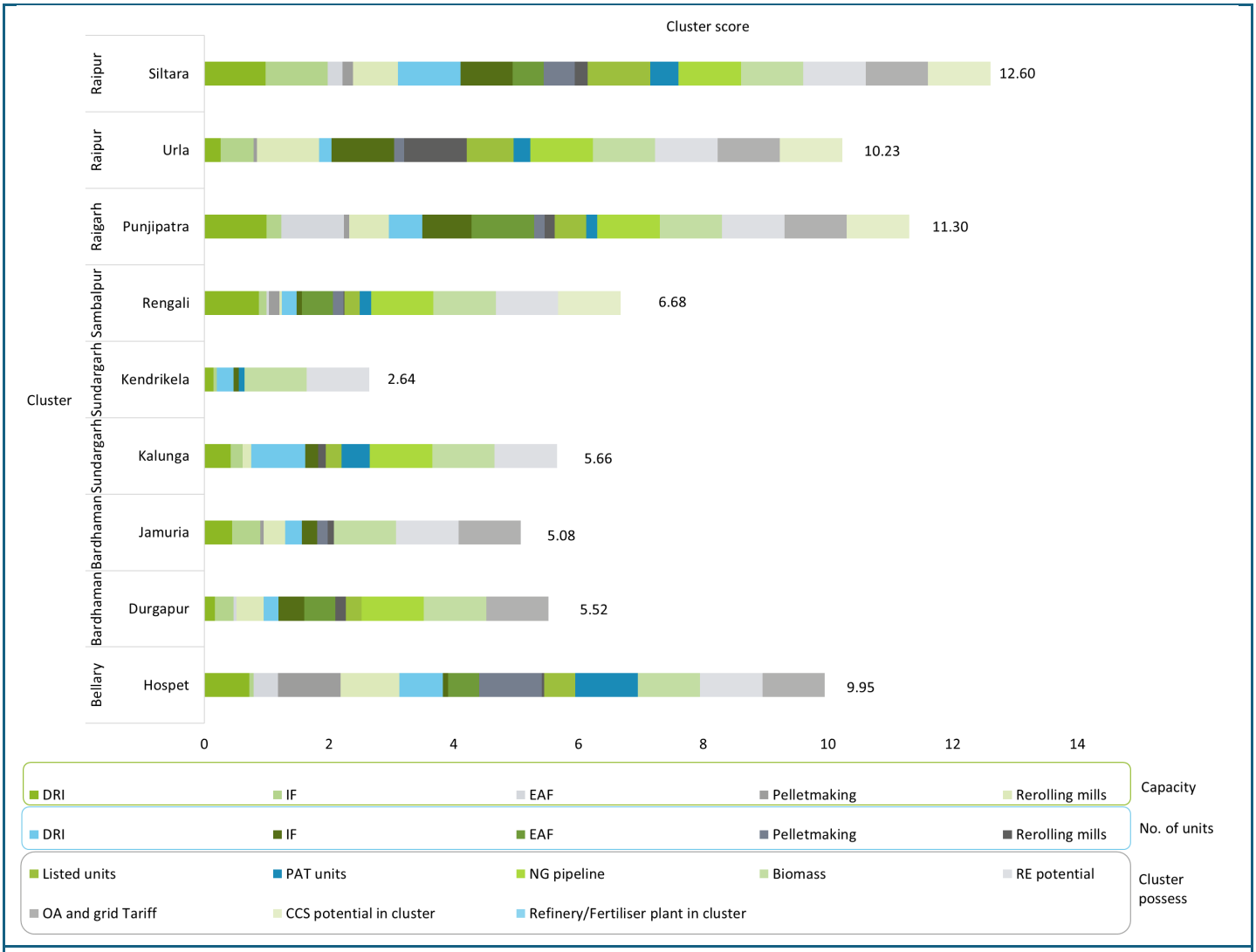


Source: Authors' analysis based on Joint Plant Committee (JPC). 2021–22. The Indian Iron & Steel Database 2021–22. Kolkata; Mallya, Hemant, Deepak Yadav, Anushka Maheshwari, Nitin Bassi, and Prerna Prabhakar. 2024. Unlocking India's RE and Green Hydrogen Potential: An Assessment of Land, Water, and Climate 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

3. Rationale for cluster selection

The nine clusters identified in the district-level analysis are compared to develop a pre-cluster analysis score, which helps identify the clusters best suited for the survey. Figure A 6 presents the overall scores. 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, PAT-covered units, NG pipelines, biomass availability, RE potential, open-access (OA) and grid-tariff conditions, CCS potential, and the proximity of refineries or fertiliser plants. On this combined measure, Siltara (12.6), Punjipatra (11.3), Urla (10.2) and Hospet (10.0) emerge as the highest-scoring clusters, well ahead of the remaining five, and are therefore identified as the clusters best suited for the survey. This quantitative scoring is then combined with the qualitative factors summarised in Figure 7 and with considerations from stakeholder discussions to select the three clusters taken forward for the survey.

Figure A 6. Pre-cluster analysis using quantitative comparison shows Siltara, Urla, Punjiputra and Hospet as the top clusters to survey.



Source: Authors' analysis

Annexure 2

This section contains the templates used to carry out the 2024 survey. The questions are divided into quantitative and qualitative sections.

1. Survey questionnaire

Table A 1. Sample survey template for rotary kiln plant.

Survey of energy consumption in rotary kilns			
General information			
Name of the company			
Site address (Full address)			
District		State	

Contact person			
Position			
Email			
Mobile			
Any other details, if any			
Plant information			
Kiln technology			
FY for which information Provided		Total DRI capacity (Mtpa)	
DRI production in the FY			
Age of the kiln			
Any other details, if any			
Fuel information			
	Feed coal	Injection coal	Remarks
Specific coal consumption (t/t-DRI)			
Annual consumption (million tonne)			
Average price (INR/tonne)			Domestic
Average price (INR/tonne)			Import coal
Blending ratio by weight (Domestic:Import)		Do the quality of feed and injection coal differ?	Yes /No
GCV (kcal/kg)			
NCV (kcal/kg)			
Proximate analysis			
	Feed coal	Injection coal	Remarks
Fixed C (%)			
Volatiles (%)			
Moisture (%)			
Proximate analysis			
	Feed coal	Injection coal	Remarks
C %			
H %			
N %			
S %			

O %			
Electrical consumption			
SEC - electricity (kWh per DRI)		Annual consumption (MWh)	
Power consumed for kiln rotation (kWh/t-DRI		Sources of electricity (CPP / Grid / RE)	
Share of Grid (%)		Share of CPP (%)	
Share of WHR (%)		Share of RE (%)	
Waste heat recovery			
Do you employ waste heat recovery		Yes / No	Remarks, if any
Is recovered heat used in boiler or for preheating?		Boiler / preheating	Remarks, if any
Which stream is used for WHR?		Rotary / ABC / kiln	Remarks, if any
What % of WHRB fuel is flue gas?			Remarks, if any
Capacity of WHR power plants (MW)		Annual electricity production (MWh)	
WHR net heat rate - Design (kcal/kWh)		Selling price of WHR power to Grid (INR/kWh)	
Raw material			
Iron ore (per t-DRI)		Annual consumption (million tonne)	
Blending ratio (Domestic:Imported)	Yes / No	Do you use pellets	Yes / No
Quality - lump ore (Fe %)		Quality - as fed (Fe %)	
Do you use dolomite or limestone or both?			Remarks, if any
Dolomite (per t-DRI)		Annual consumption (million tonne)	
Water consumption			
Fresh water (m^3/t-DRI)		Annual consumption (m^3/year)	
Waste information for DRI kilns			
Flue gas			
	Kiln exit	**Stack (of DRI kilns)**	**Remarks**
Quantity (Nm^3/hr)			
Calorific value (kcal/Nm^3)			
Composition			
N_2 (%)			
CO_2 (%)			
CO (%)			
H_2 (%)			

H_2O (%)			
O_2 (%)			
CH_4 (%)			
N_2O (%)			
Criteria pollutants			
NOx (mg/Nm^3)			
SOx (mg/Nm^3)			
PM2.5 (mg/Nm^3)			
Solid wastes			
Dolochar	Quantity (kg/hr)		
	Processing?	*Choose*	*If other, specify here*
Slag	Quantity (kg/hr)		
	Processing?	*Choose*	*If other, specify here*
Dust	Quantity (kg/hr)		
	Processing?	*Choose*	*If other, specify here*
Sponge Iron Information			
Composition			
Degree of metallisation (%)		Fe (metallic, %)	
C (%)			
Reduction in emissions			
Emissions intensity (tCO_2/t-DRI)		Annual emissions (millions tCO_2)	
Energy Efficiency Implementation			
Efficient blowers	Yes / No	VVFD for shell fans	Yes / No
Coal Quality	Yes / No	mullite lining	Yes / No
What is the projected emissions reduction after implementing EE technologies (tCO_2/t-DRI)?			Remarks, if any
How long will it take to adopt energy efficiency solutions?			Remarks, if any
Major challenges in adopting the energy efficiency technologies			
What other technologies are you planning to implement to reduce emissions?			
Major challenges in adopting to alternative fuels (e.g. natural gas, plastic waste, biomass, hydrogen)?			

Table A 2. Sample survey format for induction furnaces.

Survey of energy consumption in induction furnaces
Plant information

Furnace supplier	
FY for which info provided	
IF capacity (tonnes per annum)	
IF production (tonnes)	
Age of the furnace (years)	
Energy information	
Typical power consumption for above mix (kWh/tcs)	
Typical power consumption for pure scrap (kWh/tcs)	
Furnace oil consumption (litres/tcs)	
Any other fuel consumption	
Raw material information	
Typical raw material mix	**% share**
Pig iron	
Sponge iron	
Ore pellets	
Scrap	
Total	**100%**
Source of pig iron	
Source of sponge iron	
Source of ore pellets	
Source of scrap	
Nature of scrap	
Crude steel information	
Fe %	
C %	
Alloy element 1	
Alloy element 1 %	
Alloy element 2	
Alloy element 2 %	
Alloy element 3	
Alloy element 3 %	
Finishing process used	
Product(s) produced	
Energy efficiency information	
What energy efficiency technologies have you adopted for the IF?	
Major challenges in adopting the energy efficiency technologies	
What technologies are you planning to implement to reduce emissions?	

Will you consider procuring RE for your IF? If not, why?

Table A 3. Sample survey format for rolling mills.

Survey of energy consumption in rolling mill		
Plant information		
Type of rolling mill (Hot/Cold/Both/Other)		
FY for which info provided		
Re-rolling capacity (tonnes per annum)		
Re-rolling production (tonnes)		
Energy information		
Primary source of energy		
Typical energy consumption from above source		*unit*
Typical power consumption (kWh/t)		
Electricity from grid (%)		
Electricity from coal captive (%)		
Electricity from WHR (%)		
Any other fuel consumption/quantity		*unit*
Raw material information		
Additive materials	*Mat 1 / Mat 2 / Mat 3*	
Additive quantity (kg/tcs)	*Mat 1 / Mat 2 / Mat 3*	
Energy efficiency information		
What energy efficiency technologies have you adopted for the re-rollling mills?		

Technology	kWh/tcs reduction	CAPEX (INR crore)	OPEX (INR/year)
Tech 1			
Tech 2			
Tech 3			
Tech 4			

Table A 4. Sample survey format for a pellet plant.

Survey of energy consumption in pellet plant	
Plant information	
Type of pellet produced (Hematite Pellets/ Magnetite	

Pellets/ Blast Furnace Pellets/ Direct Reduction Pellets/ Other)		
FY for which info provided		
Pellet plant capacity (tonnes per annum)		
Pellet plant production (tonnes)		
Type of pelletising technology used? (Straight grate, Travelling grate, Grate-kiln/Others)		
Energy information		
Primary source of energy (Coal/Natural gas/Furnace oil/Coke)		
Typical energy consumption from above source		*unit*
Secondary source of energy (Coal/Natural gas/Furnace oil/Coke)		
Typical energy consumption from above source		*unit*
Typical power consumption (kWh/t)		
Electricity from grid (%)		
Electricity from coal captive (%)		
Electricity from WHR (%)		
Any other fuel consumption		
Raw material information		
Fe content in the ore (%)		
Binder materials	*Mat 1 / Mat 2 / Mat 3*	
Binder quantity (kg/t)	*Mat 1 / Mat 2 / Mat 3*	
Any other additives		
Energy efficiency information		
What energy efficiency technologies have you adopted for the pellet plant?		
Major challenges in adopting the energy efficiency technologies		
What technologies are you planning to implement to reduce emissions?		
Will you consider procuring RE for your pellet plant? If not, why?		

Technology	kWh/tcs reduction	CAPEX (INR crore)	OPEX (INR/year)
Tech 1			
Tech 2			
Tech 3			
Tech 4			

2. Semi-structured interviews

Table A 5. Semi-structured interview questions with plant leadership/managers.

Interviews with owners/ Senior leadership of plants/units	
A	**Warm up questions**
A1.	Please provide an overview of your plant operations?
B	**Industry landscape and challenges**
B1.	What would you say are the biggest challenges for the DRI sector?
B2.	How do you see the industry evolving in the next 5-10 years?
B3.	Are there any emerging technologies that you think will significantly impact the DRI sector?
C	**Knowledge, attitudes and behaviour**
C1	What is your understanding of low-carbon steelmaking?
C2	What are the prominent technologies available in the market that can enable emissions reductions in operations? (e.g. WHRs, what else?)
C3	Have you implemented any measures to reduce the environmental impact/emissions intensity of your production processes? Why/why not? *(e.g. Not aware, no clean tech companies in proximity, no finance etc.)*
C4	Do you see any potential competitive advantages in moving towards low-carbon steel production?
D	**Market and demand**
D1	Who are your primary consumers for DRI steel?
D2	Are you a supplier to any major steel players? If yes, please state the names.
D3	Is there any demand for low-carbon steel? Yes/no, which are the sectors that constitute this demand?
E	**Finance**
E1	How do you meet your financing needs e.g. For upgrading or repairing plant and machinery?
E2	Are you aware of any incentives for your sector, particularly for emissions reduction or renewable energy adoption?
E3	What types of financial incentives would motivate you to adopt low-carbon intensive processes? What type of financing do you prefer (debt, equity, or blended)?
F	**Policy and regulations**
F1	Are you aware of any government policies or incentives promoting renewable energy or energy efficiency in the DRI sector?
F2	How does the roadmap for decarbonisation by the ministry of steel and the carbon credit trading scheme affect your operations and decision-making regarding low-carbon steel production?

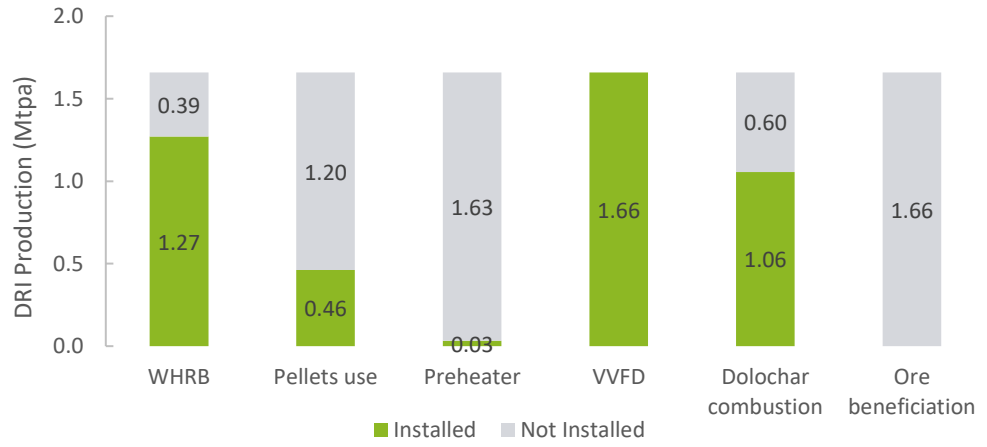
F3	For export-oriented businesses: Are you familiar with the carbon border adjustment mechanism (CBAM)? How will it impact your operations and are there any changes you are planning to respond to such regulatory mechanisms?
F4	What other policy changes do you think would be most helpful for the industry?
G	**Collaborative initiatives and future plans**
G1	Are there any collaborative efforts with other industries in your cluster to address common challenges?
G2	Have you considered any projects for captive renewable energy generation? Why or why not?
G3	Would you be open to participating in a cluster-wide initiative for low-carbon transition?
G4	What are your thoughts on transitioning to gas-based DRI?

Annexure 3

1. Energy efficiency measures from 2024 survey.

Figure A 7 displays the uptake of energy efficiency (EE) measures in the surveyed DRI units for 2024. All plants reported 100 per cent adoption of Variable Voltage and Frequency Drives (VVFD). Although high WHRB capacity penetration is in place, WHRB is not used in plants with capacities below 200 tpd, with none of these plants employing WHRB and only one plant at this capacity level using it. Other EE measures show limited adoption: only one plant reports using ore preheating, and pellet usage is restricted to just two plants in Bellary, with the remaining plants using only lump ore.

Figure A 7. In the 2024 survey, plants have reported 100 per cent VVFD installation.



Source: Authors' analysis

2. PAT coverage

Table A 6 shows that only 29 of the plants, with a capacity of just 5.31 Mtpa out of a total 14.03 Mtpa, are currently covered under the PAT scheme. This coverage is much lower than that of the wider steel sector, especially since DRI units are highly emission intensive. Furthermore, interactions with ESCOs indicate that even among the units listed under PAT, several are not actively reporting energy data and therefore not pursuing systematic efficiency improvements. This reveals a gap not

only in PAT coverage but also in its implementation, highlighting the need to strengthen compliance and expand coverage through the forthcoming Cluster-Credit Trading Scheme (CCTS).

Table A 6. Only a few numbers of plants and capacity of DRI are under the ambit of PAT scheme to improve energy efficiency.

Sr. No.	State	District	Cluster	Capacity (Mt)	No. of plants in cluster	No. of plants in district
1	Chhattisgarh	Raipur	Siltara	0.636	5	8
2		Raipur	Urla	0.61	3	
3		Raigarh	Punjipatra	0.27	2	4
4	Odisha	Sambalpur	Rengali	2.52	2	2
5		Sundargarh	Kendrikela	0.06	1	7
6		Sundargarh	Kalunga	0.375	5	
7	West Bengal	Bardhaman	Jamuria	0	0	1
8		Bardhaman	Durgapur	0	0	
9	Karnataka	Bellary	Hospet	0.839	11	12
		Total		**5.31**	**29**	**34**

3. Publicly listed companies in the clusters

Table A 7 lists the number of publicly listed companies operating within the top nine DRI clusters. These companies, being listed on stock exchanges, have stricter disclosure norms, governance standards, and financial scrutiny. Their presence within clusters provides an institutional anchor for advancing decarbonisation efforts. However, only 14 out of 129 DRI units in these clusters are publicly listed. These firms can play a role in improving emissions-related data disclosure, accelerating compliance with schemes such as PAT and the Carbon Credit Trading Scheme (CCTS), and enabling access to low-cost capital for decarbonisation through capital markets. Encouraging more DRI units to list on stock exchanges can further enhance compliance, improve financial discipline, and aid decarbonisation within the sector.

Table A 7. Listed companies in the clusters.

Sr. No.	State	District	Cluster	Capacity (Mt)	No. of listed companies in cluster
1	Chhattisgarh	Raipur	Siltara	1.215	4
2		Raipur	Urla	0.38	3
3		Raigarh	Punjipatra	1.82	2

4	Odisha	Sambalpur	Rengali	0.72	1
5		Sundargarh	Kendrikela	0	0
6		Sundargarh	Kalunga	0.03	1
7	West Bengal	Bardhaman	Jamuria	0	0
8		Bardhaman	Durgapur	0.018	1
9	Karnataka	Bellary	Hospet	1.272	2
		Total		**5.455**	**14**

4. Pellet capacity in the cluster available for DRI

Pellet-making capacities in the clusters are considered for constructing the emission profiles of the clusters, as well as serving as an indicator for the readiness score used to evaluate material efficiency readiness. The details of pellet-making plants, including the number of units and capacity, are shown in the Table A 8

Table A 8. Pellet making capacities in the clusters surveyed that are accessible to the units.

Cluster	Number of units	Pellet Making capacity (Mtpa)
Raigarh*	2	2.90
Raipur	3	3.90
Bellary*	6	6.80
Sundargarh	1	0.60
Jharsuguda	0	0.00

Note: *One unit in Raigarh is outside the cluster boundary we have considered here, but within Raigarh district. Pellet capacity of JSW Vijayanagar is not considered for Bellary as it is mostly internally consumed in its BF operations.*

5. **Electricity consumption in the steel-making value chain** shows the electricity consumption values for each major step in the steelmaking value chain—namely pelletisation, DRI making, induction furnace (IF) and electric arc furnace (EAF) steelmaking, and rerolling. These estimates are used to construct emissions profiles in Chapter 3 and to evaluate key mitigation levers such as *FDRE,* WHR, and scrap utilisation. Among all stages, steelmaking is the most electricity intensive. However, power through WHR is generated during the DRI-making process, which creates challenges for power evacuation *in case of* standalone DRI plants.

For every tonne of crude steel produced, units require 0.625 to 0.890 MWh of electricity, while rerolling requires approximately 0.130 MWh of electricity per tonne of finished steel.

Table A *9* shows the electricity consumption values for each major step in the steelmaking value chain—namely pelletisation, DRI making, induction furnace (IF) and electric arc furnace (EAF) steelmaking, and rerolling. These estimates are used to construct emissions profiles in Chapter 3 and to evaluate key mitigation levers such as *FDRE,* WHR, and scrap utilisation. Among all stages, steelmaking is the most electricity intensive. However, power through WHR is generated during the DRI-making process, which creates challenges for power evacuation *in case of* standalone DRI plants. For every tonne of crude steel produced, units require 0.625 to 0.890 MWh of electricity, while rerolling requires approximately 0.130 MWh of electricity per tonne of finished steel.

Table A 9. Electricity used in the various steps of steelmaking.

Process	Units	Electricity consumption	Source
Pellet making	MWh/t-pellet	0.022~0.068	KIOCL and (Lv, Sun and Su 2019)
DRI making	MWh/t-DRI	0.06 ~0.07	Assumed from the survey findings
IF Steelmaking	MWh/tcs	0.625 ~ 0.890*	Based on scrap use, Assumed from the survey findings
EAF Steelmaking	MWh/tcs	0.380 ~ 0.420	Assumed from CEEW study (Elango, et al. 2023)
Rerolling	MWh/tcs	0.125~0.135	Assumed from the survey findings

**Note: IF related electricity consumption depends on the scrap usage ratio in the input for steelmaking*

Annexure 4

1. Energy efficiency measures and their utility:

The following energy efficiency measures were considered in the analysis and are explained below.

- **Ore preheating**: Using waste heat from the kiln, ore can be preheated. This measure reduces the amount of coal required in the kiln, thus improving the energy efficiency of the plant

- **Pelletisation**: Using pellets as an input instead of lump ore reduces the amount of ore and coal required to make DRI, thus increasing the plant's energy efficiency. However, the pelletisation process itself requires fossil fuel, and the savings in CO_2 may be reduced. Pellets, nonetheless, also aid in operational efficiency by reducing maintenance costs in the kilns.

- **Waste heat recovery boiler (WHRB)**: Using a WHRB in a rotary kiln setup to capture waste heat generated in the rotary kiln to generate electricity. The role of waste heat recovery systems in enhancing energy efficiency by capturing and using the heat in the form of electricity that would be otherwise lost in industries is critical. As in several other sectors, their integration in DRI industries has been associated with optimising energy use and

reducing operational costs. Plants with capacities exceeding 200 tpd were equipped with WHRB, whereas WHRB is not considered viable for smaller plants.

- **Variable voltage and frequency drive (VVFD)**: Installing VVFDs on motors driving rotary kiln auxiliaries, such as ID fans, blowers, and pumps, can reduce electricity consumption. By adjusting motor speed to match actual process requirements instead of running at full capacity continuously, VVFDs helps optimise power use and reduce energy consumption. This not only lowers operational costs but also contributes to overall energy efficiency improvements across the plant.

- **Ore beneficiation**: Beneficiating ore before feeding it into the kiln improves the quality of the input by removing impurities and increasing iron content. Higher-grade ore requires less coal for reduction, which directly improves energy efficiency and reduces CO_2 emissions. While the beneficiation process itself consumes additional electricity and or fuel, its net benefit is positive in most cases, especially when integrated with other energy-saving measures in the plant.

- **Dolochar combustion:** Rotary kiln output includes ore and dolochar. Usually, it is a challenge to dispose of dolochar for rotary kiln operators, as there are regulations. Dolochar consists of unburnt coal, ash etc. It can be used as a source of fuel in FBC captive power plant.

2. Methodology of estimating MAC decarbonisation levers

This section outlines the approach used to estimate the marginal abatement cost (MAC) for each decarbonisation lever considered in the report. MAC values are derived based on the capital and operational expenditures associated with implementing each measure and the corresponding emissions reduction potential. Survey data from clusters, combined with secondary sources on fuel prices, technology costs, and emissions factors, inform the cluster-specific MAC calculations.

Pelletisation: Pellet usage in the cluster is sensitive to the cost of pellets and iron ore. As reported in Chapter 3, surveyed plants reported switching between pellets and lump ore based on economic and operational considerations. The emission reductions from pellet use are calculated by estimating the amount of coal use that will be reduced by using pellets instead of lump ore while accounting for emissions attributed to pelletmaking. The capital expenditure is computed based on the investments for setting up pelletmaking units corresponding to a 100 per cent uptake in the cluster. The MAC is obtained based on the operational expenditure (OPEX) consideration and the cost differential in procuring iron ore fines for pellet production compared to lump ore procurement.

Energy efficiency: The survey data on WHR adoption and kiln capacities (particularly those below 300 tpd) is used to estimate the WHRB capacity required for achieving 100 per cent WHRB penetration in the cluster. The annual cost of power generated from WHRB is then calculated by considering CAPEX and OPEX requirements. The cost difference between the existing cost of power in the DRI units from survey data (which is based on the mix of power from captive, RE and grid sources, depending on the cluster) is then used to estimate the cost of energy efficiency from WHRB. These calculations yield net cost savings for the clusters evaluated, as power from WHRB is usually less expensive as compared to power from RE, captive power and the grid.

Renewable energy use: The remaining power requirement in the cluster that cannot be fulfilled by

WHRB power is then obtained using FDRE. The CAPEX and OPEX requirements are calculated based on the oversizing of solar and wind power plants and the deployment of storage capacities to fulfil the FDRE requirements. Based on recent FDRE tenders (Central Electricity Regulatory Commission 2025), we consider an FDRE cost of INR 5 per kWh. Subsequently, we use the open-access dashboard to compute the delivered cost of power across clusters. The cost of power obtained from RE is then compared with the existing power cost (based on the existing energy mix) in the DRI cluster to estimate the MAC for RE uptake.

Use of imported coal over domestic coal: The cost of coal substitution is assessed by utilising the current coal use ratio of domestic and imported coal in the clusters using data from the surveyed plants. The additional costs incurred due to the transition to higher-quality, lower-emission fuel sources is estimated by calculating the cost differential between the existing domestic and imported coal ratio against a scenario where 100 per cent imported coal is used.

Increase in scrap utilisation for crude steel making: In order to evaluate the impact of an increase in scrap usage in induction furnaces for crude steel production, this study assumes a 5 per cent increase in scrap utilisation in the clusters from the existing rate of scrap usage in the clusters. The cost of 5 per cent additional scrap usage is estimated by considering market prices for scrap and cost savings resulting from displacing DRI requirements and energy savings. The cost of scrap varies across clusters due to demand, supply, and access. However, we have applied uniform prices based on average scrap rates in Indian metros, as these differences are marginal with a 6 per cent standard deviation. Additionally, the cost of scrap in Raipur aligns with the median value. (AYRON MART n.d.). However, due to India's dependence on scrap imports and an underdeveloped domestic scrap supply chain, the net cost of increasing scrap usage in crude steelmaking remains positive across clusters. (Table A 15)

CCUS: CCS is considered for the remaining emissions that cannot be mitigated from all the other measures described above, with an assumed carbon capture rate of 85 per cent (Verma, et al. 2024). The cost of carbon capture, transport and storage is estimated using secondary data from Niti Aayog (Mukherjee and Chatterjee 2022) and the CCUS chapter in the *Greening the Steel Sector in India Roadmap and Action Plan* report by the Ministry of Steel (Verma, et al. 2024). This cost is uniformly applied to the rest of the emissions from all the clusters.

Carbon offsets: The residual 15 per cent emissions that cannot be captured through CCUS is designated for offsets. For our calculations, we do not consider the cost of offsets.

3. Assumptions for MAC calculations

Table A 10 to Table A 16 contain the list of assumptions/values for the decarbonisation measures described in the methodology above.

Table A 10. Assumptions for calculating emission mitigation and MAC for the clusters: Material efficiency – Pelletisation.

Sr. No.	Parameters	Value	Units	Source
	Pelletisation			

1	Ore used per tonne of pellet	1.375	t-ore/t-DRI	(Elango, et al. 2023)
2	CEPCI deflector for 2014	576.1		(Towering Skills 2025)
3	CEPCI deflector for 2024	798.8		(Towering Skills 2025)
4	Cost of building 1 Mt of Pellet making unit	32	USD/t-pellet	(RML_Pellet 2014)
6	Iron ore grade considered (Fe content)	58~60 %		Survey data
7	Iron ore fines grade (Fe content)	62~65 %		(Indian Bureau of Mines 2011)
8	Cost of Iron ore lumps - Odisha	4,882	INR/t	(Indian Bureau of Mines 2025)
9	Cost of Iron ore lumps - Karnataka	4,892	INR/t	(Indian Bureau of Mines 2025)
10	Cost of Iron ore lumps - Chhattisgarh	4,211	INR/t	(Indian Bureau of Mines 2025)
11	Cost of Iron ore fines - Odisha	4,894	INR/t	(Indian Bureau of Mines 2025)
12	Cost of Iron ore fines - Karnataka	5,173	INR/t	(Indian Bureau of Mines 2025)
13	Cost of Iron ore fines - Chhattisgarh	4,949	INR/t	(Indian Bureau of Mines 2025)

Table A 11. Assumptions for calculating emission mitigation and MAC for the clusters: Energy efficiency (WHRB)

Sr. No.	Parameters	Value	Units	Source/ Notes
	Waste heat recovery boiler (WHRB)			
1	Electricity generation from WHRB	380	kWh/t- DRI	(Nitturu, et al. 2024)
2	CAPEX for WHRB	4242	INR/t-DRI	(Elango, et al. 2023)
3	OPEX	5% of CAPEX		Assumed

Table A 12. Assumptions for calculating emission mitigation and MAC for the clusters: FDRE

Sr. No.	Parameters	Value	Units	Source/ Notes
	Firm and dispatchable renewable energy (FDRE)			
1	Cost of captive power	3.72	INR/kWh	(Elango, et al. 2023)
2	FDRE cost	5.00	INR/kWh	(SECI 2024)

3	Grid Emission factor	0.716	Kg CO_2/kWh	(CEA 2023)
4	CPP coal NCV	18.90	GJ/tonne	(IPCC 2006)

Table A 13. Discom and OA charges in the clusters based on FDRE requirements

Cluster	Jharsuguda	Sundargarh	Bellary	Raipur	Raigarh
Discom charges	6.76	6.76	8.03	8.61	8.61
OA charges: Solar intra state	3.02	3.04	2.52	0.7	0.7
OA charges: Wind from states with good wind capacity	3.51	3.53	2.57	1.35	1.35
Mean OA charges	3.36	3.38	2.55	1.15	1.15

Table A 14. Assumptions for calculating emission mitigation and MAC for the clusters: Alternate fuels – Use of imported coal

Sr. No.	Parameters	Value	Units	Source/ Notes
	Alternate fuels: Use of imported coal			
1	GCV Domestic coal FC 30 -40 %	4450	kCal/kg	(Ministry of Coal 2025)
2	GCV Imported coal - RB2	5850	kCal/kg	(globalCOAL 2019)
3	Emissions intensity of domestic coal	96100	kg CO_2/TJ	(IPCC 2006)
4	Emissions intensity of imported coal	94600	kg CO_2/TJ	(IPCC 2006)

Table A 15. Assumptions for calculating emission mitigation and MAC for the clusters: Material efficiency – Increase scrap utilisation by 5 per cent

Sr. No.	Parameters	Value	Units	Source/ Notes
	Scrap utilisation			
1	Cost of scrap	46848.75	INR/t	(JPC 2022-23)
2	Cost of DRI	40660	INR/t	(JPC 2022-23)
3	DRI required per tonne of crude steel (tcs)	1.25		(Elango, et al. 2023)
4	Scrap required per tonne of crude steel (tcs)	1.1		(Elango, et al. 2023)

Table A 16. Assumptions for calculating emission mitigation and MAC for the clusters: CCS

Sr. No.	Parameters	Value	Units	Source/ Notes
	CCS			
1	Carbon capture rate using CCS	85%		(Verma, et al. 2024)
2	CAPEX - Carbon capture	900	INR/t CO_2 capture capacity	(Mukherjee and Chatterjee 2022)
3	OPEX - Carbon capture	2100	INR/t CO_2 capture capacity	(Mukherjee and Chatterjee 2022)
4	CO_2 transport cost	7	USD/t	(Verma, et al. 2024)
5	CO_2 sequestration cost	20	USD/t	(Verma, et al. 2024)

4. MAC results tabulated

The report presents the results of the MAC calculations as a MAC curve and provides a detailed explanation. Table A 17 also shows the MAC for each measure across the clusters for more clarity on the actual values

Table A 17. MAC values for all the clusters

MAC (USD/t CO_2)	Bellary	Jharsuguda	Sundargarh	Raipur	Raigarh
Material efficiency: Pellet use	40	20	23	44	31
Energy efficiency: WHR	-153	-22	-30	-114	-52
FDRE	47	54	48	14	42
Alternate fuel use: Imported coal	0	94	115	89	46
Material efficiency: Increased scrap use	-24	-11	-14	-21	-7
CCUS	64	64	64	64	64

Annexure 5

1. Cluster-wise emissions and mitigation

The section below provides the details of each sub-lever, evaluation method and data inputs used to compute the readiness scores for each cluster, shown in Chapter 5. The readiness indicator is structured around 27 sub-levers, classified under two categories: decarbonisation levers and low-carbon enablers.

1.1 Decarbonisation levers.

Decarbonisation levers contain 8 sub-levers and are scored either based on binary or relative scoring based on min-max method

Table A 18. Sub-levers under decarbonisation levers have 80 per cent of the total weight

Sr. No.	Lever	Sub-lever	Nature of rating	Score rating
1	Energy efficiency	Presence of ESCO	Binary	0 - No ESCOs 1 - ESCOs present within/near the cluster
2	Material efficiency	Presence of pellet making units	Relative	$= \frac{Pellet\ capacity\ ratio}{\frac{District\ pellet\ capacity}{Pellet\ required\ for\ cluster\ DRI}}$
3.1	Renewable Energy	Has the state adopted or issued draft - Green Open Access Rules	Binary	0 - No rules 0.5 - Draft 1 - Adopted
3.2		Delivered cost of RE through Open Access Charges – Solar intra-state and inter-state	Relative	Based on the solar injection tariff of INR 2.5/kWh
3.3		Delivered cost of RE through Open Access Charges– Wind	Relative	Based on the wind injection tariff of INR 3/kWh
4.1	CCUS	CCU potential in the cluster based on green Hydrogen potential in the region	Relative	Based on the green hydrogen potential in the region, i.e, the cost of green hydrogen through OA
4.2		CCS potential in the cluster (Geological storage availability: basalt, saline aquifers)	Binary	0 - No 1 - Yes
5	Alternate Fuels	Access and connectivity with port infrastructure for imported coal through railways	Binary	0 - No 1 - Yes

1.2 Low-carbon enablers:

Low carbon enablers with 20 per cent weights contain 19 sub-levers under 4 main categories.

Table A 19. Sub-levers under low-carbon enablers have 20 per cent of the total weight

Sr. No.	Lever	Sub-lever	Nature of rating	Score rating

1.1	Finance	Access to finance	Binary	Proximity to SIDBI Branch: (0-50 Kms- 1, 50-100 kms- 0.5, > 100 kms - 0)
1.2		Bankability	Relative	$Bankability = \frac{Number\ of\ non\ stand\ alone\ DRI\ units}{Total\ number\ of\ DRI\ units}$
1.3		Affordability of low interest loans and interest subvention	Binary	0 - No 1 - Yes
2.1	Ecosystem readiness	Awareness of Green Steel and developments such as Green Steel Roadmap and National Carbon Markets	Binary	Low-0 Medium -0.5 High 1
2.2		Status of Association	Binary	Defunct-0 Association Exists-0.5 Active-1
2.3		Training and workshops on LCT for DRI sector	Binary	0 - No 1 - Yes
2.4		Share of non-standalone DRI	Relative	$Ratio\ of\ Non\ standalone\ units = \frac{Non-standalone\ DRI}{DRI\ Total\ Capacity}$
2.5		DRI capacity covered under CCTS scheme (PAT coverage used as a proxy till CCTS data is available)	Relative	$PAT\ ratio\ (DRI) = \frac{DRI\ Capacity\ under\ PAT}{DRI\ Total\ Capacity}$
2.6		Steelmaking capacity (IF) covered under CCTS (PAT coverage used as a proxy till CCTS data is not available)	Relative	$PAT\ ratio\ (IF) = \frac{IF\ Capacity\ under\ PAT}{IF\ \ Total\ Capacity}$
2.7		Finished steelmaking capacity under CCTS (PAT coverage used as a proxy till CCTS data is available)	Relative	$PAT\ ratio\ (Rerolling\ mills) = \frac{Capacity\ under\ PAT}{Total\ Capacity}$
2.8		Presence of an anchor steel plant	Relative	$Anchor\ steel\ capacity\ ratio = \frac{ISP\ capacity}{Total\ Capacity}$
3.1	Alternate fuels	Presence of natural gas pipelines	Binary	1- Yes, 0.5- under construction/authorised 0 - None
3.2		Delivered cost of NG	Relative	Absolute value, for an LNG price of 11.5 USD/MMBtu
3.3		State-level GH_2 policy	Binary	1- Yes, 0.5 - under preparation/draft, 0 - None

3.4		State-level support for GH_2 (USD/kg)	Relative	Absolute value
3.5		Increase in delivered cost of GH_2 due to OA	Relative	Absolute value in USD/kg
4.1	Policy	Taxonomy of green steel definition	Binary	0 - No 1 - Yes
4.2		Green steel procurement Policy - Central government	Binary	0 - No 1 - Yes
4.3		Green steel procurement Policy - State government	Binary	0 - No 1 - Yes
4.4		MRV mechanism for green steel certification	Binary	0 - No 1 - Yes

Annexure 6

1. Other approaches to evaluation framework

In the main report we have considered x axis as annualised decarbonisation costs; this value balances out cost per capita of emission mitigated, but there are several other approaches to creating the evaluation framework. The example below is of a cluster plot where the total costs of decarbonisation are used as the x-axis.

1.1 Decarbonisation costs calculations and results

The annualised decarbonisation costs for all the clusters are estimated by using:

- **Emissions mitigation potential (A):** The total emissions in each cluster and the mitigation potential through each measure, which are tabulated in Table A *20*
- **Cost of emissions mitigation (B):** Abatement costs for various decarbonisation measures across each cluster, measured in USD per tonne of CO_2 abated, are estimated by using an analysis of the survey and secondary data. They are tabulated in Table A *17*.

Multiplying the emission mitigation potential from each measure in a cluster (A) with its respective abatement costs in each cluster (B) and then summing up the costs gives the total costs for each cluster and is also represented in Table A *20***Error! Reference source not found.** Naturally, clusters with high emissions, like Sundargarh, Raipur and Raigarh, have high costs. Sundargarh cluster has relatively higher costs because of its dependence on domestic coal (88 per cent share in total coal use) compared to other clusters. The comparatively higher cost of imported coal (INR 12,000 per tonne) compared to domestic coal (INR 3,000 per tonne) significantly increases the cost of fuel replacement in clusters like Sundargarh, Raipur and Raigarh that are heavily dependent on domestic coal.

Table A 20. Decarbonisation costs are inflated mainly because of CCUS and the incorporation of imported fuels

Sr. No.	Parameter	Bellary	Jharsuguda	Sundargarh	Raipur	Raigarh

A	**Total emissions (Mtpa)**	**4.96**	**1.40**	**7.29**	**7.75**	**10.66**
Annualised decarbonisation costs **(INR Crore per year)**						
1	ME: Pellet use	35	8	90	3	57
2	EE: WHRB	-321	-20	-260	-377	-183
3	FDRE	0	148	61	54	545
4	Alternate fuels	0	177	1821	983	561
5	ME: Increase in scrap use	-8	-5	-20	-45	-13
6	CCUS	2069	284	1609	2392	3071
	Total	**1768**	**592**	**3300**	**3011**	**4038**

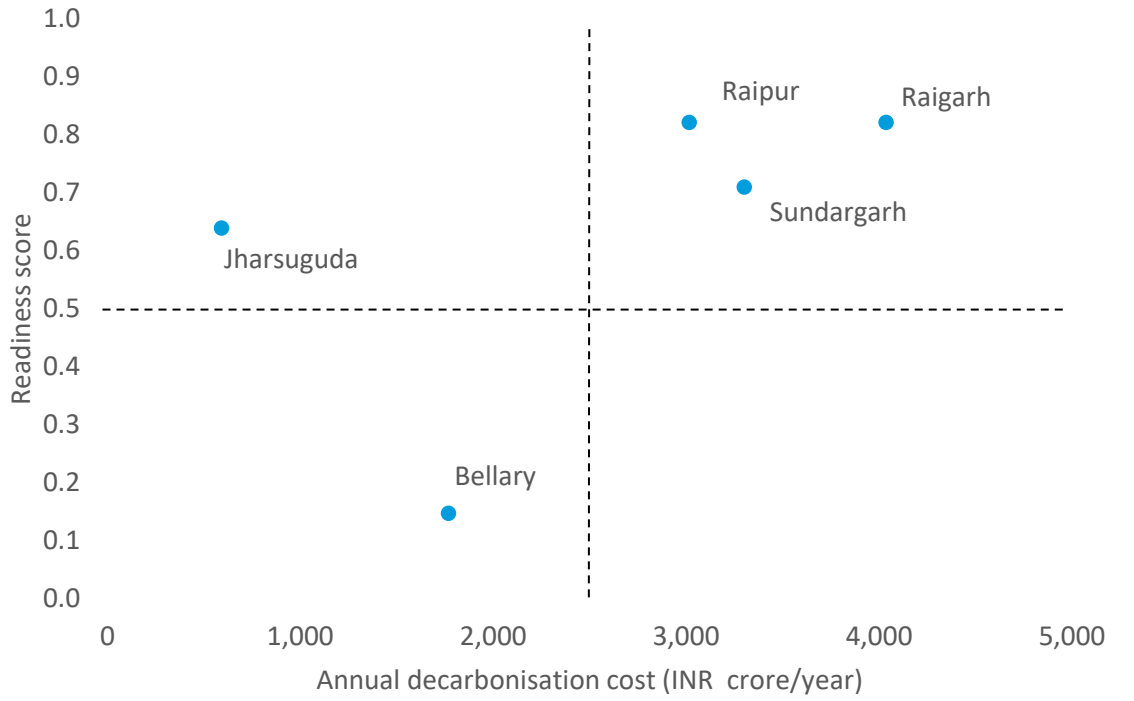
As seen in Table A *20*, Raigarh requires nearly INR 545 crore per year for RE due to the cluster's higher power demand, driven by the greater capacity of IF and EAF steel-making units. Clusters that use a larger share of grid power tend to have lower MAC for FDRE. For instance, as indicated in Table A *17*, the MAC in Raipur is around USD 12 per tonne CO_2, compared to roughly USD 53 per tonne CO_2 in Jharsuguda. As a result, Raipur shows an annual cost of only INR 54 crore for mitigating 0.5 Mtpa of CO_2, whereas Jharsuguda shows INR 148 crore per year for mitigating just 0.33 Mtpa. OA charges for third-party RE and grid power tariffs vary across states and significantly influence RE costs. In Odisha, lower grid tariffs are offset by high OA charges, which effectively increase FDRE costs. The use of scrap and WHRB lowers decarbonisation costs in clusters, as both have negative MAC values. Pelletisation, on the other hand, adds only marginally to the annual costs, as it leads to relatively minor CO_2 reductions compared to other measures.

Implementing CCUS as a measure to mitigate emissions largely inflates the annual costs in all the clusters. Since there are no examples of CCUS implementation in India, this technology is unlikely to be used as a measure in the near future. The report from the Ministry of Steel (Verma, et al. 2024) also considers CCUS as a measure that will most likely only be utilised post-2030 when all other measures are implemented first, especially low-hanging fruits like WHRB and RE. Hence, we have created a separate cluster plot for all mitigation pathways except for CCUS to gauge the performance of the clusters with readily available measures.

Cluster plots are derived by plotting readiness indicators ranging from 0 to 1 on the y-axis and annual decarbonisation cost for the clusters, indicating annual costs for decarbonisation on the x-axis. The cluster rankings based on annual decarbonisation cost and readiness indicators are shown in Figure A 8. Raigarh, Raipur and Sundargarh clusters have high annual decarbonisation cost and readiness indicator scores compared to other clusters. It can be seen that Raigarh, Sundargarh and Raipur clusters have high readiness and high annual decarbonisation cost values, largely driven by higher capacities and the possibility of CCS. Jharsuguda also has a high readiness score, as the cluster is located in the vicinity of a saline aquifer as well. However, as the cluster is relatively smaller than

other clusters, its overall annual decarbonisation cost is small. Bellary has low readiness and annual decarbonisation cost values, because of a lack of CCS for the readiness indicator, and a lack of need for renewable energy or Imported coal use to reduce emissions.

Figure A 8. Raigarh, Raipur and Sundargarh clusters have high annual decarbonisation cost and readiness indicator scores compared to other clusters.



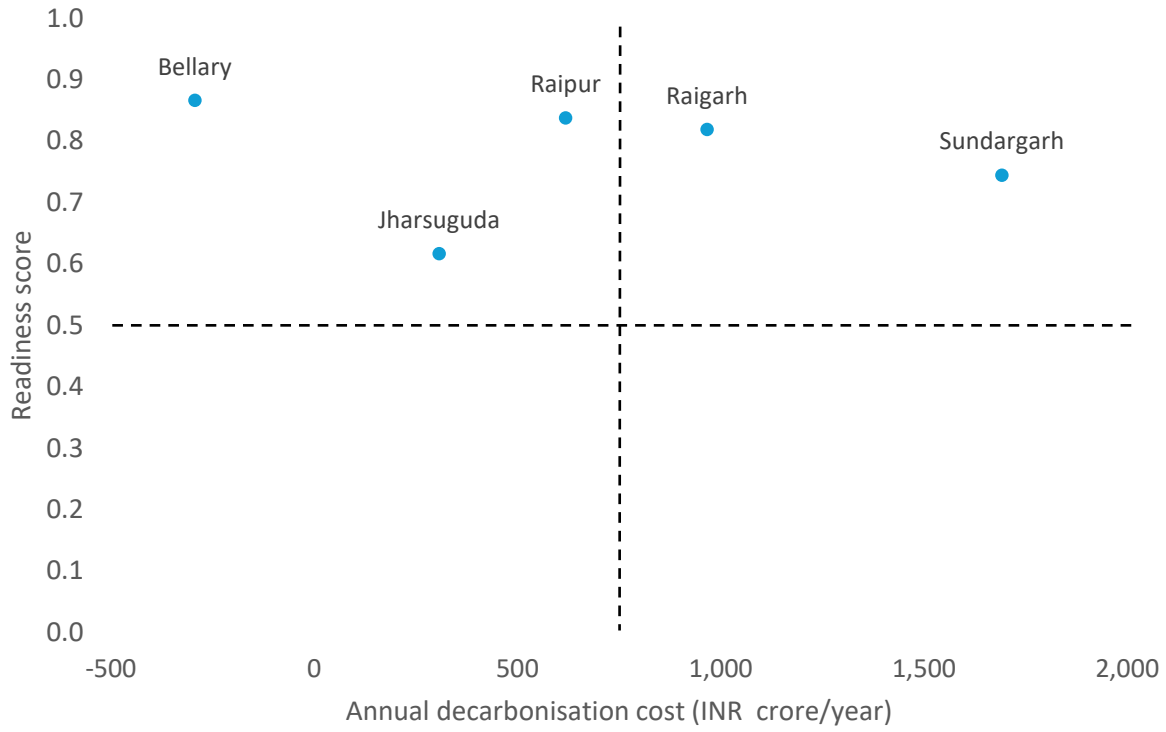
Source: Authors' analysis

A limitation of this plot and cluster comparison is that CCUS, as a single measure, disproportionately influences both the readiness and potential values. CCUS as a measure dominates in terms of potential score in all the clusters. Additionally, because of high weightage to CCUS in decarbonisation levers which represent 80 per cent of the weights to readiness indicators, clusters in Odisha and Chhattisgarh have a readiness score above 0.5, and Bellary has a readiness score of less than 0.2, especially since the cluster also gets a 0 weight for alternate fuel and RE. This is because the Bellary cluster is already using imported coal and does not need RE deployment since the entire electricity requirement in the cluster can be met using WHR alone. It is hence necessary to independently evaluate the cluster plot for the clusters without CCUS, as the technology is not ready to be deployed like other decarbonisation measures.

As discussed in the earlier sections, CCUS largely skews both the readiness and annual decarbonisation cost because of how dependent these clusters will currently be on CCUS if they need to go to net zero immediately. Removing CCUS from calculating readiness and annual decarbonisation cost yields an alternative cluster plot, as seen in Figure A 9. The readiness scores for each cluster now range between 0.7 and 0.9. Without CCUS, the Bellary cluster scores higher at 0.9 as energy efficiency and material efficiency gets higher weights for Bellary. Bellary as a cluster, has presence of ESCOs and has higher pellet capacity, which increases its readiness. Annual decarbonisation cost without CCUS largely shift to alternate fuel use, the Bellary cluster again scores

low on annual decarbonisation cost as it uses 100 per cent imported coal. Sundargarh becomes a cluster with high annual decarbonisation cost because it needs to replace its domestic coal (88 per cent) with imported coal.

Figure A 9. For low-hanging fruits like RE, ME, EE and AF all clusters have similar readiness scores, but Sundargarh cluster has high annual decarbonisation cost.



Source: Authors' analysis

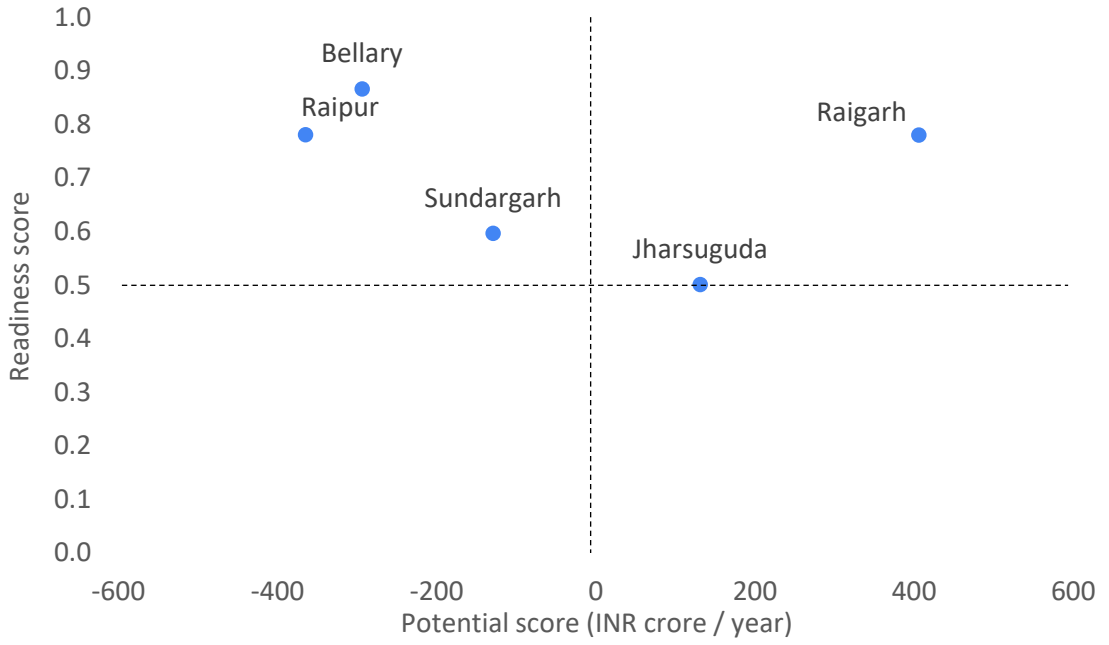
Switching to higher calorific imported coal can reduce emissions. However, it is highly sensitive to price fluctuations between the types of coal considered. The MAC values for the clusters inflate as the cost difference between imported coal and domestic coal increases, in addition to the amount of coal used. Our survey found domestic coal prices ranging from INR 1,000 to INR 5,000 per tonne, while imported coal costs ranged from INR 10,000 to INR 13,500 per tonne. For clusters that have higher dependence on domestic coal, this inflates the annual decarbonisation cost largely. This is especially true in the case of Sundargarh, a cluster with large DRI capacity and 100 per cent domestic coal use. This makes the coal switch an expensive proposition, even though it lowers emissions. Relying on imported coal also 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 A 10, presents readiness and annual decarbonisation cost excluding alternate fuels and CCUS, to better isolate the results of "low-hanging fruit" related interventions like WHR, scrap, pelletisation and FDRE.

From our MAC values, it is evident that WHR and Scrap utilisation result in cost savings. Pelletisation, as a measure, has a low impact on Raipur as it already has high pellet usage, but it adds costs in Raigarh, Sundargarh, and to some extent in Bellary. FDRE requirement is zero in Bellary, and Sundargarh requires just 14 MW of additional FDRE, as WHRB can meet 88 per cent of its power

needs. Raipur, which relies more on grid power, and has the lowest open access (OA) charges compared to clusters of other states, shows significantly lower MAC values for FDRE. All these factors result in only Jharsuguda and Raigarh having positive MAC values. Driven primarily by FDRE and pelletisation.

In terms of readiness scores, as the readiness scores depend on relative scores of the indicator, as well as the weights described in section Figure A 10. All the clusters score above or equal to 0.5 on Readiness, with Bellary highest at 0.87 and Jharsuguda lowest at 0.50. In Bellary's case, the absence of RE-related emissions reductions shifts most indicator weight to EE and ME levers, where the cluster scores well due to strong ESCO presence and pellet-making capacity exceeding local DRI demand. Jharsuguda, by contrast, has no pellet capacity and scores poorly on ME readiness. Even other clusters underperform on ME indicators because of Bellary's higher pellet capacity (Annexure EE). Chhattisgarh clusters 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 where it performs poorly, contributing to its lower overall readiness.

Figure A 10. For low-hanging fruits like RE, ME and EE, clusters in Chhattisgarh have high annual decarbonisation cost because of high RE requirements in the clusters.



Source: Authors' analysis

Annexure 7

The policy recommendations included in Chapter 6 exclude cluster-specific recommendations for Raigarh and Jharsuguda, which are presented here

Raigarh

The Raigarh cluster has the highest coal-based DRI production capacity among the surveyed clusters. Additionally, it has a high steelmaking capacity due to its substantial EAF capacity; the cluster also

hosts more integrated plants with larger capacities. Consequently, it records the highest emissions among all clusters. The cluster has moderate pellet usage and already has more than 70 MW of WHR installed, with an additional requirement of 96 MW. Given its greater steelmaking capacity, the cluster would need a substantial amount of FDRE, amounting to more than 330 MW. Given its higher share of non-standalone units, this cluster can be suitable for demonstrating more expensive interventions.

Table A 21. Cluster specific recommendations for Raigarh cluster

Lever Issue	Recommendations
Energy efficiency	Raigarh cluster has a WHR potential of 96MW, which can fulfil 19 per cent of the existing power requirement in the cluster. Therefore, *Chhattisgarh State Power Distribution Company Limited (CSPDCL)* should allow other industries, such as induction furnaces in the cluster, to buy WHR power from the DRI units. The WHR power should be available at an affordable price to the end-consumers so that they can switch from grid electricity to WHR power. The state and the ministry of steel should provide incentives for smaller DRI plants to install WHRB
Material efficiency	**Incentivise the uptake of pellets in the DRI industry** The survey in the Raigarh cluster showed high pellet usage (65 per cent). However, Raigarh lacks enough pellet production capacity for the entire cluster. Excluding capacities from ISPs, existing pellet-making capacity can only fulfil 35 per cent of the cluster's pellet demand. The ministry should ensure that the pellet demand in the cluster is met through the supply of competitively priced pellets. Pellet production involves GHG emissions; therefore, the Bureau of Energy Efficiency should include pellet-making units under the Indian Carbon Markets. Additionally, emissions from pellet production should be included in the GHG emissions accounting for steel plants in India to ensure decarbonisation in pellet-making units.
Renewable energy	The Raigarh cluster has high solar energy potential, but it lacks wind energy potential. It requires 331 MW of renewable energy (RE), in addition to WHRB, to meet its overall power needs. This is mainly because Raigarh has relatively lower DRI capacity compared to its steelmaking and re-rolling capacities. Chhattisgarh has the lowest open access (OA) charges among the states, and incentives for captive RE and sourcing RE through OA can further support Raigarh's transition to a low-carbon cluster.
Alternative fuels	**Aggregate natural gas demand in the cluster to promote completion of ongoing NG pipeline projects for NG access and reduce the delivered cost of NG in Chhattisgarh** Raigarh is expected to benefit from the upcoming Mumbai–Nagpur–Jharsuguda pipeline. The Ministry of Steel should aggregate natural gas demand in the cluster to prioritise connection and supply to Raigarh, helping transition from coal to vertical shaft-based gas DRI **Reduce the delivered cost of NG in Chhattisgarh:** The delivered cost of natural gas in Chhattisgarh is significantly higher than in Karnataka and Odisha, mainly 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 use NG instead of coal DRI. The Chhattisgarh government should consider reducing these taxes to make gas-based DRI more cost-competitive. **Create state level green hydrogen policy**: Green hydrogen can be key fuel that can aid in transitioning the cluster to low-carbon emissions cluster. Chhattisgarh government should create and launch a dedicated state level green hydrogen policy to promote use and access of green hydrogen in the cluster like Odisha. Additionally, Odisha offers a subsidy of 3.01 USD/kg for green hydrogen production, Chhattisgarh should also implement competitive support pricing and incentives to accelerate uptake in the steel sector.
Policy	**Develop a GPP policy in Chhattisgarh** Raigarh is a big cluster and has the largest DRI capacity in the country, with large number of non-standalone DRI plants, with a high WHR penetration. Therefore, the state government should develop a GPP policy as it can boost production and consumption of green-rated steel, further providing edge in being first mover to fulfil demand for low-carbon steel

Jharsuguda

Jharsuguda is a relatively small DRI cluster in Odisha with limited installed capacity but significant decarbonisation challenges. The cluster requires 38 MW of FDRE because it has a higher steelmaking capacity than DRI capacity and relies entirely on domestic coal, leading to higher baseline emissions intensity. Although it has access to the under-construction Jagdishpur–Haldia–Bokaro–Dhamra (JHBDPL) natural gas pipeline, it currently lacks the infrastructure and policies needed to support a shift to cleaner fuels. Furthermore, Jharsuguda has limited renewable energy uptake, no pellet-making capacity, and only one unit (0.29 Mtpa out of 0.72 Mtpa) covered under PAT, underlining the need for targeted ecosystem and infrastructure interventions.

Table A 22. Cluster-specific recommendations for the Jharsuguda cluster

Lever Issue	Recommendations
Energy efficiency	**Enable purchase of WHR power by induction furnaces within the cluster** Jharsuguda cluster being a small cluster with 5 units, has WHR potential of 13 MW which can meet 21 per cent of the power required by the steel industry in the cluster. Therefore, *Western Electricity Supply Company of Odisha* Ltd. (WESCO) should allow other industries, such as induction furnaces in the cluster, to buy WHR power from the DRI units. The WHR power should be available at an affordable price to the end-consumers so that they can switch from grid electricity to WHR power.
Material efficiency	**Incentivise the uptake of pellets in the DRI industry:** Jharsuguda has no pellet-making capacity, with a demand for 0.62 Mtpa of pellet capacity for

	100 per cent pellet adoption. None of the plants surveyed in Odisha were using pellets. Therefore, the *Ministry of Steel* should direct efforts to ensure that pellets are available at a competitive cost to the industry to maximise their uptake in the sponge iron sector.
Renewable energy	**Release green open access rules in Odisha and reduce open access charges:** Jharsuguda has high solar energy potential, although it lacks wind potential. However, compared to the Raipur and Raigarh clusters, the OA costs for RE in Jharsuguda are higher. Especially the OA charges for intra-state solar. To incentivise broader RE adoption compared to other sources, the *state government* should reduce OA charges, encouraging more units in the cluster to integrate renewable sources into their energy mix. Additionally, it should also implement its green open access rules.
Ecosystem	**Revive defunct Odisha SIMA:** 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 steel making.

References

Indian Bureau of Mines. 2011. “Iron & Steel - Vision 2020.” In *Agglomeration*, by Indian Bureau of Mines Controller General, 101. Ministry of Mines, GOI. https://ibm.gov.in/writereaddata/files/06062017101203Iron%20and%20Steel%202020_4.pdf.

AYRON MART . n.d. *Scrap Iron Prices, Market Rates.* Accessed July 23 , 2025. https://ayronmart.com/steel-scrap-iron-prices/.

Bakshi, Tuli, Hemant Mallya, and Deepak Yadav. 2023. *Assessing India’s CO_2 Storage Potential: A Critical Analysis of What Lies Beyond the Theoretical Potential.* New Delhi: Council on Energy, Environment and Water. https://www.ceew.in/publications/how-can-india-scale-carbon-capture-storage-projects-co2-storage-potential-sequestration.

CEA. 2023. “CO2 Baseline Database for the Indian Power Sector: User Guide - Version 19.0.” *Central Electricity Authority, Ministry of Power, Government of India.* December. https://cea.nic.in/wp-content/uploads/baseline/2024/01/User_Guide__Version_19.0.pdf.

Central Electricity Regulatory Commission. 2025. “Order in Petition Nos. 312/AT/2024.” *CERC.* March. https://www.cercind.gov.in/2025/orders/312-AT-2024.pdf.

Delhi Electricity Regulatory Commission. 2024. “Delhi Electricity Regulatory Commission (Peer to Peer Energy Transaction) Guidelines, 2024.” 24 06. https://www.derc.gov.in/sites/default/files/DERC%20Peer%20to%20Peer%20Energy%20Transaction%20Guidelines%202024%20-%2024.06.2024.pdf.

Elango, Sabarish, Kartheek Nitturu, Deepak Yadav, Pratheek Sripathy, Rishabh Patidar, and Hemant Mallya. 2023. *Evaluating Net-zero for the Indian Steel Industry: Marginal Abatement Cost Curves of.* New Delhi: Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/How-Can-India-Decarbonise-For-Net-Zero-Sustainable-Steel-Production-Industry.pdf.

globalCOAL. 2019. *Standard Trading Contract, SCoTA Specifications and Definitions, RB2 5700.* October. https://www.globalcoal.com/scota/specifications.cfm#RB2-5700.

Government of India, Ministry of Mines. 2024. *Indian Minerals Yearbook–2022 VOLUME - III MINERAL REVIEWS.* Yearbook, Nagpur: Controller General Indian Bureau of Mines, 208 - 234. https://ibm.gov.in/writereaddata/files/1733387213675163cd04de2IMYB_2022_Volume_III.pdf.

Indian Bureau of Mines. 2025. *Average Sale Price.* Accessed December 2024. https://ibm.gov.in/IBMPortal/pages/Average_Sale_Price.

IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Guidelines, Kanagawa : Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf.

JPC. 2022-23. *ANNUAL STATISTICS 2022-23.* Report, Kolkata: Joint Plant Committee.

Karnataka Electricity Regulatory Commission. 2024. “KERC (Implementation of Peer to Peer Solar Energy Transaction) Regulations, 2024.” 06 08. https://kerc.karnataka.gov.in/uploads/media_to_upload1724310950.pdf.

KSIMA. n.d. *Karnataka Sponge Iron Manufacturers Association (R) - KSIMA Ballari .* Accessed March 2025. https://ksima.in/.

Lv, Wei, Zengqing Sun, and Zijian Su. 2019. “Life cycle energy consumption and greenhouse gas emissions of iron pelletizing process in China, a case study.” *Journal of Cleaner Production* 1314-1321.

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.

https://www.ceew.in/publications/how-can-india-unlock-renewable-energy-and-green-hydrogen-potential.

Ministry of Coal. 2025. *Coal Grades.* https://coal.gov.in/en/major-statistics/coal-grades.

Mukherjee, Atanu, and Saurav Chatterjee. 2022. "Carbon Capture Utilization and Storage (CCUS), Policy Framework and its Deployment Mechanism in India." https://www.niti.gov.in/sites/default/files/2022-12/CCUS-Report.pdf.

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. https://www.ceew.in/sites/default/files/decarbonising-coal-based-dri-production.pdf.

Pandey, Sweety, Navin Kumar Vidyarthi, Rajnath Ram, and Rakesh Sarwal. 2022. *State Energy and Climate Index: Round-I.* New Delhi: NITI Aayog. https://www.niti.gov.in/sites/default/files/2022-04/StateEnergy-and-ClimateIndexRoundI-10-04-2022.pdf.

PMAI. n.d. *Pellet Manufacturers Association of India.* Accessed April 2025. https://pmai.co.in/statistics/.

PTC. n.d. *Power Tech Consultants .* Accessed April 2025. https://www.pwrtch.com/index.html.

RML_Pellet. 2014. "FEASIBILITY REPORT of 900000 TPA (0.9 MTPA) Pellet Plant." *RASHMI METALIKS LIMITED.* https://environmentclearance.nic.in/writereaddata/Online/TOR/0_0_28_Oct_2014_1722498701PFR.pdf.

SECI. 2024. "SECI FDRE-IV- 630 MW result website upload.xlsx." *Solar Energy Corporation of India (SECI).* https://www.seci.co.in/Upload/New/638592698466612984.pdf.

Singh, Anjali, and Prabhas Jain. 2015. "A study on the accretion formation in DRI kilns and possible ways for its reduction." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* Volume 12 (Issue 6 Ver. V): 101. doi:10.9790/1684-126598103.

Towering Skills. 2025. *Cost Indices.* https://toweringskills.com/financial-analysis/cost-indices/.

UPERC. n.d. "Guidelines for peer-to-peer solar energy transaction through blockchain." https://uperc.org/App_File/P2P-Guidelines_UPERC-pdf416202393822PM.pdf.

Verma, Neha , Deepak Yadav, Karthik Shetty, Rudhi Pradhan, Karan Kothadiya, Rishabh Patidar, Hemant Mallya, et al. 2024. *Greening the Steel Sector in India Roadmap and Action Plan.* Ministry of Steel, Government of India, New Delhi: Ministry of Steel, Government of India, Table 9.13, 221. https://steel.gov.in/sites/default/files/GSI%20Report.pdf.