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Scope for Deep Decarbonisation in the MSME Manufacturing Sector

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Disclaimer

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(The author list provided assumes no particular order as every individual contributed to the successful execution of the project.)

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Executive Summary

As India aims to achieve its net-zero targets by 2070, serious commitment is required from all sectors, primarily the industrial sector. While large industries have already been inducted into the ambit of energy efficiency and conservation (Perform, Achieve and Trade scheme), the Micro, Small and Medium Enterprise (MSME) industries have not received the same attention. MSMEs are still majorly dependent on fossil fuels for their energy requirements, making them particularly susceptible to increasing fuel prices. With energy costs having a substantial share in the overall manufacturing costs, the need for sustainable alternatives is crucial. Decarbonisation of MSMEs is necessary to reduce fossil fuel dependency in the industrial sector. However, this potential currently remains unrealised due to factors such as low awareness and lack of access to low-cost finance. Moreover, energy-efficient technologies have technical limitations, which constrain their decarbonisation potential. Thus, the need for examining deep decarbonisation measures is imperative.

Considering these challenges, CSTEP conducted a scoping study to assess the potential for deep decarbonisation in the MSME manufacturing sectors. The objective was to evaluate the overall scope for implementing decarbonisation technologies via demand electrification and fuel switching. The study estimated the potential for mitigating GHG emissions and analysed the techno-economic feasibility of decarbonisation technologies. Energy- and emission-intensive MSME manufacturing clusters were selected across India. The energy consumption in each unit was carefully mapped through a detailed energy audit. The data collected were used to create an energy and emission baseline to understand and identify potential areas for decarbonisation and relevant technologies to achieve it. A detailed techno-economic analysis was conducted for all demand electrification and fuel switching technologies to evaluate their feasibility. Through a four-stage scenario model, the impact of decarbonisation measures at various levels was analysed. The four stages included different levels of decarbonisation as follows:

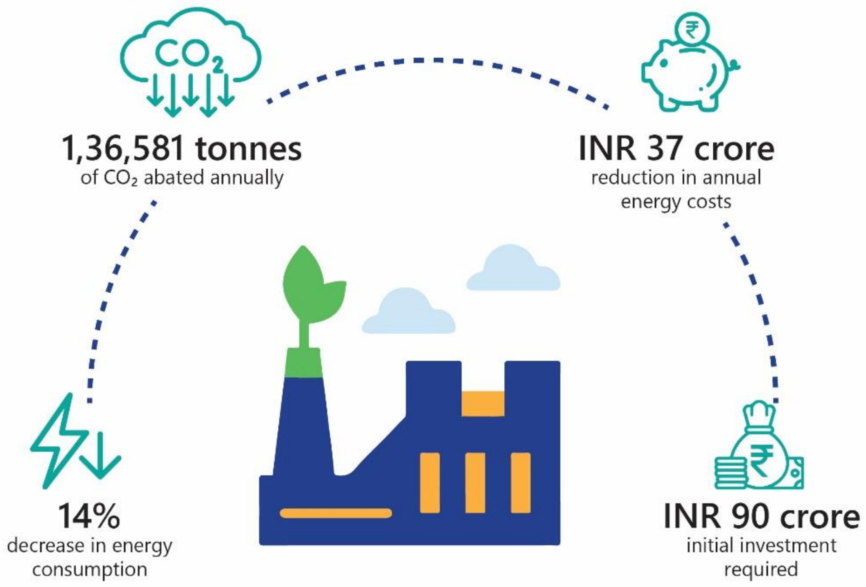
- *Business as Usual (BAU):* Without any interventions
- *Energy Efficiency (EE):* Implementation of EE measures on existing equipment
- *Energy Efficiency with Renewables (EE + RE):* Use of EE measures and renewables for electricity generation
- *Advanced Technologies (EE + RE + AT):* Implementation of EE + RE measures and advanced decarbonisation technologies (such as the use of clean fuels and process electrification)

The analysis showed the impact of these technologies on energy consumption, emissions, energy cost, and investment required. This process was replicated across all sample MSME units in each of the selected clusters. The study provided insights on the potential and impacts of various decarbonisation technologies. In total, seven clusters from five energy- and emission-intensive sectors, covering an aggregate of 66 MSME units, were included in this study. The selected cluster locations are given below:

- Alathur (*Pharmaceutical cluster*)
- Asansol–Chirkunda (*Refractory cluster*)
- Bengaluru (*Aluminium die-casting cluster*)
- Coimbatore (*Bakery cluster*)
- Delhi-NCR (*Aluminium die-casting cluster*)
- Ludhiana (*Textile cluster*)
- Tiruppur (*Textile cluster*)

The results of the modelling have been detailed for the seven selected clusters, estimating the energy reduction, emission drop, energy cost savings, and required investments.

Overall potential impact of decarbonisation in the seven clusters



Following are some policy recommendations to facilitate the implementation of the decarbonisation measures in the aforementioned sectors:

- Improvement of access to lower-cost, collateral-free financing for MSMEs
- Formation of state-wise MSME policies comprising emission targets and a roadmap for decarbonisation (through energy audits, research and development (R&D), pilots and demonstrations, and financing schemes)
- Development of a reliable ecosystem for the production and supply of biofuels (such as biomass briquettes, bio-compressed natural gas, and biodiesel) for direct fuel switching in thermal equipment
- Increase in the usage of renewables such as solar rooftop and open-access systems (net billing/feed-in tariff arrangements and RE financing)
- Provision of regulatory incentives to nudge MSMEs towards fuel switching

In conclusion, deep decarbonisation in the industrial sector is a necessary step for India to achieve its net-zero goals. Through an analysis of the clusters' energy consumption patterns, a clear pathway for emission reduction in the aforementioned clusters can be charted out.

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List of abbreviations

AT	Advanced technology
BAU	Business-as-usual
BEE	Bureau of Energy Efficiency
BLDC	Brushless direct current motor
CAPEX	Capital expenditure
CNG	Compresses Natural Gas
CO_2	Carbon dioxide
DG	Diesel generator
DIC	District Information Centre
DISCOM	Distribution company
EE	Energy efficiency
ESCO	Energy Service Company
GCV	Gross calorific value
GHG	Greenhouse gas
HSD	High-speed diesel
IE3	International Efficiency 3 (premium efficiency)
IE4	International Efficiency 4 (super premium efficiency)
INR	Indian Rupee
LCOE	Levelised cost of electricity
LED	Light emitting diode
LPG	Liquefied petroleum gas
MCA	Multi- criteria analysis
MGIRI	Mahatma Gandhi Institute of Rural Industrialization
MoEFCC	Ministry of Environment, Forest and Climate Change
MSME	Micro, Small, and Medium Enterprises
NCR	National Capital Region
NIMSME	National Institute of Micro, Small and Medium Enterprises
NPV	Net present value
NSIC	National Small Industries Corporation
PDC	Pressure die-casting
PEACE	Promotion of Energy Audit and Conservation of Energy
PNG	Piped natural gas
RAMP	Raising and Accelerating MSME Performance
R&D	Research and development
RE	Renewable energy
ROI	Return on investment
RTPV	Rooftop photovoltaic
SATAT	Sustainable Alternative Towards Affordable Transportation
SDG	Sustainable Development Goal
SEC	Specific energy consumption
SIDBI	Small Industries Bank of India
SIDO	Small Industries Development Organisation
SSIDC	Small Scale Industries Development Corporation
TANGEDCO	Tamil Nadu Generation and Distribution Corporation Limited
TFH	Thermic fluid heater
VFD	Variable frequency drive

1. Introduction

1.1 Background

India has a long history of the association of small and cottage industries and artisan groups spread across the country. Typically, units with similar processes have naturally formed around certain geographical 'clusters' owing to landscape factors such as trade routes and raw material availability. Historical examples include the Hooghly region (indigo, tea, and other industries) during colonial times or the Moradabad brassware industries. In addition to agriculture, this decentralised arrangement has been the largest source of the country's livelihood for generations. This sector is presently categorised as the Micro, Small, and Medium Enterprise (MSME) segment, covering all industries having less than INR 250 crore turnover, as per the latest definition by the Ministry of MSME (2020). MSMEs involve both manufacturing and services by nature, contributing to 31% of the country's gross domestic product and almost 50% of exports. Manufacturing is a key part of MSMEs, accounting for almost 2 crore units and employing 3.6 crore people in India. This contributes to an estimated 57% of all employment in manufacturing sectors (including large industries), indicative of the social importance of MSMEs (Ministry of Micro, Small and Medium Enterprises, Government of India, 2021).

This sector is also highly energy- and emission-intensive. Approximately 20%–25% of India's industrial energy consumption can be attributed to MSMEs, indicating an estimated energy consumption of 105–130 Mtoe (4,400–5,442 petajoules) and 150–200 million tonnes CO_2 equivalent of greenhouse gas (GHG) emissions (Bureau of Energy Efficiency, Government of India, 2023). MSMEs have a large carbon footprint, partly owing to their nature of energy consumption, with over 80% of the energy consumed required for thermal processes over electrical consumption. These thermal energy demands have traditionally been met through fossil fuels (such as coal, natural gas, and pet coke), and the problem is exacerbated owing to the use of old and inefficient equipment (boilers and furnaces). From an emissions perspective, MSMEs remain a hard-to-abate sector.

At the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27), India submitted its long-term strategy to achieve 500 GW of renewable energy (RE) capacity by 2030 and net-zero emissions by 2070 (Ministry of Environment, Forest and Climate Change, 2022). To meet the climate reduction targets, emission reductions and RE capacity additions will be required in every economic sector, including MSMEs. Encouraging MSMEs to adopt decarbonisation measures is essential for the progress of sustainable development goals (SDGs) including industry, innovation and infrastructure (SDG 9), responsible consumption and production (SDG 12), and climate action (SDG 13).

However, energy is a major cost burden in MSMEs. In most states, electricity tariffs for industries are hiked to cross-subsidise residential segments. Global inflation fears since 2021 have led to the rise in prices of several fossil fuels like natural gas and pet coke. MSMEs are vulnerable to these increases in energy prices owing to their heavy reliance on such fossil fuels and thus have high energy costs as a share of the total manufacturing costs (Verma, 2016). The sector-wise energy costs for manufacturing in MSMEs are shown in Figure 1.

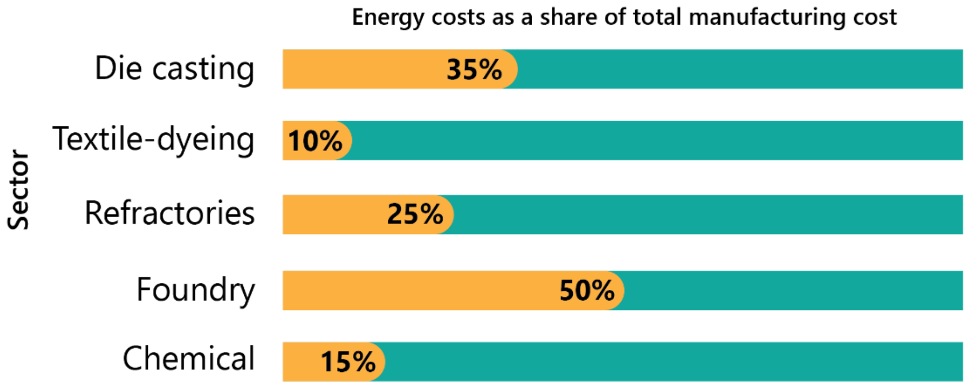


Figure 1: Sector-wise energy cost as a percentage of manufacturing cost

Decarbonisation (by reducing or eliminating fossil fuel consumption) is the route to solving both issues. Reducing energy consumption or using cleaner and cheaper fuels for production processes can have the twin benefits for the environment as well as the MSME unit's financial health. Energy efficiency (EE) technologies are an accepted measure within industries to save expenditure and reduce emissions. Research studies and energy audits are regularly conducted in MSME clusters by the Bureau of Energy Efficiency (BEE), World Bank, and other agencies (Bureau of Energy Efficiency, Government of India, 2008). However, EE measures are limited in their ability to decarbonise the sector due to the carbon intensity of the energy sources used. As technical efficiencies in these sectors reach saturation, the focus must shift to exploring deep decarbonisation technologies for the MSME manufacturing sector. However, the scope for the implementation of decarbonisation technologies in existing production processes remains uncertain.

1.2 Objective of the study

The primary objective of this study was to evaluate the scope for implementing decarbonisation technologies (advanced demand electrification and fuel switching) in the MSME manufacturing sectors. The study aimed to

- estimate the potential for mitigating GHG emissions and
- analyse the technical and economic viability of implementing decarbonisation technologies.

1.3 Key stakeholders

The study catered to various key stakeholders, which included organisations from various verticals such as state and central government agencies, financial organisations, MSME associations, unit owners, technology partners, and academia.

The detailed list of stakeholders under each vertical are as follows:

- Central government agencies, including BEE, Ministry of MSME; NITI Aayog, MOEFCC, Ministry of New and Renewable Energy
- State departments, including State Small Industries Development Corporations (SSIDCs), Small Industries Development Organisation (SIDO), District Information Centres (DICs), and distribution companies (DISCOMs)
- Financial Institutions, such as Small Industries Development Bank of India (SIDBI), State Financial Corporations, and microfinancing organisations
- MSME unit owners
- MSME development organisations, namely MSME Development Institute, National Small Industries Corporation Limited (NSIC), Mahatma Gandhi Institute for Rural Industrialization (MGIRI), and National Institute for MSME (NIMSME)
- Industrial associations (cluster associations)
- Technology partners and service providers
- Research organisations and academic institutions
- Philanthropy foundations and nongovernmental organisations.

2. Methodology

This study assessed the potential for deep decarbonisation through various levels of technology interventions in the MSME sector. This required a bottom-up understanding of the MSME segment, the different types of sectors present, energy mix, overall emissions, technology and efficiency levels, and financial health.

The research components included in the study to analyse the scope for decarbonisation in the MSME sector are shown in Figure 2.

Figure 2. Research components in the methodology

2.1 Identification and categorisation

The first step in this study was to identify the various energy- and carbon-intensive MSME sectors. As MSMEs are highly unorganised, the initial data were collected through extensive secondary research and literature review by evaluating the Ministry of MSME's annual reports, published reports from BEE, research articles, and reports. Overall, 32 major manufacturing sectors were identified across all fields ranging from pharmaceuticals, engineering works, and chemicals to dairy, coir, foundry, forging, and textiles. Next, using these data, the top six sectors suitable for the study Several optimisation methodologies exist for such purposes, including multi-criteria decision-making methods, such as analytic hierarchy process and weighted product method, as well as methods such as genetic algorithms for continuous and complex datasets. Given the discrete nature of our data for the 32 sectors, a robust and well-tested method known as Technique for Order Preference by Similarity to Ideal Solution was used. This method compares a dataset of alternatives through normalisation scores for each selected criteria with a certain allocated weightage. It calculates the distance of each alternative from the best and worst alternatives and ranks them accordingly. The sectors were selected on the basis of certain criteria, as shown in Table 1.

Table 1: Criteria for identification of sectors

Criteria for MCA	Description	Units	Weightage
Energy intensity	Amount of energy required per unit product	MJ/T of product	0.2
Emission intensity of production	Amount of GHG emissions per unit product	tCO_2 eq/T of product	0.2
Potential for energy use reduction	Expected potential for reduction in energy consumption for a given sector	Fraction between 0 and 1 (no units)	0.2
Overall market size of sector	Total market size (as a function of emissions) of the selected sectors	tCO_2 eq for a sector	0.05
Energy as a percentage of manufacturing cost	Ratio of energy cost/overall processing cost	Fraction between 0 and 1 (no units)	0.2
Industry growth rate	Macro-economic trend of growth for the selected sector (CAGR)	Fraction between 0 and 1 (no units)	0.1
Research by other projects	Whether the sector was previously researched in similar studies (i.e. sectors with a higher score were rarely researched)	Fraction between 0 and 1 (no units)	0.05

MCA: Multi-criteria analysis, GHG: Greenhouse gas, CAGR: Compound annual growth rate

Based on the aforementioned criteria with their respective allocated weightages, an MCA was conducted for 32 MSME sectors. The top six sectors selected for the study are mentioned below:

- Pharmaceuticals
- Chemicals
- Bakeries
- Aluminium die-casting
- Refractories
- Textiles

After finalising the sectors, the second step was to identify all clusters under each of these sectors. The necessary data were collected through a detailed literature review through which all clusters under these sectors were mapped across India. Similar to sector identification, an MCA was performed using a set of criteria defined in Table 2.

Table 2. Criteria for identification of clusters

Criteria for MCA	Definition	Units	Weightage
Number of units	<100, 100–250, >250 units	Number	0.35
SEC of cluster	Amount of energy consumed per total annual production of cluster	MJ/T of product	0.35
Comprehensive Environmental Pollution Index score	Characterises the quality of the environment in a specific area	Number	0.1
Climate vulnerability score	Scores of the critically polluted industrial clusters/areas	Number	0.05
State energy efficiency index	Assessment of energy efficiency performance using qualitative and quantitative indicators	Number	0.1
Proximity to major cities	For ease of access to technology service providers	No units	0.05

MCA: Multi-criteria analysis, SEC: Specific energy consumption

Using the above criteria, the clusters were ranked and the top two clusters from each sector were selected. Beyond the academic parameters, a practical consideration of the unit's willingness to be a part of the study played a key role in the final selection of the clusters. In the chemical sector, the shortlisted clusters were excluded as they either had recently conducted an energy audit or were unwilling to take part in the study. Thus, based on the cluster rankings and willingness to participate, the final clusters selected for the study are given in Table 3.

Table 3. List of clusters identified

Location	Sector	Number of units
Alathur	Pharmaceuticals	10
Bengaluru	Aluminium die-casting	10
Delhi-NCR	Aluminium die-casting	10
Asansol–Chirkunda	Refractories	8
Tiruppur	Textiles	10
Ludhiana	Textiles	12
Coimbatore	Bakeries	6
Total units		**66**

NCR: National Capital Region

Additionally, the sample size in each cluster was decided based on parameters such as unit type (micro, small, and medium), nature of activity, end product (types of products manufactured within the sector), and willingness to participate. The sample size consisted of 10 units per cluster, except the Asansol–Coimbatore cluster due to lack of willingness to participate. In total, 66 units that were selected based on the above-mentioned parameters and in consultation with respective industrial associations were included in the study.

2.2 Data collection

Following the identification of the clusters under the respective sectors, data collection was performed through the following methods:

- Review of secondary literature sources such as MSME Development Organisations (including MSME Development Institute, NSIC, MGIRI, and NIMSME), state departments (SSIDCs, SIDO, and DICs), and SAMEEEKSHA knowledge platform;
- Engagements with industrial experts and cluster associations;
- Ground-level surveys for primary data collection; and
- Detailed energy audits.

The initial data collection was performed through secondary literature review and on-ground surveys of cluster associations and unit owners. The majority of data was collected by conducting detailed energy audits from participating MSME units. These detailed energy audits involved performance assessment of all energy-consuming equipment in the unit, establishment of a baseline for energy consumption and emissions, estimation of the operating efficiencies and specific energy consumption (SEC) of the unit, determination of energy losses (thermal/electrical), etc. These audits were conducted by BEE-certified energy auditors using measuring instruments (such as power analyser, flue gas analyser, and digital infrared temperature gun) to record the parameters of fuel and energy consumption.

The detailed energy audits for all 66 units covered various parameters, including overall annual production, plant operating hours, type of technology used, type of equipment used (number of units, rating of equipment, etc), manufacturing process and sub-processes, raw materials required (quantity, cost, etc.), types and quantity of fuel used (electrical, coal consumptions etc.), fuel cost, product share, SEC, thermal efficiencies, energy loss of the equipment, and local service providers.

During data collection, the energy auditors were accompanied by our research team to ensure coordination and cooperation between unit owners and the audit team and to supervise the process. Subsequently, the research team reviewed the collected data with the help of industry experts and project advisors to ensure that there were no discrepancies and errors in data. The data were cleaned, categorised, and analysed for each cluster. Overall, 66 unit reports were generated with unit-specific data highlighting areas of focus for EE and conservation.

2.3 Baseline analysis

Data acquired from the energy audits were used to create a baseline dataset, which assessed the current technological and financial state of the selected clusters. This analysis also helped verify the data collected by the energy auditors and identify errors, which were corrected. The following technical and economic parameters were included in the baseline analysis for each of the 66 units: SEC, energy consumption (type of fuel and quantity), energy cost, operating efficiency, and emission intensity (Figure 3).

The baseline SEC calculated for each sector was compared with the existing secondary literature to observe variations, if any, and their underlying reasons. The above parameters helped identify equipment with the highest scope for energy conservation and decarbonisation potential. This was crucial as identifying decarbonisation measures for carbon-intensive equipment is dependent on these parameters.

The Scope 1 and Scope 2 carbon emissions were estimated for all manufacturing units. The parameters listed above were estimated based on various inputs, including process flow, type of technology used, carbon-intensive equipment, total operating hours, raw material mix, fuel share, production, product share, and manufacturing processes. These inputs helped create an SEC and emission dataset to identify the most suitable areas for implementing deep decarbonisation technologies. In addition, energy costs were calculated to determine the need for efficient technologies and fuel switching. This is vital for MSME clusters, as it helps unit owners understand the extent to which decarbonisation technologies can improve their financial health.

Following this step, various suitable decarbonisation technologies specific to each sector were identified. Further, a scenario model was created to estimate the energy, emissions, and energy cost reduction potentials for different equipment in each cluster.

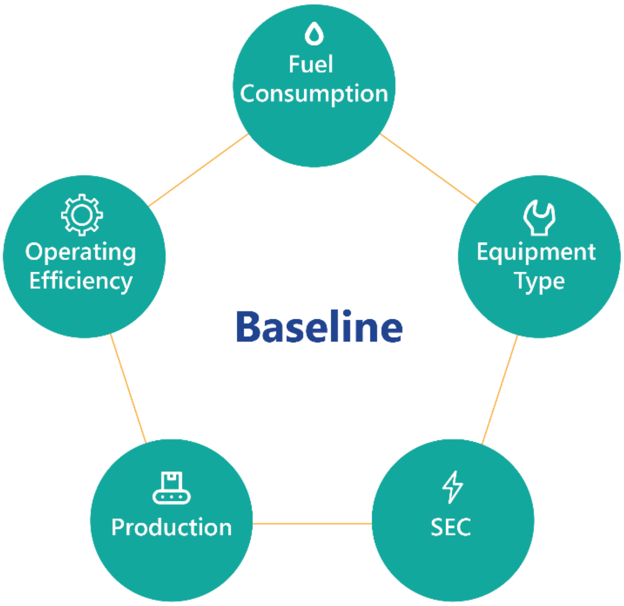


Figure 3: Baseline parameters

2.4 Identification of suitable decarbonisation technologies

Decarbonisation is defined as the net carbon removal from the atmosphere. This can be achieved through its key pillars, which include EE, process electrification, use of renewables, fuel switching (e.g. biofuels and hydrogen and others), and behavioural changes. Technologies that enable decarbonisation through any of the abovementioned pillars are categorised under decarbonisation technologies. In this study, the technologies to achieve deep decarbonisation were divided into three categories (Figure 4):

- Energy efficiency
- Renewable energy
- Advanced technologies (process electrification and fuel switching)

Advanced technologies cover two main components—process electrification and fuel switching. Process electrification is the conversion of any thermal-powered production process (such as melting and steam generation) to an electricity-powered alternative through the use of suitable technologies (e.g. electric boiler and electric furnace). Fuel switching involves the use of green sources of fuel, such as biodiesel, bio-compressed natural gas [CNG], diesel blends, and hydrogen, as a substitute for fossil fuels. One key assumption for defining advanced technologies is the level of commercial presence and maturity in the MSME sectors.

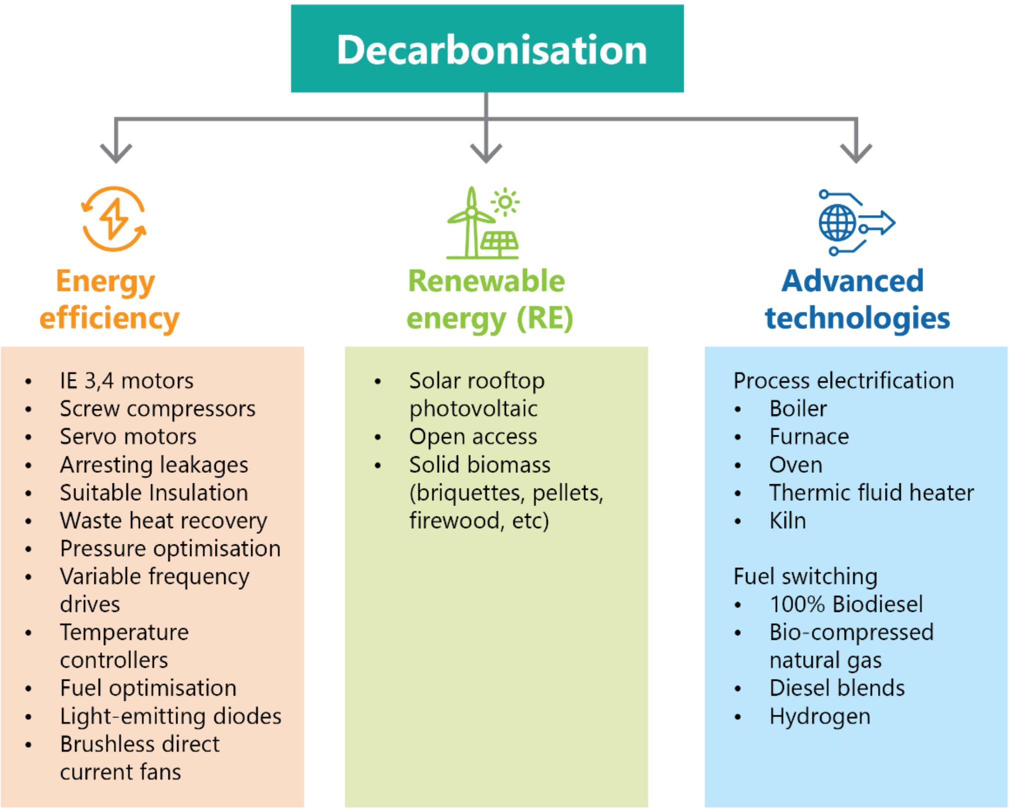


Figure 4. Classification of decarbonisation technologies

In this study, a techno-economic analysis was performed to estimate the impact of integrating these deep decarbonisation technologies on energy consumption and emissions. It also helped assess the cost of current energy route and suggest possible decarbonisation measures considering all parameters involved in manufacturing processes. To aid the techno-economic analysis, it was crucial to identify decarbonisation technologies suitable for each cluster. Using the baseline analysis, process equipment with the highest scope for decarbonisation were identified. To determine suitable decarbonisation technologies for these equipment, the process parameters and energy inputs were mapped. Some of the important technical parameters considered are given below:

- Energy and electricity requirements
- Sanctioned load of the unit
- Power rating of equipment used
- Temperature requirement in process heating
- Total technology implementation cost
- Emission reduction in the process
- Fuel savings
- Maturity of technology
- Internal rate of return (IRR) and payback period
- Process-related constraints/concerns in technology implementation (including fuel reactivity and safety)

The following unit-specific parameters were also critical in identifying the appropriate decarbonisation technologies:

- Availability of unused land on site, which also extends to rooftop area availability
- Geographical location of site
- Investing capacity of unit owners
- Commonly used equipment (e.g. furnaces and boilers) across units
- Unit size

The study also involved several levels of secondary research of promising commercial decarbonisation technologies used globally, in addition to discussions with technical experts, cluster associations, and unit owners regarding possible challenges in implementation. Market and technology leaders as well as product manufacturers were consulted on the efficiency and costs of the equipment to analyse their suitability in each cluster.

2.5 Techno-economic analysis and scope for implementation

To assess the scope for decarbonisation, the study applied scenario modelling that compares the impact of different levels of decarbonisation. Using the baseline data, the scenario modelling considered four different scenarios mentioned below (Figure 5):

- **Business-as-Usual (BAU):** The first scenario considered the current status of MSME units without any interventions at any level. It included the existing values of energy consumption, emissions, and energy cost.
- **Energy Efficiency (EE):** The second scenario considered EE measures for existing equipment, which are feasible and commercially available in the market. This included optimisation, retrofitting, and replacement with energy-efficient equipment.
- **Energy Efficiency with Renewables (EE + RE):** The third scenario involved a combination of EE measures and the use of RE (rooftop photovoltaics (RTPV) and small-scale wind units) for electricity generation.
- **Advanced Technologies (EE + RE + AT):** The final scenario involved an integration of EE and RE measures with advanced decarbonisation technologies, including a switch to clean fuels (biomass, biodiesel, hydrogen, etc) and electrification of thermal processes.

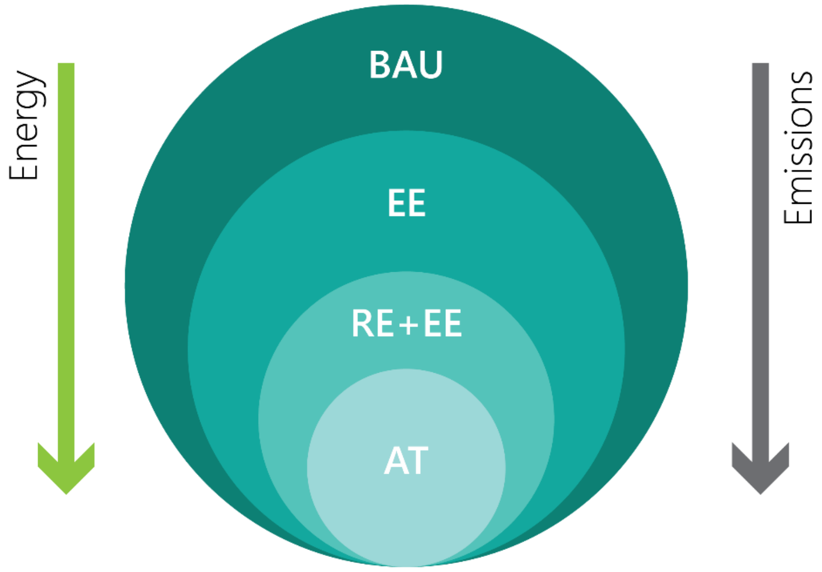


Figure 5. Scenario model framework

The technical and financial viability of the suggested decarbonisation technologies was analysed based on the cluster-specific constraints and risk factors. Considering all technical and financial parameters involved, the scope for implementation of these measures was assessed.

2.5.1 Technical analysis

The scenario modelling comprised two parts—technical analysis and financial analysis. In the technical analysis, the identified decarbonisation measures were evaluated to observe the impact on energy consumption and emissions across all seven clusters. First, the BAU scenario was considered, wherein data from the baseline analysis acted as the input. This analysis was performed for every major equipment in all clusters, taking into account the quantity and type of fuel used. Next, under the EE scenario, the respective EE measures were incorporated and the resulting changes in the total energy consumption and emissions were calculated. The third scenario introduced the use of RE sources, which offsets a certain share of the grid electricity used. Although the total emissions decreased due to RE integration, the overall energy consumption remained the same as that under the EE scenario. Based on the availability of land/rooftop space at the site and the maximum energy consumption of the unit, RE solutions were accordingly sized. For process heating, the suggested new technology was technically evaluated to estimate the required heat for the manufacturing process. Each of these solutions were specific to the identified clusters. The final scenario displayed the impact of the advanced technologies beyond the RE scenario through the use of process electrification and fuel switching. Notably, the use of bio-CNG and biodiesel (blended) was considered an advanced technology despite being an RE source because of its uncommon use. Additionally, the SEC and emission intensity and the changes in their values were calculated across the scenarios.

The energy consumed was quantified in giga joules (GJ), while the emission intensity was represented in tonnes of CO_2. For the sake of uniformity, the gross calorific value of fuels, energy conversion factors, and emission factors taken from the literature were kept constant throughout the model. In this study, it was assumed that biomass and its byproducts have zero GHG emissions (IPCC, 2008) because the carbon cycle for biomass is balanced, making it a carbon-neutral energy source.

The outputs of the technical analysis across all four scenarios for each cluster included (a) savings in the overall energy consumption and fuel and (b) the impact on GHG emissions.

The formulae used for the technical analysis and scenario modelling across all clusters are mentioned below.

Energy consumption

Energy consumption from the unit is in the form of electrical or thermal energy. Electrical energy was sourced from the grid or RE systems and was presented in terms of kilowatt-hr (kWh), with 1 kWh being equivalent to 0.0036 GJ.

For thermal energy, the energy consumption was calculated using the formula:

$$Energy_{thermal} = m_1 * GCV_1 + m_2 * GCV_2 + m_3 * GCV_3 + \cdots, \qquad (1)$$

where m is the quantity of fuel (either in terms of mass or volume) and GCV is the gross calorific value of fuel (in terms of GJ/tonne, GJ/kL, GJ/SCM etc).

Emissions

After calculating the energy consumption from every fuel used within a unit, the associated emissions were calculated using the respective fuel emission factor, as follows:

$$Emissions = E_1 * x_1 + E_2 * x_2 + E_3 * x_3 + \cdots$$

where E is the total energy consumption for a given fuel, x is the fuel emission factor (in terms of tonnes CO_2/GJ), and fuel emission factors for a fuel are considered a constant value. For electricity, a ‘grid emission factor’ was obtained for the particular region, given the different sources used to produce electricity.

SEC and emission intensity

SEC and emission intensity of a unit is a measure of the energy consumption and emissions, respectively, involved in producing 1 kg of manufactured product.

$$SEC = \frac{Total\ energy\ consumption\ of\ unit}{Total\ production\ of\ unit\ (in\ kg)}$$

$$Emission\ intensity = \frac{Total\ emissions\ of\ unit}{Total\ production\ of\ unit\ (in\ kg)}$$

2.5.2 Financial analysis

After completion of the technical analysis for all four scenarios, the financial viability of the decarbonisation measures in each cluster across all scenarios was assessed. This analysis focused on two components—first, the energy or fuel cost for each equipment, and second, the investment required for each decarbonisation measure, as shown in Figure 6. Both these components entailed various aspects, as given below:

a) Energy costs
  - Fuel rate per unit (cluster specific)
  - Electricity tariff (location specific)
  - Provision of any subsidies by the government

b) Investment
  - Total capital required
  - Payback period
  - Net present value (NPV) of investment
  - IRR
  - Return on investment (ROI)

To evaluate the economic benefits, the total fuel and electricity cost savings were calculated across all scenarios, and the percentage reduction against the BAU scenario was determined for each of the decarbonisation measures.

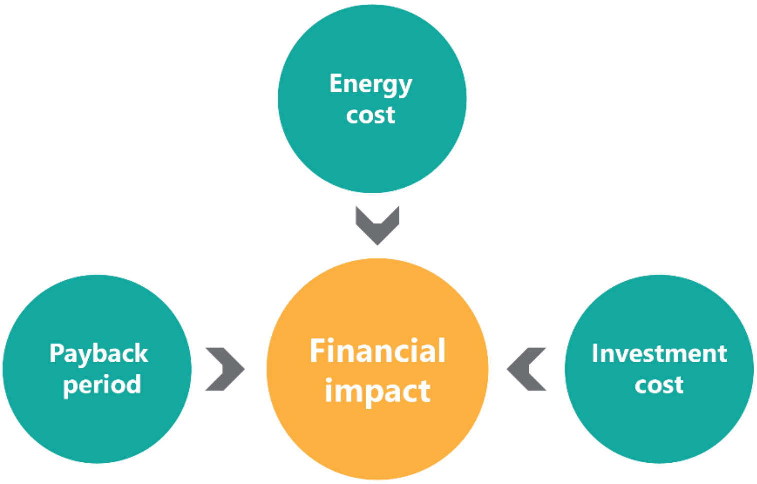


Figure 6. Components of financial analysis

To determine the financial viability of a suggested decarbonisation technology, a cash flow analysis was performed to calculate the total savings expected in the lifetime of the solution. This involved computing the payback period, NPV of investment, IRR, and ROI. To calculate the above parameters, the following assumptions were considered:

- Payback period categorised into
  - Short term (<1 year)
  - Medium term (1–2 years)
  - Long term (>2 years)
- Discount rate at 9.6%

Finally, a sensitivity analysis was performed to determine the economic viability of the decarbonisation measures under variations in fuel costs and discount rates. Considering the feasibility of the technology from both technical and financial perspectives, the scope for implementation of such measures was assessed and tabulated in the form of a feasibility matrix. In the absence of necessary financial support for incorporating these measures, viable financial mechanisms have been suggested in this paper. The formulae used for financial calculations in each cluster are described below.

Energy savings

On implementation of decarbonisation measures to improve the EE of a certain equipment and/or process, the resultant energy savings were calculated as follows:

$$Energy\ savings = Energy\ consumption_{BAU} \times (1 - \frac{\eta_{old}}{\eta_{new}}),$$

where Energy consumption$_{BAU}$ is the current energy consumption of the unit/process and η_{old} and η_{new} are the old and new efficiencies, respectively.

Discount rate

Discount rate calculations were performed using the Fischer formula, which is based on the relationship between inflation rates and real interest rates (*Real Discount Rate*, n.d.) .

$$i = \frac{i'-f}{1+f},$$

where i is the real discount rate, i' is the nominal discount rate, and f is the inflation rate.

The real discount rate was taken as 5.15% (International Monetary Fund, 2023), while the inflation rate was taken as 4.25% (Forbes India, 2023).

Using the above formula, the nominal discount rate was calculated to be 9.61%.

O&M costs

For calculating the annual O&M costs of the equipment for the financial analysis, the O&M costs were assumed to be a fixed percentage of the capital cost of the equipment. This method has previously been used for estimation of RE systems in the literature. In a 2016 regulations document released by the Central Electricity Regulatory Commission (2016), 0.5% of the capital cost was considered as the O&M cost for solar PV systems.

NPV

To estimate the financial viability of an investment made for a decarbonisation measure, the time value of money needs to be considered, given the nature of the benefits observed over a course of years.

The NPV method factors this by equating the current value of all yearly cash flows, including information on all expenditures (capital, operation, and maintenance costs) and income (in terms of fuel cost savings), lifetime of equipment, and discount rate.

$$NPV = -\,CAPEX\ - \sum_{i=1}^{i=N} \frac{O\&M}{(1+r)^i} + \sum_{i=1}^{i=N} \frac{Savings}{(1+r)^i}\,,$$

where CAPEX is the initial capital cost, O&M is the operation and maintenance costs, savings indicate fuel cost savings due to the decarbonisation measure, N is the time period, and r is the discount rate.

The cash flow was calculated year-wise, and based on the initial capital expenditure (CAPEX), the payback period was determined.

The feasibility of each decarbonisation technology was calculated, and few examples are shown in Appendix B.

2.6 Stakeholder engagement

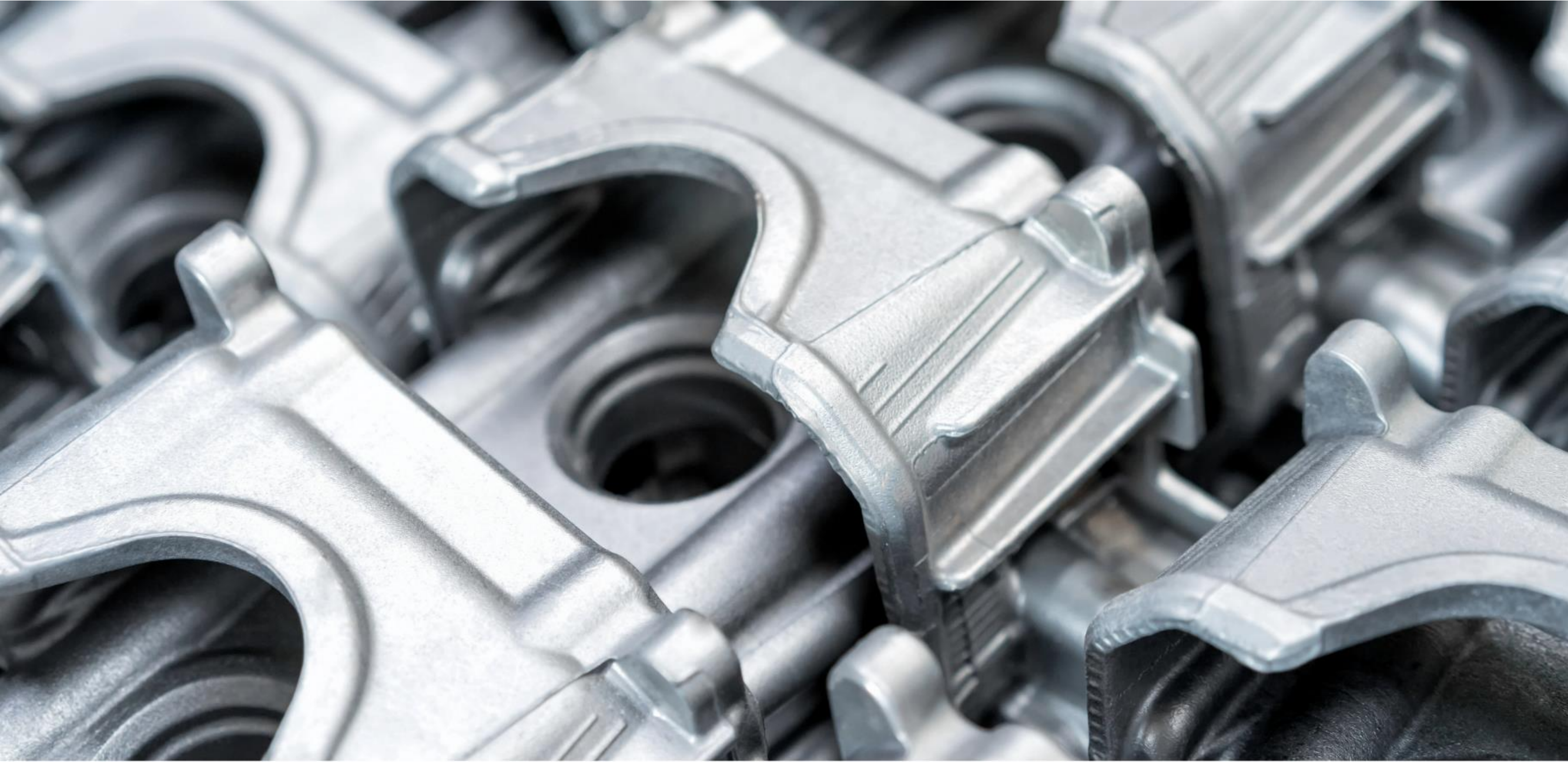
Stakeholder engagements were an integral part of this study. For various analyses including identification of clusters and decarbonisation technologies, the research team engaged with unit owners, cluster associations, industrial experts, BEE officials, MSME Development Organisations, respective state departments for small industries, DICs, and DISCOMs. This ensured accuracy in our assessments and a greater buy-in by the entities involved. The study also involved interactions with financial institutions to analyse the possibility of providing suitable fiscal incentives and schemes to enable unit owners to adopt decarbonisation technologies.

The information acquired from various stakeholders provided valuable data to analyse the potential for switching from conventional carbon-intensive technologies to alternative solutions. The study also offered an opportunity to assess and analyse the post-pandemic challenges faced by unit owners. The unit-level reports contained various details and parameters concerning the current energy status, possible deep decarbonisation interventions, technical and financial feasibility, and benefits involved in each of the identified clusters. The results of the study can help refine the existing policy framework and introduce amendments to decarbonise the MSME sector, which can contribute to attaining the SDGs and nationally determined contributions of the country.

2.7 Documentation

The findings of this study have been documented through unit-level reports, cluster-level reports, and a detailed final report. In total, 66 unit-level reports were generated, each of which contain unit-specific information on the MSME production unit, product mix, facilities, process description, energy consumption (fuel-wise), average production, GHG emission levels, overall SEC, equipment-wise efficiencies, and recommendations for viable decarbonisation measures. These reports have been submitted to unit owners to maintain confidentiality. The cluster-level reports are cumulative in nature and provide deeper insights into the clusters. These reports provide detailed information on the energy and emission profiles (fuel- and equipment-wise), reasons for high SEC, EE recommendations, insights from techno-economic analyses, and feasibility of relevant decarbonisation measures including investment costs and payback periods.

The final report is a comprehensive documentation of the findings of the study, current data gaps, and recommendations for further research. The report elaborates various parameters including the current energy status, possible deep decarbonisation interventions, technical and financial feasibility and benefits, and policy insights for each of the identified clusters.



3 Results

3.1 Aluminium die-casting

Aluminium die-casting is an important sector in the manufacturing industry. Aluminium castings are a critical component in industries such as automobiles, aerospace, and railways. Various products including brackets, seals, process control parts, sub-assemblies, electrical and medical components, machinery spare parts, and other specialised parts are manufactured in Delhi-National Capital Region (NCR) and Bengaluru. Both clusters have over 30–40 MSME units, of which 10 units were selected from each location.

In these units, aluminium is melted at high temperatures and the molten metal is injected into a die (or mould) under high pressure. Once the metal solidifies, it is removed for further finishing processes. These casting techniques are required to manufacture high-quality and precise products. The detailed process is shown in Figure 7.

The major energy- and emission-intensive equipment in these units are described below:

Furnace (melting and holding): A furnace is the largest energy-consuming component in the die-casting process. In this study, the MSME units were categorised based on the type of furnace used—electric (resistance type) or thermal (powered by piped natural gas [PNG]). Thermal furnaces have a recorded SEC of 4.5–23.76 GJ/tonne, whereas electrical furnaces have a recorded SEC of 1.62–6.54 GJ/tonne.

Pressure die-casting (PDC) machine: PDC machines consume a large quantum of electricity. This is because of the high pressure (more than 30 MPa) required to produce high-precision and intricate castings. The die-casting units include both fully and semi-automatic horizontal cold chamber machines. The recorded SEC for the PDC machines was in the range of 2.2–16 GJ/tonne.

Air compressor: Air compressors are power guzzlers in most aluminium die-casting units. Compressed air is a reliable means of running a variety of pneumatic actuators, ejection processes, and other tools in machining. Ideally, 0.16–0.18 kW of energy is required for every cubic feet per minute (CFM) of compressed air, given the pressure requirements of the sector. The recorded SEC for the air compressors was in the range of 0.16–0.2 kW/CFM.

Cooling towers: Cooling water systems are essential for furnaces, compressors, and PDC machines. Heat is rejected from the equipment using cooling towers, which includes components such as pumps and fans.

Tool room machinery: Various finishing processes along with other operations employing several machines (such as computer numerical control and lathe) are required after the casts are prepared. Some of these processes are run by air compressors and motors with (often) intermittent requirement of electricity.

Diesel generator (DG) sets: A DG set is primarily used for backup power in case of an outage. It consumes a large amount of high-speed diesel (HSD), operating with typical efficiencies of 25%–45% depending on the age of the equipment.

The decrease in energy consumption and emissions due to the implementation of decarbonisation technologies was modelled equipment-wise, highlighting the areas of maximum decarbonisation potential for the sector. The cluster-wise observations have been described below.

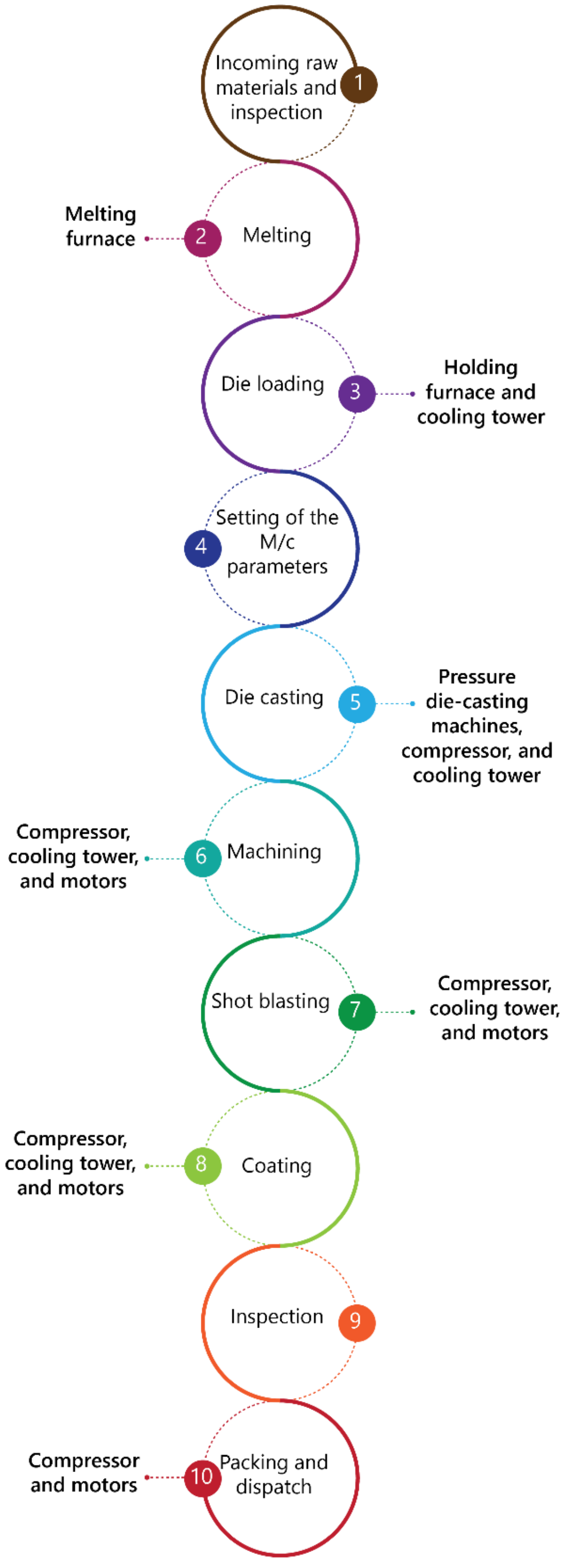


Figure 7: Process flow of aluminium die-casting

3.1.1. Cluster-wise observations: Delhi-NCR and Bengaluru

3.1.1.1. Delhi-NCR

The fuel usage was recorded, and based on the energy content and emission factors, the total energy consumption and emissions under the BAU scenario were calculated (Figure 8).

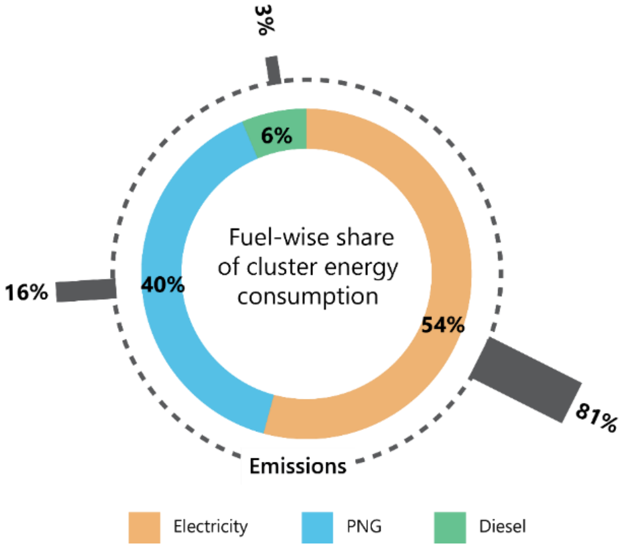


Figure 8: Energy consumption and emission profile for Delhi-NCR cluster

The energy consumption and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 9.

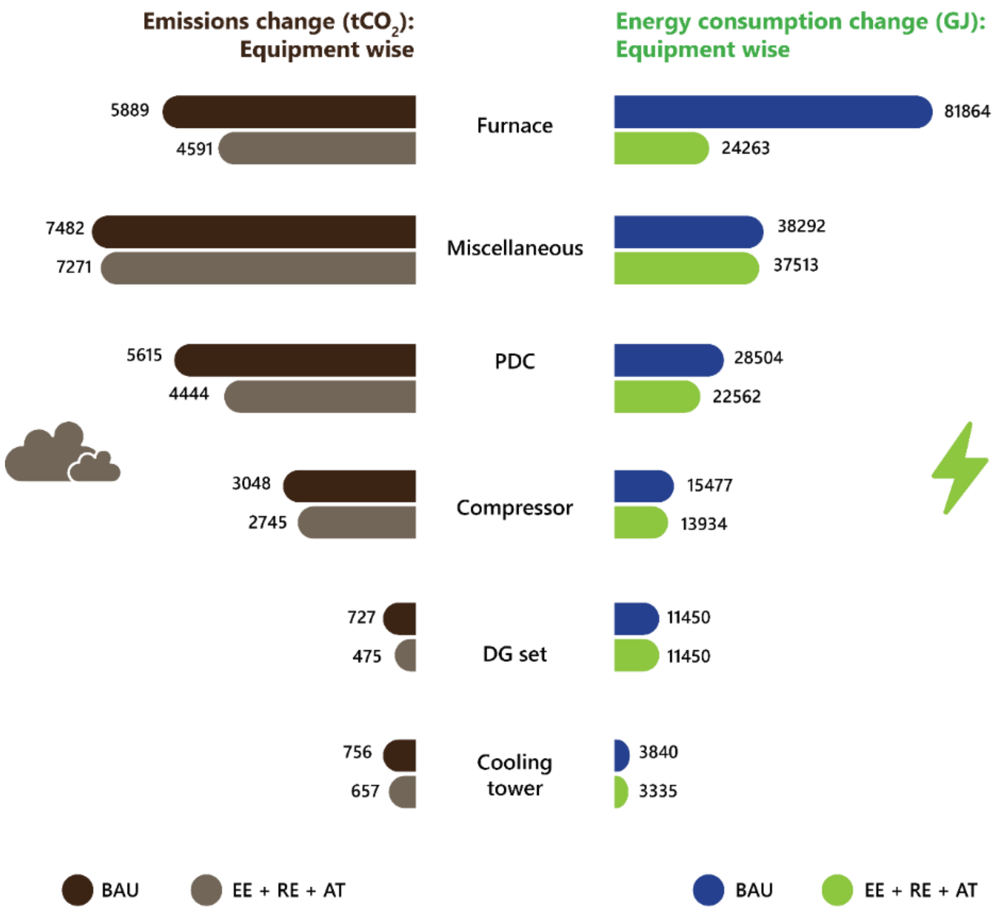


Figure 9: Equipment-wise differences in energy consumption and emissions in Delhi-NCR

The modelling was performed according to the location while measuring the overall impacts of implementing the decarbonisation technologies across technical and economic parameters (Table 4).

Table 4. Total impact of decarbonisation measures in Delhi-NCR

Parameters	Observations
Percentage of energy savings	36%
Annual emissions savings (tCO_2/year)	3,123
Energy cost savings (INR crore)	11
Investment cost required (INR crore)	9

Further, two other parameters, SEC and emission intensity, were calculated. These parameters normalise the energy consumption and emissions against the unit's annual production numbers and highlight the energy required and emissions produced while manufacturing a standard measured amount of the product. For units that provided production data, the SEC and emission intensity under all four scenarios were compared. The differences in SEC and emission intensity for a representative unit in Delhi-NCR are plotted in Figure 10.

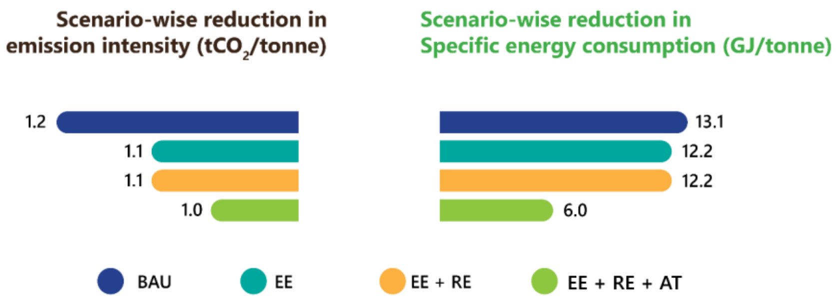


Figure 10: Differences in the specific energy consumption (SEC) and emission intensity of a representative unit in Delhi-NCR

3.1.1.2. Bengaluru

The fuel usage was recorded, and based on the energy content and emission factors, the total energy consumption and emissions under the BAU scenario were calculated (Figure 11).

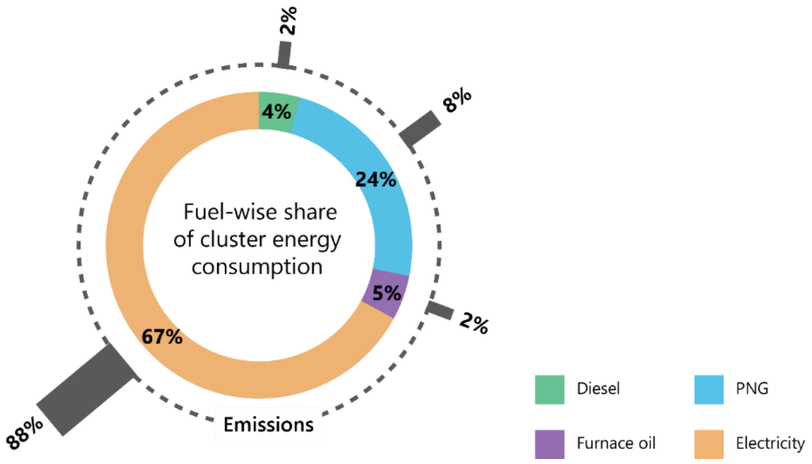


Figure 11: Energy consumption and emission profile for Bengaluru cluster

The energy consumption and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 12.

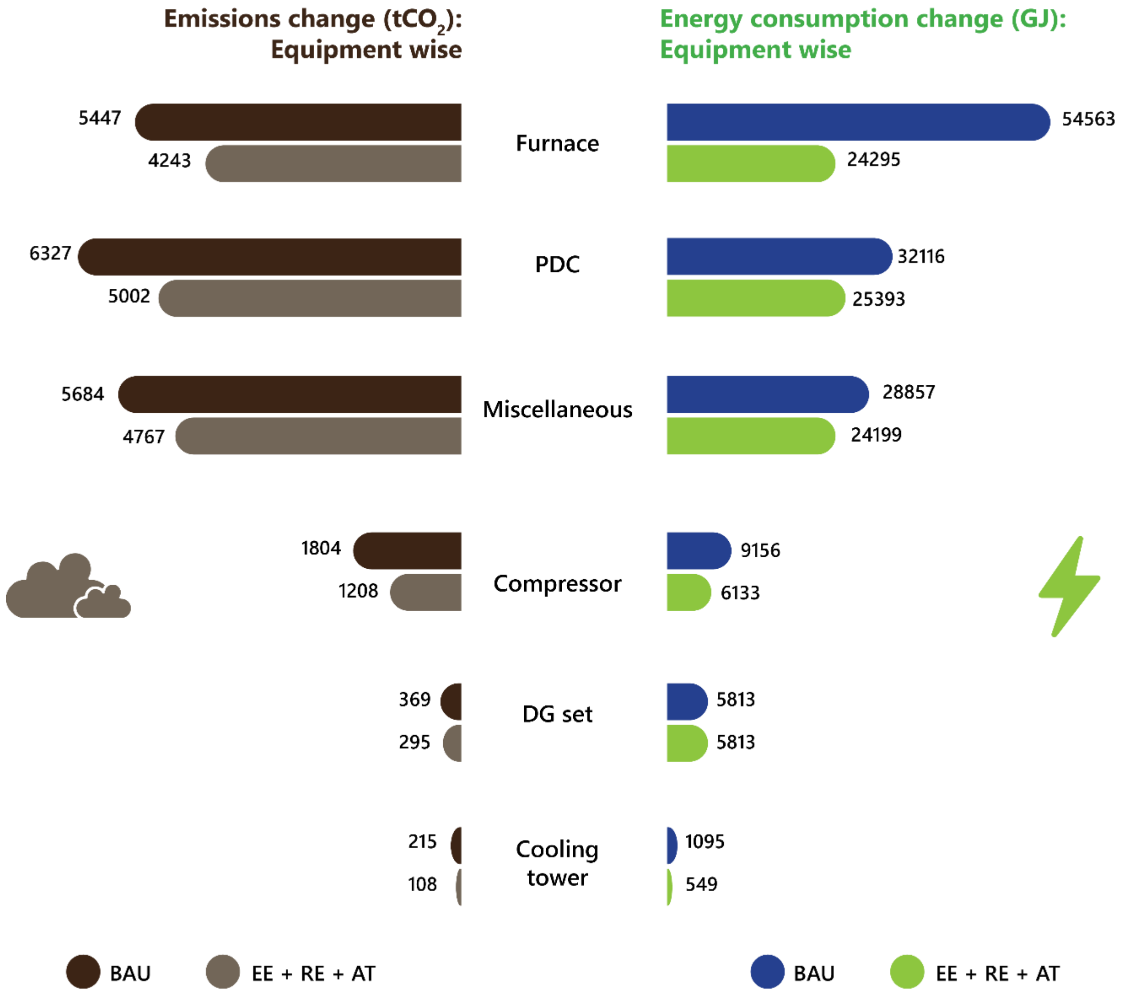


Figure 12: Equipment-wise differences in energy consumption and emissions in Bengaluru

The modelling was performed according to the location while measuring the overall impacts of implementing the decarbonisation technologies across technical and economic parameters (Table 5).

Table 5. Total impact of decarbonisation measures in Bengaluru

Parameters	Observations
Percentage of energy savings	26%
Annual emissions savings (tCO_2/year)	4,106
Energy cost savings (INR crore)	6.5
Investment cost required (INR crore)	15

Further, two other parameters, SEC and emission intensity, were calculated. These parameters normalise the energy consumption and emissions against the unit's annual production numbers and highlight the energy required and emissions produced while manufacturing a standard measured amount of the product. For units that provided production data, the SEC and emission intensity under all four scenarios were compared. The differences in SEC and emission intensity for a representative unit in Bengaluru are plotted in Figure 13.

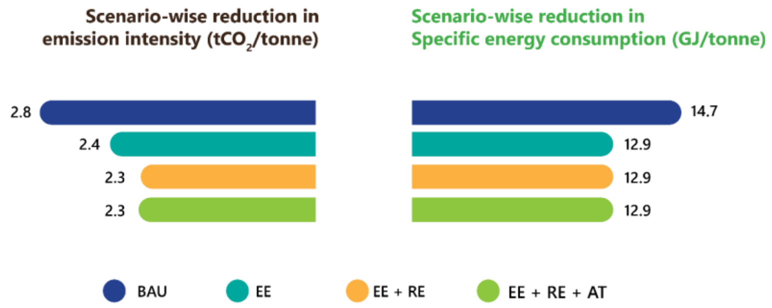


Figure 13: Differences in the specific energy consumption (SEC) and emission intensity of a representative unit in Bengaluru

3.1.2. Insights

The feasibility of these technologies was assessed based on four important parameters, namely energy consumption, emissions, investment cost, and payback period. The scope for implementing each of the identified decarbonisation technologies was tabulated in the form of a feasibility matrix, as shown in Table 6.

Table 6. Decarbonisation technologies considered for aluminium die-casting sector

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
Furnace	Conversion of gas furnace to electric furnace	High	Medium	High	<4 years
Furnace	Use of bio-CNG in gas furnaces	-	High	Low	Immediate
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from the grid	-	High	Low	Immediate
DG set	Biodiesel blending (20%) in DG set	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years
DG set	Conversion of DG set to battery	Medium	Low	High	Not feasible

DG: Diesel generator; CNG: Compressed natural gas

In the aluminium die-casting sector, changes can be made on multiple levels to reduce emissions. Some of the EE measures for reducing the energy consumption of the unit (and thereby emissions) are given below:

  - Improvement in operating power factor,
  - Reduction of contract demand (wherever suitable) and monitoring of electrical maximum demand,
  - Reduction of compressed air leakage and installation of variable frequency drives (VFDs) to avoid unloading power consumption,
  - Use of servo motor pumps for PDC machines,
  - Replacement of older motors with International Efficiency 3 (IE3)/International Efficiency 4 (IE4) motors,
  - Installation of thyristor-based temperature control for heating elements, and
  - Installation of air preheaters or waste heat recovery systems for PNG furnaces.

The use of RTPV systems and open-access RE can help reduce emissions due to electricity consumption in the unit (because of high emissions associated with traditional grid electricity). This is also beneficial for saving energy costs for the units, given the high electricity tariffs. Clean fuels (such as biodiesel and bio-CNG) were also considered, given the emission reduction potential and the simplicity of direct fuel substitution in existing equipment. In the aluminium die-casting sector, the study recommended the use of bio-CNG in existing gas-fired furnaces and biodiesel blending in existing DG sets. Advanced technologies like process electrification were also considered (i.e. conversion of gas-fired furnaces into electric furnaces), and the corresponding energy consumption, emissions, and investment costs were calculated. However, conversion of DG sets into battery electric storage systems (for backup power) was not considered owing to the high space requirements and economic unfeasibility.

Some of the major challenges faced by the MSME units in this sector that hinder the decarbonisation of their manufacturing processes are described in Table 7.

Table 7. Challenges to decarbonisation faced by MSMEs in aluminium die-casting sector

Nature of challenge	Description
Technical	• Inefficient combustion performance of gas-based systems • Use of thermal energy-based furnaces instead of electricity-based furnaces • Improper insulation, fuel combustion, and cooling of dies in furnaces • Higher material rejection rates (up to 28%) • Under-loading or partial loading of equipment • Intermittent operations of the plants leading to cold starts • Higher unloading time (and corresponding energy consumption) in conventional air compressors • Use of conventional hydraulic equipment and contact-based heaters in pressure die-casting machines
Financial	• Lack of low-cost, collateral-free financing for energy-efficient equipment and RE systems • High electricity tariffs for MSMEs

	• Uncertainties in policy landscape affecting fuel and equipment costs
Organisational	• Deficiencies in monitoring of fuel and energy usage • Lack of focus on improving energy efficiency in the unit, with expenditure focussed on increasing production • Lack of skilled manpower for operating latest machinery

Moreover, location-specific differences observed between the Bengaluru and Delhi-NCR clusters must be factored. Owing to local availability, units in Delhi typically had higher consumption of natural gas than those in Bengaluru. However, although several units in Delhi-NCR displayed an interest in shifting to electric furnaces due to higher prices of PNG than electricity, is not there are many hurdles related to the costs and required downtime, along with other challenges associated with a complete change of equipment. In Bengaluru, the opposite phenomenon was observed. Most units operated with an electric furnace due to unavailability of PNG, However with rising electricity tariffs, some units expressed a desire to switch to gas-based furnaces.

Given the higher efficiencies of electric furnaces and the ability to be coupled with RE sources, electrification of furnaces would be a step forward in decarbonising the sector. Ensuring that units already operating electric furnaces are not dissuaded to move back to fossil fuels is a top priority. However, cognizance must be taken regarding units with gas-powered furnaces that are unable to immediately change their equipment and focus on fuel switching (replacing natural gas with bio-CNG) as a means to decarbonise.

EE: There is considerable scope for reduction of fossil fuel consumption by implementing EE measures across the units. However, the barriers highlighted in the table above remain. Enabling measures are required to promote the implementation of these technologies in the following ways:

- For Bengaluru, a thermal energy savings target should be included in Karnataka’s Energy Conservation and Energy Efficiency Policy 2022–27.
- Sector-specific targets are warranted for MSMEs with strategy framework to achieve it, through
    - increasing on-site demonstrations and pilot programmes to boost awareness and confidence in technologies, and
    - mandating energy audits or making energy audits conditional to subsidies/incentives
- The financing ecosystem for EE equipment should be improved. Even with the existing schemes (such as SIDBI 4E scheme), due to a variety of reasons (including eligibility criteria, higher interest rates, collateral requirements, and low awareness), their uptake by the MSME sector remains poor. It is imperative for state and central governments to develop dedicated schemes to subsidise EE equipment for increasing their uptake.
- While assurances to banks are being provided by the government (in the form of risk sharing and credit guarantee funds), greater capacity building is required to value and disburse loans for the sector.

RE: In both clusters, electricity generation accounted for more than 80% of the associated emissions. This is largely because of the high grid emissions associated with electricity generation. The use of RE sources such as solar and wind is key to decoupling electricity generation process and its associated emissions. Solutions such as on-site RTPV systems are constrained by challenges like current energy policies and rooftop availability. This can be improved through the following measures:

- Allowing consumers to have gross metering above the sanctioned load,
- Use of RE open access/virtual net metering, and
- Aggregating the demand of MSME units for open-access/common RE systems.

Advanced technologies: The furnace used for melting and holding aluminium had the largest share of energy consumption in the units. Several units in the sector still utilise natural gas and other fossil fuels (furnace oil, HSD, etc) to operate the furnace. However, given the technological maturity of electric resistance furnaces and their proven suitability in the sector, a widespread adoption is feasible. To continue along the path of electrification,

- Industrial tariffs should be rationalised and RE generation should be increased to ensure cost-competitiveness of electricity as a fuel.
- Subsidies, tax rebates, and other forms of viability gap funding should be made available for electric furnace equipment.
- Regulatory incentives from pollution control boards, such as reduction in fees and increase in time period of consent certificates, should be provided.

The use of bioenergy is also an extremely important measure because it directly substitutes fossil fuel consumption for equipment without the associated emissions. To aid decarbonisation of manufacturing in MSMEs, the supply chain of biodiesel and bio-CNG can be strengthened by assisting the sale of bio-CNG (through the Sustainable Alternative Towards Affordable Transportation [SATAT] and GOBARdhan schemes) to industrial clusters directly, integrating bio-CNG in mature gas grids (e.g. in the Delhi-NCR region), and including biodiesel in the Pradhan Mantri JI-VAN Yojana due to high usage of HSD in industrial sectors (e.g. for DG sets).

3.2 Textile

The textiles industry is one of India’s largest manufacturing sectors. It can be broadly classified into yarn preparation, fabric preparation, and processing/finishing items. Both Ludhiana and Tiruppur are large textiles clusters in the country. The Ludhiana cluster consists of almost 15,000 MSME units that employ over 4 lakh people. The Tiruppur cluster has 3,200 units that employs 6 lakh direct workers and 2 lakh indirect workers. This cluster generates revenue worth INR 60,000 crore yearly and contributes to 1.06% of India’s exports. Products manufactured in the sector include vests, t-shirts, summer and spring knitwear, hosiery items, shawls, blankets, winter wear (mufflers, cardigans, pullovers, etc), and caps. In total, 10 units were selected in Tiruppur, whereas 12 units were selected in Ludhiana.

The production process for activities such as knitting, dyeing, compacting, and embroidery follows a similar pattern across units, with adjustments for final product quality and raw materials. Knitting involves loop formations using knitting machines, offering single-stage ornamentation. Fabric scouring is a preparatory process to remove impurities such as wax, oil, dust, and dirt. In the clusters studied, a white cloth is typically dyed with different colours in a 10–12-hour batch time. Singeing involves the controlled removal of protruding fibres from the fabric's surface, while stentering is used to set the fabric's width and shape. After dyeing, the fabric is folded, heat-set, and compacted to remove folds and enhance fabric quality. Embroidery or printing is done on a job basis based on customer requirements, with designs developed by specialists and programmed into computer-operated machines. Boilers and thermic fluid heaters are used to provide steam and heat required for different processes. The process map shown in Figure 14 is representative, indicating the presence of heterogeneous textile manufacturing procedures or sub-processes.

Following are the major energy- and emission-intensive equipment in these units:

Boilers: Boilers are the primary source of steam, an important prerequisite in manufacturing processes such as dyeing. Most boilers are fired using solid fuels, such as coal, pet coke, and biofuels including tamarind wood, woodchips, and rice husk. In some units, furnace oil is also used. The various fuels used in boilers and their efficiency ranges are depicted in Table 8.

Table 8. Boiler fuels and efficiency range

Fuel	Recorded efficiency (%)
Coal	25%–52%
Pet coke	80%–85%
Furnace oil	75%
Biofuels (tamarind wood)	14%–78%
Biofuels (rice husk and woodchips)	75%–85%

Thermic fluid heater: Thermic fluid heaters are required to meet the heating requirements for several processes, such as drying, printing, and stentering, in manufacturing units but without the use of steam. The fuels used in thermic fluid heaters include coal, pet coke, and wood; their efficiency ranges are depicted in Table 9.

Table 9. Thermic fluid heater fuels and efficiency range

Fuel	Recorded efficiency (%)
Coal	45%
Pet coke	80%–85%
Wood	50%–70%

Compressors: Air compressors are another energy-intensive component, which is primarily used in stenters to hold the fabric. Compressed air is a reliable means of running a variety of pneumatic actuators, ejection processes, and other tools in machining. Ideally, 0.16–0.18 kW of energy is required for every CFM of compressed air, given the pressure requirements of the sector. The recorded SEC for the air compressors was in the range of 0.145–1.95 kW/CFM.

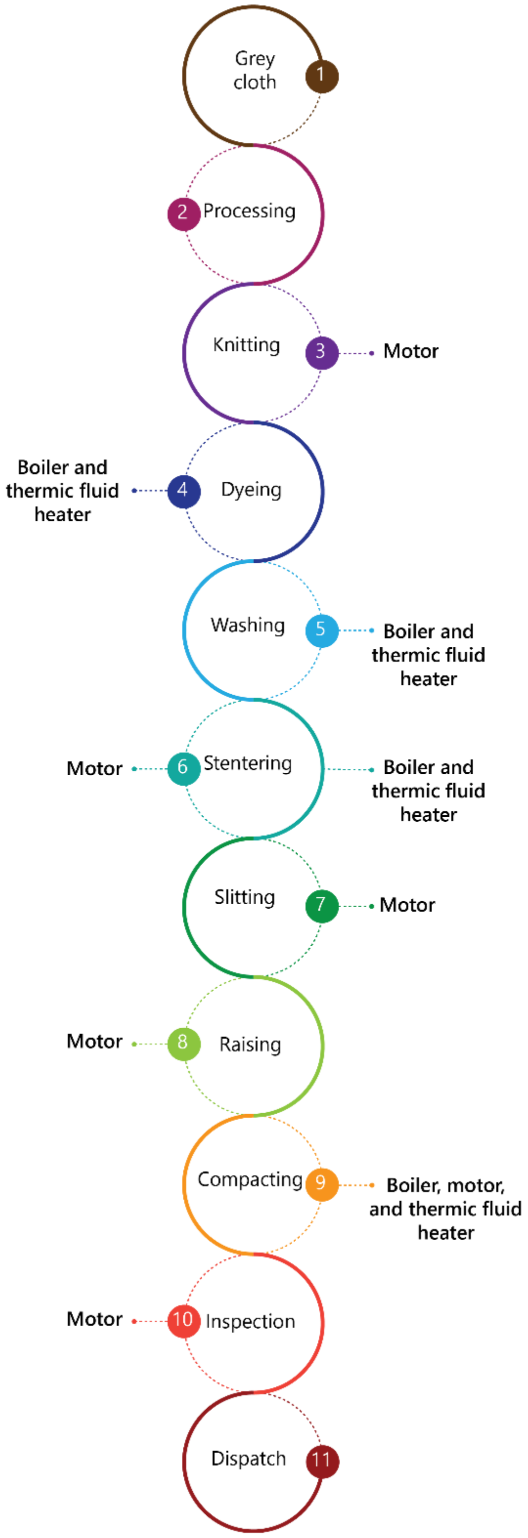


Figure 14: Process flow of textile manufacturing

Process equipment: Various equipment in textile units used for processes such as knitting, dyeing, compacting, stentering, finishing, and drying require electricity to run their motors and pumps.

DG sets: A DG set is primarily used as backup power in case of an outage. It consumes a large amount of HSD in units, operating with typical efficiencies of 25%–45% depending on the age of the equipment.

The decrease in energy consumption and emissions due to the implementation of decarbonisation technologies was modelled equipment-wise, highlighting the areas of maximum decarbonisation potential for the sector. The cluster-wise observations have been described below.

3.2.1. Cluster-wise observations: Ludhiana and Tiruppur

3.2.1.1. Ludhiana

The fuel usage was recorded, and based on the energy content and emission factors, the total energy consumption and emissions under the BAU scenario were calculated (Figure 15).

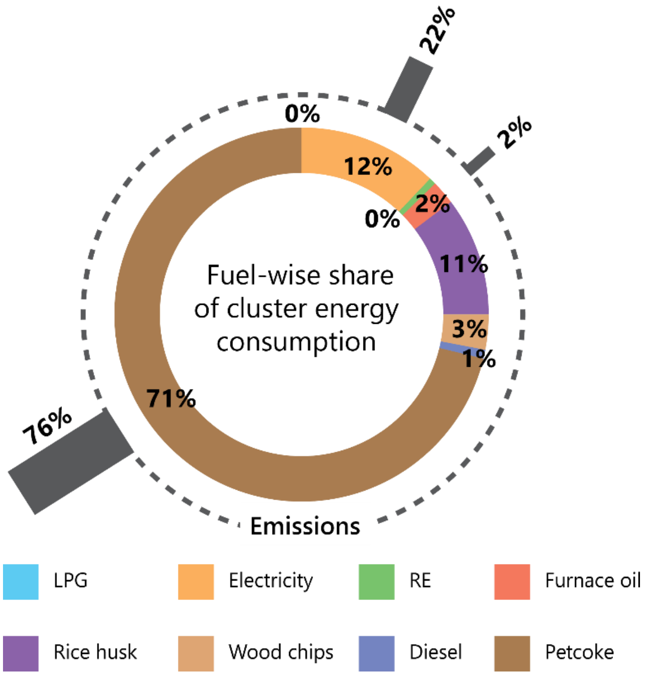


Figure 15: Energy consumption and emission profile for Ludhiana cluster

The energy and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 16.

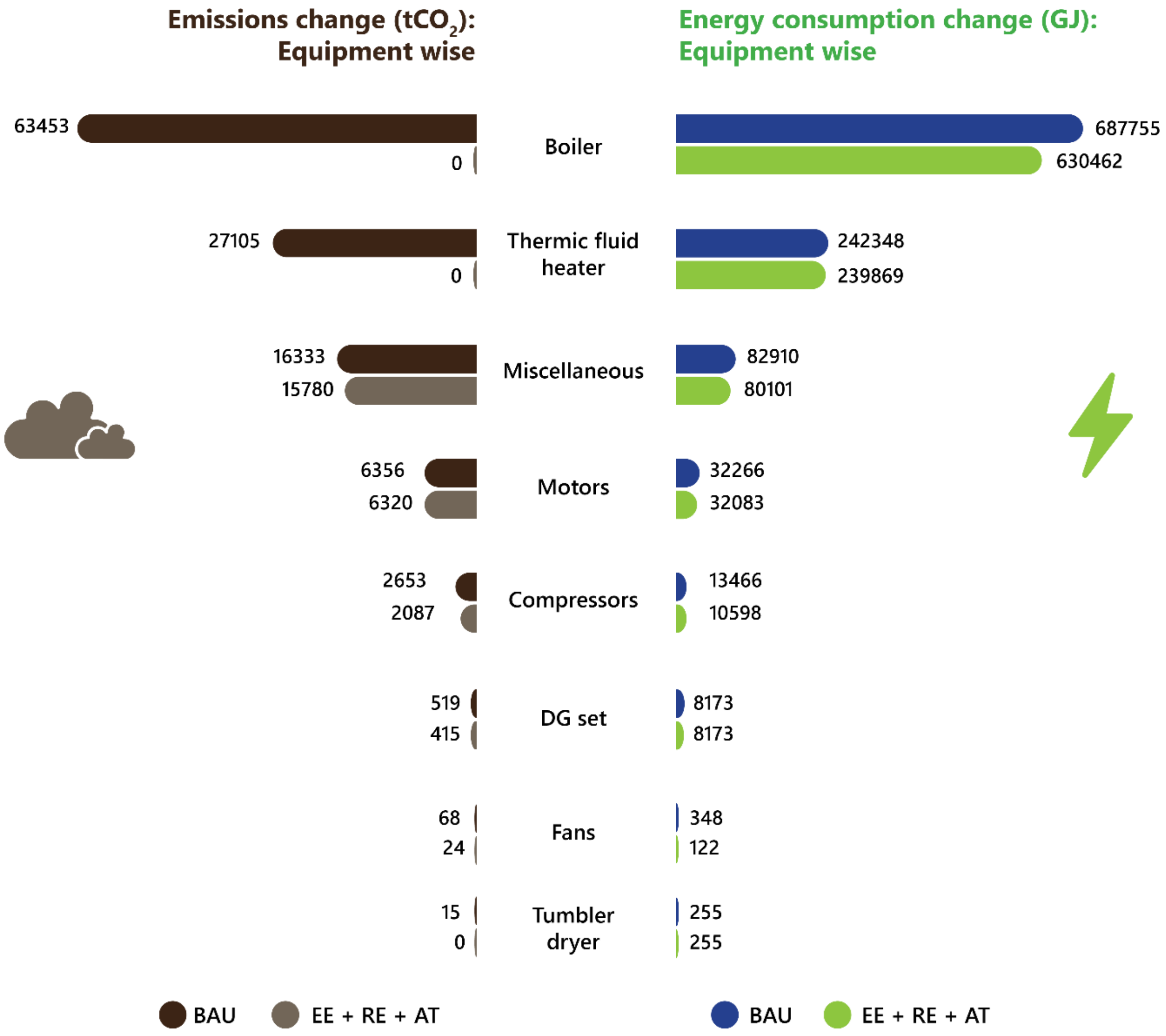


Figure 16: Equipment-wise differences in energy consumption and emissions in Ludhiana

The modelling was performed according to the location while measuring the overall impacts of implementing the decarbonisation technologies across technical and economic parameters (Table 10).

Table 10. Total impact of decarbonisation measures in Ludhiana

Parameters	Observations
Percentage of energy savings	6%
Annual emissions savings (tCO_2/year)	91,876
Energy cost savings (INR crore)	14
Investment cost required (INR crore)	7.1

Further, two other parameters, SEC and emission intensity, were calculated. These parameters normalise the energy consumption and emissions against the unit's annual production numbers and highlight the energy required and emissions produced while manufacturing a standard measured amount of the product. For units that provided production data, the SEC and emission intensity under all four scenarios were compared. The differences in the SEC and emissions intensity for a representative unit in Ludhiana are shown in Figure 17.

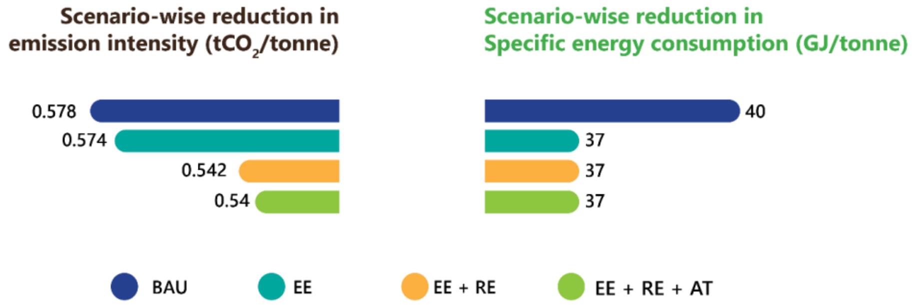


Figure 17: Difference in the specific energy consumption (SEC) and emission intensity of a representative unit in Ludhiana

3.2.1.2. Tiruppur

The fuel usage was recorded, and based on the energy content and emission factors, the total energy consumption and emissions under the BAU scenario were calculated (Figure 18).

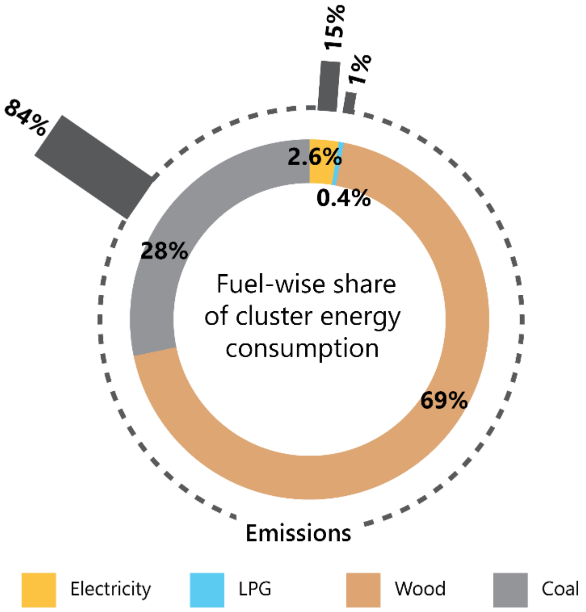


Figure 18: Energy consumption and emission profile for Tiruppur cluster

The energy and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in the energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 19.

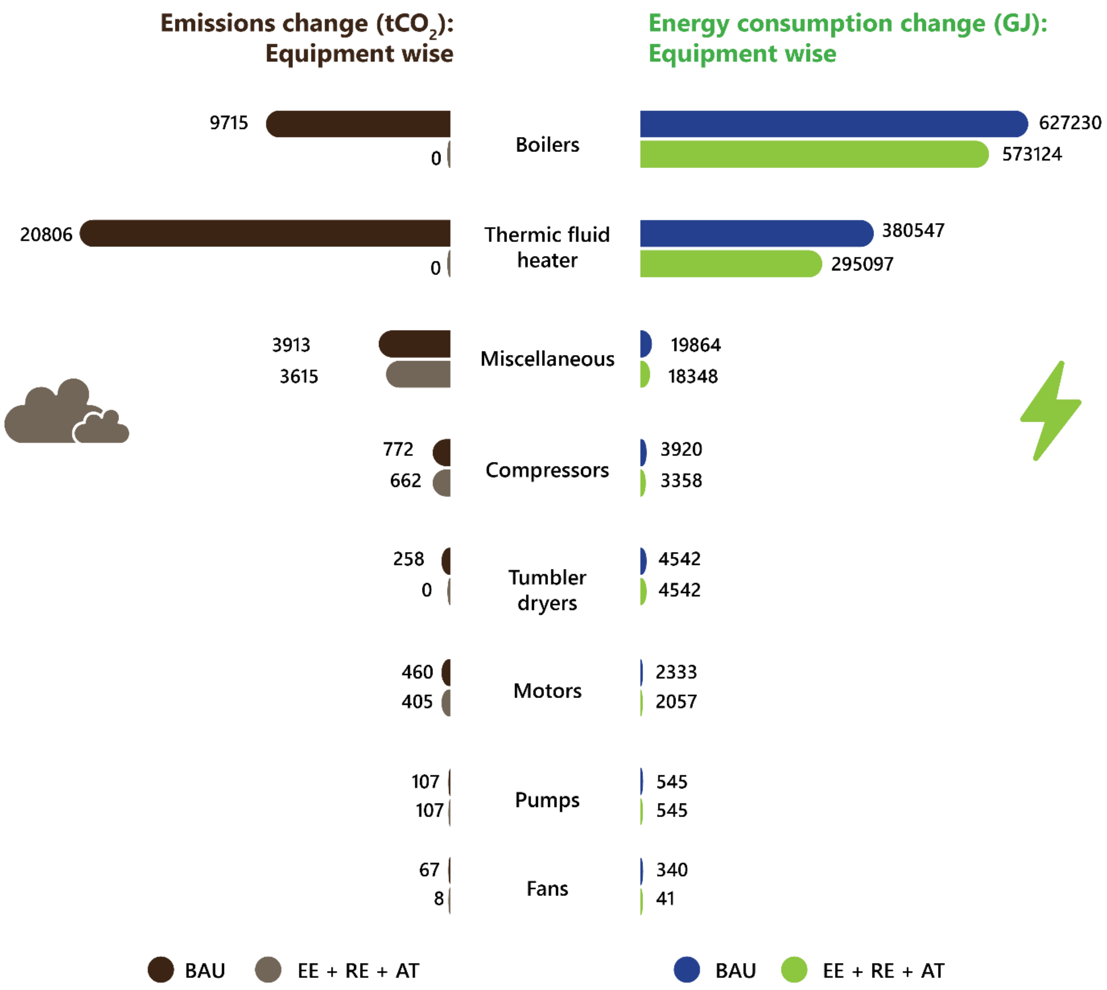


Figure 19: Equipment-wise differences in energy consumption and emissions in Tiruppur

The modelling was performed according to the location, while measuring the overall impacts of implementing the decarbonisation technologies across technical and economic parameters (Table 11).

Table 11. Total impact of decarbonisation measures in Tiruppur

Parameters	Observations
Percentage of energy savings	13.5%
Annual emissions savings (tCO_2/year)	31,302
Energy cost savings (INR crore)	7.7
Investment cost required (INR crore)	1.3

Further, two other parameters, SEC and emission intensity, were calculated. These parameters normalise the energy consumption and emissions against the unit's annual production numbers and highlight the energy required and emissions produced while manufacturing a standard measured amount of the product. For units that provided production data, the SEC and emission intensity under all four scenarios were compared. The differences in the SEC and emissions intensity for a representative unit in Tiruppur are shown in Figure 20.

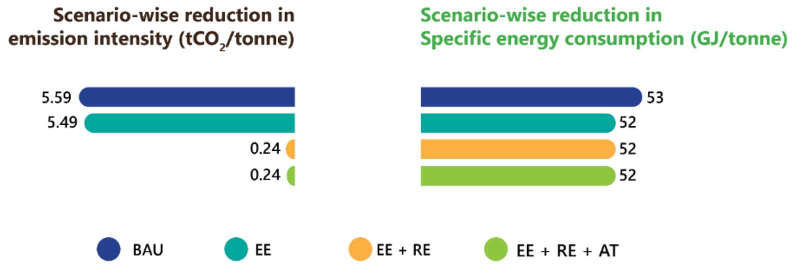


Figure 20: Difference in the specific energy consumption (SEC) and emission intensity of a representative unit in Tiruppur

3.2.2. Insights

The decarbonisation technologies identified for the textile sector cater to its energy- and carbon-intensive equipment. The feasibility of these technologies was assessed based on four important parameters, namely energy consumption, emissions, investment cost, and payback period. The scope for implementing each of the identified decarbonisation technologies was tabulated in the form of a feasibility matrix, as shown in Table 12.

Table 12. Renewable energy and advanced technologies considered for textile sector

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from the grid	-	High	Low	Immediate
DG set	Biodiesel blending (20%) in DG set	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years
DG set	Conversion of DG set to battery	Medium	None	High	Not feasible
TFH	Pet coke TFH to electricity	Low	None	High	Not feasible
TFH	Pet coke TFH to biomass briquettes	None	High	Low	0.2–4 years*
Boiler	Coal boiler to electric	Low	None	High	Not feasible
Boiler	Coal boiler to biogas	Low	High	High	Not feasible
Boiler	Coal boiler to green hydrogen	Low	High	High	Not feasible
Boiler	Pet coke boiler to biomass briquettes	None	High	Low	<4 years*
Boiler	Back pressure turbine for energy recovery	Low	Low	Medium	1–3 years
Tumbler dryer	LPG to bio-CNG	None	High	Low	Immediate

CNG: Compressed natural gas; DG: Diesel generator; LPG: Liquefied petroleum gas; TFH: Thermic fluid heater

**Depending on pet coke prices*

In the textile sector, changes can be made on multiple levels to reduce emissions. Some of the EE measures for reducing the energy consumption of the unit (and thereby emissions) are given below:

- Improvement in operating power factor (short term)
- Optimisation of air-to-fuel ratio for boilers and thermic fluid heaters (short term)
- Reduction of compressor air leakage (short term)
- Compressor pressure optimisation (short term)
- Insulation of hot water and condensate lines (short term)
- Insulation of boiler surfaces, steam pipes, and condensate recovery pipes (short term)
- Reduction of compressor inlet air temperature (short term)
- Increase in air temperature in the preheater (medium term)
- Replacement of V-belt drives in motors with synchronous belt drives (medium term)
- Installation of energy-efficient screw compressors (medium term)
- Installation of VFD to avoid power consumption during compressor unloading (medium term)
- Flash steam recovery to preheat boiler feed water (medium term)
- Installation of brushless direct current (BLDC) fans (long term)

The use of RTPV systems and open-access RE can help reduce emissions due to electricity consumption in the unit (due to the high emissions associated with traditional grid electricity). This is also beneficial for saving energy costs for the units, given the high electricity tariffs.

Clean fuels (such as biodiesel, biomass briquettes, and bio-CNG) were also considered, given the emission reduction potential and simplicity of direct fuel substitution in existing equipment. In the textile sector, boilers and thermic fluid heaters, which were typically running on solid fuels (like coal and pet coke), have been converted into biomass briquettes. Tumbler dryers, which were fuelled by liquefied petroleum gas (LPG), have been switched to bio-CNG. Biodiesel was blended into diesel for consumption in DG sets (backup power). Both clusters take advantage of local biomass availability, with units in Ludhiana using rice husk from agricultural producers in the state and those in Tiruppur using local wood. In Tiruppur, almost 70% of the energy requirement is met through biomass.

Process electrification was considered for thermal equipment like boilers and thermic fluid heaters. However, it was not included in the modelling because of the following reasons:

- Higher electricity tariff leading to unviable economic case (economic analysis for several units showed that **cost of electricity of less than INR 2.5–3/kWh was required** to ensure fuel cost parity with conventional boilers and thermic fluid heaters)
- Less-than-required capacity of electric-based boilers and thermic fluid heaters

- Availability of promising bio-based energy ecosystems at both locations, with abundance of resource and technology service providers.

Some of the challenges faced by the MSME units in this sector preventing them from decarbonising their manufacturing processes are mentioned in Table 13.

Table 13. Challenges to decarbonisation faced by MSMEs in the textile sector

Nature of challenge	Description
Technical	• Lack of insulation in most process heating equipment (generation and distribution) • Insufficient monitoring of air–fuel ratio, fuel feeding, and pressure in process heating equipment • Lack of flue gas heat recovery systems • Use of V-belt drives in motors • Air compressor leakage and the use of compressed air in space cleaning • Use of conventional compressors with high unloading time and excessive pressure • Inefficient motors and pumps
Financial	• Lack of low-cost, collateral-free financing for energy-efficient equipment and RE systems • High electricity tariffs for MSMEs • Uncertainties in policy landscape affecting fuel and equipment costs
Organisational	• Rented machinery in small units resulting in oversized utilities (e.g. boilers) • Deficiencies in monitoring of fuel and energy usage • Lack of skilled manpower for operating latest machinery • Low focus on implementing energy efficiency in the units, with expenditure focus on increasing production

The two clusters have similar processes and fuel consumption patterns and face similar challenges to decarbonisation. However, it is important to highlight that in Tiruppur, almost 70% of the energy requirement is already being met through biomass, whereas in Ludhiana, only ~15% of the energy requirement is being met through biomass. Thus, there is a greater scope for decarbonisation in the Ludhiana cluster than in the Tiruppur cluster, and using the available biomass to meet industrial requirements can have the added benefit of reducing air pollution in the state.

Energy efficiency (EE): There is a limited scope for EE measures in both clusters (10%–15% reduction in energy consumption and emissions through implementation of EE measures). However, improvements in the form of insulation and equipment replacement (such as motors and compressors) are still possible. Further advancements through EE measures can be facilitated through utilisation of available funds under the Amended Technology Upgradation Fund Scheme for EE equipment in the textile sector and via state government support through the upcoming Raising and Accelerating MSME Performance (RAMP) scheme, one of the main objectives of which is to promote greening of MSME sectors.

Renewable Energy (RE): About 15%–22% of emissions are attributed to electricity generation in both clusters. This is largely due to the high grid emission factor associated with generating electricity. Solutions to decarbonise like RTPV systems are constrained by challenges such as current energy policies and rooftop availability. This can be improved through the following measures:

- Use of RE-specific financing schemes (e.g. MNRE grid-connected rooftop solar scheme)
- Use of open-access RE and aggregating demand from multiple MSME units
- Allowing RTPV installation above the sanctioned load in the gross metering regime
- Provision of a power evacuation infrastructure by DISCOMs for RE systems

Clean fuels: The use of bioenergy is also an extremely important measure, as it directly substitutes fossil fuel consumption for equipment without the associated emissions. For boilers and thermic fluid heaters, the switch to biomass briquettes has a high potential for decarbonisation as well as reduction in fuel costs.

Strengthening the supply chain of biomass briquettes, biodiesel, and bio-CNG to MSMEs can help decarbonise the manufacturing process. However, policy gaps in the sector remain despite the potential benefits. Although the Punjab Industrial Policy 2022 highlights the use of bio-CNG in industries, other bio-based fuels need to be considered in policymaking. The following potential measures can be implemented to improve clean fuel usage:

- Use of policy instruments (e.g. mandates) to expand the use of biomass briquettes in boilers and thermic fluid heaters,
- Inclusion of biodiesel under the Pradhan Mantri JI-VAN Yojana, given the usage of HSD in industrial sectors (e.g. in DG sets),
- Provision of regulatory incentives (such as reduction in fees and increase in time period of consent certificates from pollution control boards) for industries to implement fuel switching, and
- Provision to sell bio-CNG to industrial clusters directly as part of SATAT and GOBARdhan schemes.

Systemic measures beyond equipment-level changes are also potential solutions to decarbonisation in the clusters. In the Ludhiana cluster, there is a proximity of units with similar processes and resource requirements. There are existing schemes, such as the MSME Cluster Development Programme and the Integrated Processing Development Scheme, that can be utilised to a greater extent. These schemes provide funds for centralised steam distribution, compressed air systems, and centralised RE systems, which are required in the textiles sectors. Moreover, if MSMEs are included in the upcoming voluntary carbon market scheme, they can leverage carbon finance to improve the financial viability of decarbonisation measures. With an additional source of financing (beyond fuel cost savings), the payback period for several decarbonisation measures will be reduced further, thereby making them more attractive for implementation. However, for this to happen, further clarity is needed on the regulations and framework on market design. Sensitisation and capacity building will also be required for MSMEs, given the enhanced compliance and monitoring requirements for the carbon market. Lastly, common enabling strategies for MSMEs including pilots, demonstration projects, and enforcement of energy audits are important for units in any sector.

3.3 Refractories

Refractory materials play a critical role in several thermal processes in the industrial sector because of their capability to withstand harsh environments (including high temperatures and abrasive loading), particularly in steel, cement, and glass industries.

3.3.1. Cluster-wise observations: Asansol–Chirkunda

In this study, one refractory cluster was identified in Asansol and its neighbouring town Chirkunda. There are about 206 refractory industries in the cluster, of which about 200 units use downdraft (DD) kilns. The refractory materials produced are used within the country. The primary domestic market includes large steel manufacturing industries in Asansol. Eight refractory units were studied in the neighbouring towns of Asansol and Chirkunda. The refractory units manufacture refractory blocks and bricks, graphite stopper heads, insulation bricks, refractory mortar, roof bricks, sillimanite bricks, monolithic refractory materials, and silica bricks.

Process flow

The refractory manufacturing process primarily consists of die/mould preparation, crushing, grinding, mixing, shaping (pressing/casting), drying, and firing (Figure 21). Depending on the specific refractory product being manufactured, the raw materials are crushed using crushers to achieve the desired chemical composition and properties. The crushed product is sent to mills to further reduce the size of the particles. The end product is screened to remove large particles and maintain homogeneity. The resulting powder is then mixed into a paste in muller machines or blungers. The paste is then pressed to desired shapes using a hydraulic or friction press. The green products are dried before being loaded into refractory kilns. During sintering, the most energy-consuming step in the process, the refractory materials coalesce into a solid mass as the refractory kilns are heated to 1,000°C–1,500°C.

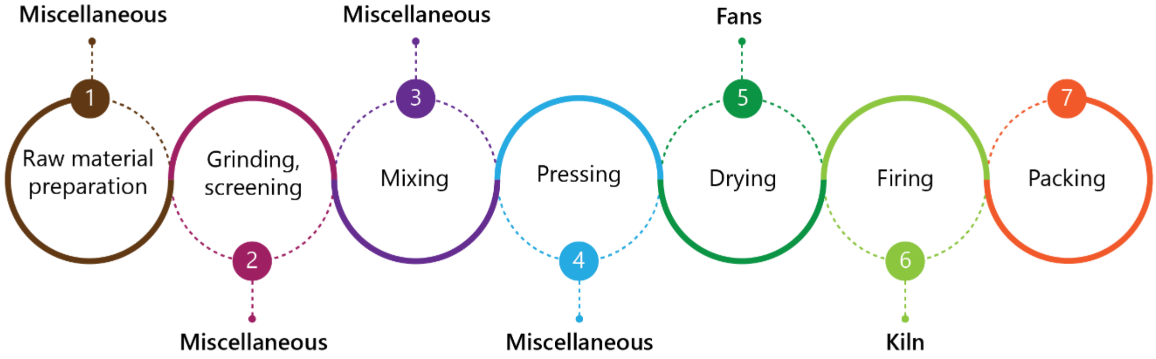


Figure 21: Process flow of refractory manufacturing

Following are the major energy- and emission-intensive equipment in the refractory cluster:

Kilns: Kilns are the largest energy-consuming component in refractory manufacturing. Sintering is a crucial process for achieving the desired properties of refractory materials. The two types of furnaces in the cluster are DD kilns and tunnel kilns. DD kilns are an old and extensively used technology across the cluster. Because no standards have been established for designing DD kilns, they are designed based on practical approximations. DD kilns are used for batch-wise production, are powered by coal, and are not efficiently designed, resulting in significant energy losses. The kiln efficiencies in the cluster were minimal, dropping to as low as 6%.

In a tunnel kiln, green products are passed on a moving cart through a long horizontal tunnel. Tunnel kilns in the cluster are used for continuous production, fired by pet coke, and designed with better heat distribution and efficiency. They have lower energy losses but are suited for larger production capacities. Tunnel kilns can also be equipped with waste heat recovery systems to recover heat from flue gases. The recorded SEC in kilns is listed in Table 14.

Table 14. Specific energy consumption (SEC) recorded in kilns

Type of kiln	Recorded SEC (GJ/tonne)
Downdraft	5.79–17.42
Tunnel	3.36–4.97

Fans: Fans are used for multiple purposes in these units, such as to dry green bricks, create a draft, and cool the working environment.

DG sets: A DG set is primarily used as backup power in case of an outage. It consumes a large amount of HSD in the units, operating with typical efficiencies of 25%–45% depending on the age of the equipment.

Miscellaneous: These include process equipment such as mixers, grinders, and hydraulic press machines to prepare refractory bricks before the drying and firing processes.

Baseline energy and emissions profile

The total energy consumption of the units surveyed was 1,20,269 GJ. Coal was the primary fuel source for the DD kilns in the cluster, followed by pet coke, electricity, and diesel. The total energy consumption and emissions under the BAU scenario are shown in Figure 22.

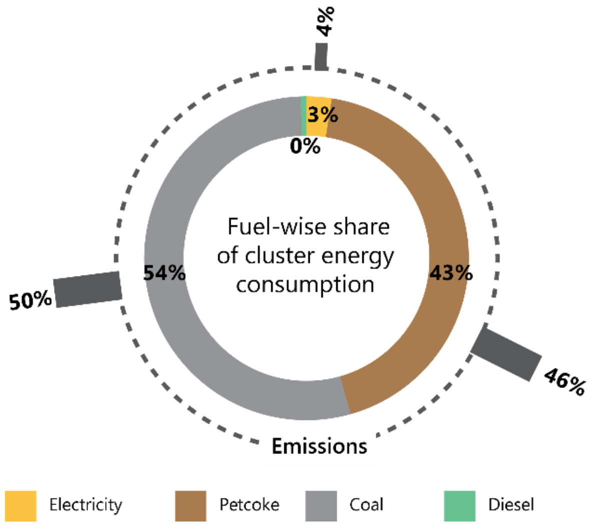


Figure 22: Energy consumption and emission profile for Asansol–Chirkunda cluster

The energy consumption and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 23.

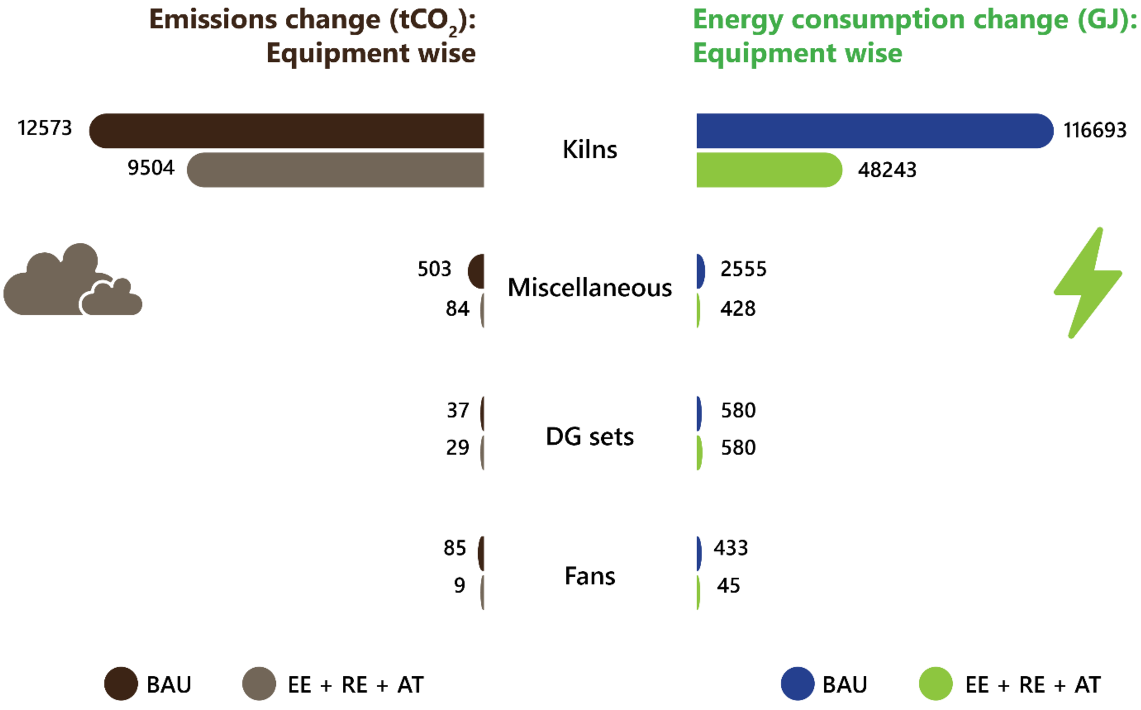


Figure 23: Equipment-wise differences in energy consumption and emissions in Asansol–Chirkunda

Table 15 shows the reduction in energy consumption, emissions, and energy costs upon implementation of decarbonisation measures in the Asansol–Chirkunda cluster. The total investment required for decarbonising the units studied is INR 48 crore.

Table 15. Total impact of decarbonisation measures in Asansol–Chirkunda

Parameters	Observations
Percentage of energy savings	57%
Annual emissions savings (tCO_2/year)	3,583.03
Energy cost rise (INR crore)	5.3
Investment cost required (INR crore)	48

The changes in SEC and emissions for a representative unit under all four decarbonisation scenarios are depicted in Figure 24.

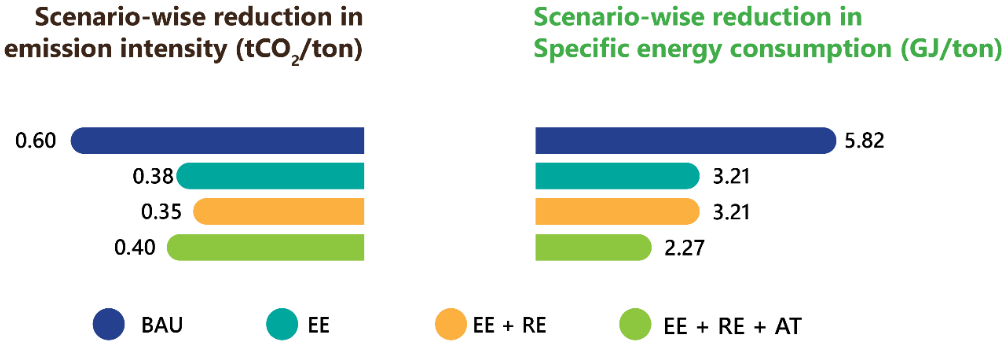


Figure 24: Difference in the specific energy consumption (SEC) and emission intensity of a representative unit in Asansol–Chirkunda

Due to a high grid emission factor at present, a rise in emission intensity was observed on introduction of electric kilns.

3.3.2. Insights

The decarbonisation technologies identified for the refractory sector cater to its energy- and carbon-intensive equipment. The feasibility of these technologies was assessed based on four important parameters, namely energy consumption, emissions, investment cost, and payback period. The scope for implementing each of the identified decarbonisation technologies are tabulated in the form of a feasibility matrix, as shown in Table 16.

Table 16. Renewable energy and advanced technologies considered for refractories

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from the grid	-	High	Low	Low
DG set	Biodiesel blending (20%) in DG sets	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years
DG set	Conversion of DG sets to battery	Medium	None	High	Not feasible
Kiln	DD kiln to tunnel kiln (coal)	Medium	Medium	High	<5 years
Kiln	DD to tunnel kiln (coal to electric)	High	Low	High	Not feasible
Kiln	Tunnel kiln (pet coke to electric)	High	Low	High	Not feasible

DD: Downdraft; DG: Diesel generator

In the refractories sector, changes can be made on multiple levels to reduce emissions. The following EE measures can be implemented to reduce the energy consumption of the unit (and thereby emissions):

- Improvement in the operating power factor through Active Power Factor Control panels (short term)
- Insulation of the heating zone surface in kilns (short term)
- Reduction of rejection rates (short term)
- Installation of waste heat recovery systems in kilns (medium term)
- Installation of temperature controllers in kilns (medium term)
- Installation of IE3 energy-efficient motors with VFDs (medium term)
- Installation of tunnel kiln furnaces in place of DD furnaces (long term)
- Optimisation of the air-to-fuel ratio by installing online oxygen analysers (long term)
- Replacement of pipe burners with swirl burners in refractory kilns (long term)

Installation of RTPV systems can mitigate the emissions from electric loads and save energy costs for refractory units, given their higher electricity tariffs. The GHG mitigation potential of RTPV systems is 491 tCO_2 for the entire cluster. One issue that may arise is the lack of rooftop space and weak structural integrity of the asbestos or galvanised iron-based roofs in the

MSME units. There is adequate ground space available for the installation of solar PV systems. However, complications may arise with accounting solar PV systems installed on ground as rooftop solar PV systems.

Fuel switching options were also explored for the refractory units. Using firewood, temperatures over 1,000°C are difficult to achieve; hence, firewood or biomass briquettes cannot be recommended for refractory kilns. Bio-CNG, which has a very good calorific value of 52,000 kJ/kg, can be recommended for the tunnel kilns in the cluster. However, data on the use of bio-CNG in DD kilns are extremely limited and require further research before ascertaining suitability.

In addition, electric tunnel kilns were explored for the cluster. Due to their high efficiency, electric tunnel kilns have the potential to reduce emissions and energy usage of the current DD kilns by more than 50%. However, because electricity is four times more expensive than coal (per kJ output) in Asansol and the electric tunnel kiln has a large capital cost, the technology is not feasible for implementation at present. The same applies to the replacement of pet coke-fired tunnel kilns with electric kilns. Moreover, the operating cost of an electric kiln is roughly 1.5 times that of a pet coke-fired tunnel kiln.

A feasible decarbonisation measure is the introduction of biodiesel blending in DG sets. However, biodiesel has a higher viscosity and a higher cloud point of 15°C than diesel (1°C). This means that at lower temperatures (<15°C), biodiesel may rot or create clogging in DG sets. This issue could be avoided by including additives to the blended fuel and by changing filters in the DG sets.

The option of replacing DG sets with lithium-ion battery backup was also considered. The grid emissions resulting from lithium-ion battery backup are higher than the emissions from DG sets. This issue is further aggravated by the exorbitant capital costs and higher operating costs of lithium-ion batteries than those of DG sets. Hence, replacing DG sets with battery backup can be realised only when the grid emission factor drops significantly and the cost of lithium-ion battery reduces drastically.

Some challenges to decarbonisation in the refractory sector are described in Table 17.

Table 17. Challenges to decarbonisation faced by MSMEs in the refractory sector

Nature of challenge	Description
Technical	• Use of inefficient downdraft kiln technology • Lack of basic energy efficiency measures in kilns (improper insulation, excess air, and inadequate waste heat recovery) • High rejection rates (up to 10%) • Inconsistent quality of coal and raw materials • Low-capacity utilisation of kilns • Lack of temperature monitoring • Lack of power factor correction measures • Lack of standards for building refractory kilns
Financial	• Lack of low-cost, collateral-free financing for energy-efficient equipment and RE systems • Low purchasing power • High electricity tariffs for MSMEs • Coal is a local resource and is available at a cheap rate, demotivating the switch from fossil fuels • Uncertainties in policy landscape affecting fuel and equipment costs
Organisational	• Lack of awareness regarding energy audits and energy efficiency measures • Improper monitoring of fuel and energy usage and electricity bills • Low focus on implementing energy efficiency in the units, with expenditure focus on increasing production • Lack of skilled manpower for operating latest machinery

Some policy recommendations to tackle the challenge of decarbonising the refractory sector in Asansol and Chirkunda are presented below.

An important step toward enhancing the efficiency and sustainability of refractory production involves the development of standards for constructing both DD kilns and tunnel kilns. This necessitates a close and collaborative partnership with the Bureau of Indian Standards to formulate and implement these standards effectively. Awareness creation workshops organised by MSME DICs, think tanks, and pilot projects supported by bilateral and multilateral institutions can create awareness and confidence among MSMEs.

EE: EE remains to be the best bet for reducing energy consumption and emissions from the cluster. The conversion of DD kilns to tunnel kilns has the potential to reduce emissions from the kiln by 40%–45%. However, it is imperative to note that this transition comes with investment costs of over INR 1.5 crore per unit.

Existing schemes like the SIDBI 4E and the SRIJAN financing schemes can be leveraged by the industries looking to install energy-efficient tunnel kilns. To further boost the uptake, relaxing collateral and the profitability criteria in the schemes could prove to be useful. Further, initiatives such as the SIDBI green finance scheme, which has funding corpus and risk sharing facility to support green projects in the MSMEs, can play a pivotal role in empowering energy service companies (ESCOs) and the MSME sector. Other schemes that can support the path to decarbonisation include the RAMP scheme announced in the Union budget 2022–23.

Clean fuels: Bio-CNG-powered kilns can meet the process heating requirements at a lower expense than electric kilns. However, wider adoption of the technology requires design and R&D in technology centres, training institutions, and DST; pilot projects for proof of demonstration; possible technology transfer/licensing (use of the TIFAC-SIDBI programme); and building bio-CNG supply chains for MSMEs (through SATAT and GOBARdhan schemes).

Process electrification: Electric tunnel kilns reduce energy usage and GHG emissions from the cluster. However, shorter payback cannot be achieved currently because of high investments and high electricity costs. West Bengal has one of the highest retail tariffs for industrial customers (close to INR 10–13/kWh). This gap in viability can be bridged by reducing electricity rates (through tariff revision or RTPV/RE open access) and by facilitating low-cost financing by stakeholders (>80% equipment capital subsidy necessary currently).

Certain changes can be made to the grid infrastructure or the regulatory environment to incentivise savings or clean energy introduction. Presently, in West Bengal, there are no penalties for non-compliance with maintaining a power factor close to unity.

The recommended advanced technologies for the cluster have longer payback periods (more than 3 years). The upcoming voluntary carbon market scheme can be used as a potential source to leverage carbon finance and reduce the payback period of the decarbonisation measures. However, for this to happen, further clarity is needed on the regulations and framework on market design. Sensitisation and capacity building will also be required for MSMEs, given the enhanced compliance and monitoring requirements for the carbon market.

3.4 Pharmaceuticals

3.4.1. Cluster-wise observations: Alathur

The pharmaceutical cluster is one of the fastest-growing industries in the country. The Alathur Small Industries Development Corporation (SIDCO) industrial complex lies immediately south of Chennai, with 23 small-, medium-, and large-scale industrial units working in the pharmaceutical sector. Units in this complex manufacture chemical intermediates, tablets, injectables, eye drops, ointments, oral liquids capsules, oral rehydration solution sachets, medical gear and equipment, hand wash, petroleum jelly, and bulk drugs. Detailed energy audits were conducted in nine pharmaceutical units in the SIDCO complex and one pharmaceutical unit in Tiruvallur.

The units in the pharmaceutical cluster manufacture various components of pharmaceutical drugs, namely formulations, intermediates, and active pharmaceutical ingredients (APIs). APIs are the core components of pharmaceutical products that provide the intended therapeutic effect. Intermediates are compounds that are produced during the synthesis of the API but are not the final active ingredient itself. Intermediates can undergo further reactions or processing steps to eventually become an API. A formulation refers to the final mixture of all active and inactive ingredients that make up a drug product. Formulations include not only the API but also various excipients, which are inactive substances added to the formulation to aid the manufacturing process, improve stability, and provide other functionalities. Formulations can be produced in various forms, such as tablets, capsules, injections, and creams.

Process flow

In a formulation manufacturing unit, the API is mixed with excipients, such as binders, fillers, and lubricants, to create a homogeneous blend. This blend is then granulated using dry or wet granulation techniques, then compressed into tablets, encapsulated in capsules, or processed into liquid formulations, depending on the desired dosage form. Dryers are used to dry the drugs produced.

In API and intermediate manufacturing facilities, boilers are employed to generate steam to start the chemical reactions within reactors. The reactors play a pivotal role by facilitating the synthesis of APIs through various reactions. Distillation columns and centrifuges are involved in separating and purifying the synthesised compounds, and pressure vessels are used for high-pressure reactions. Precise control systems, heat exchangers, and filtration equipment ensure the quality and purity of the APIs throughout the manufacturing process. The process flow of pharmaceutical manufacturing has been outlined in Figure 25.

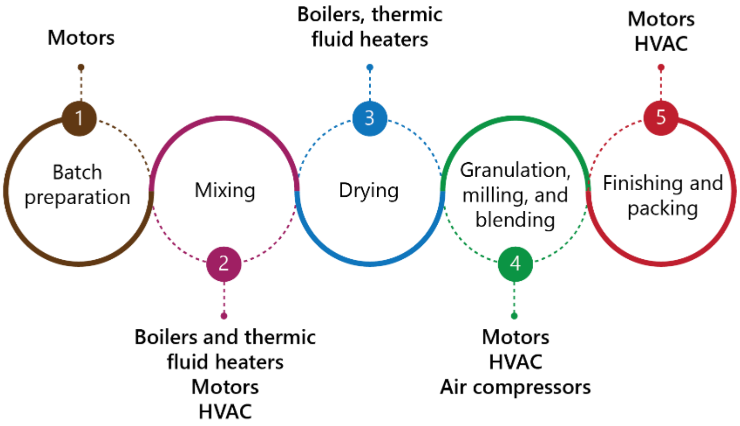


Figure 25: Process flow of pharmaceutical manufacturing

Following are the major energy- and emission-intensive equipment in pharmaceutical units:

Boilers: Boilers are used for the generation of steam and hot water for process requirements. Steam is mainly used for drying the formulation and is used in coils to provide indirect heating in fluidised bed dryers and tray dryers. Boilers in Alathur are primarily powered by diesel, in addition to the use of briquettes and firewood.

Thermic fluid heaters: Thermic fluid heaters meet the needs of several process-heating requirements in manufacturing units but without the use of steam. They are also used in mixing vessels to maintain temperatures.

Motors: Motors are the major electricity-consuming equipment in the pharmaceuticals sector and are required to run several process equipment such as granulators, material handling systems, and milling machines.

Heating ventilation and air conditioning (HVAC): Pharmaceutical processes require specific humidity levels and temperature ranges to ensure proper product quality. HVAC systems are used in pharmaceutical units to regulate humidity levels and maintain desired temperature ranges. Packaged chillers, split air conditioners, air handling units, and cold storage rooms are installed in the pharmaceutical units. Their performance is measured in terms of tonne of refrigeration (TR). The SEC range for the HVAC system is recorded to be 1.7–3.9 kW/TR.

Compressors: Compressed air is used for packaging and filling, atomising the coating solution, and operating pneumatic systems. Compressed air is mainly used to operate the pneumatic system of the manufacturing/process machinery such as fluidised bed dryers and formulation systems. The recorded SEC of air compressors was in the range of 0.11–0.28 kW/CFM

DG sets: A DG set is primarily used as backup power in case of an outage and typically has efficiencies between 25%–45% depending on the age of the equipment.

The total energy consumption of the units surveyed was 63,360 GJ/year. The total GHG emissions was 98,325.2 tCO_2/year. About 72% of the energy consumed by the units and 95% of the emissions from the pharmaceutical units could be attributed to electricity generation, as electricity is used to drive the motive loads, HVAC systems, and air compressors. Thermal energy accounts for the remaining 28% of the energy consumed and 5% of the GHG emissions from the pharmaceutical units. The total energy consumption and emissions under the BAU scenario are shown in Figure 26.

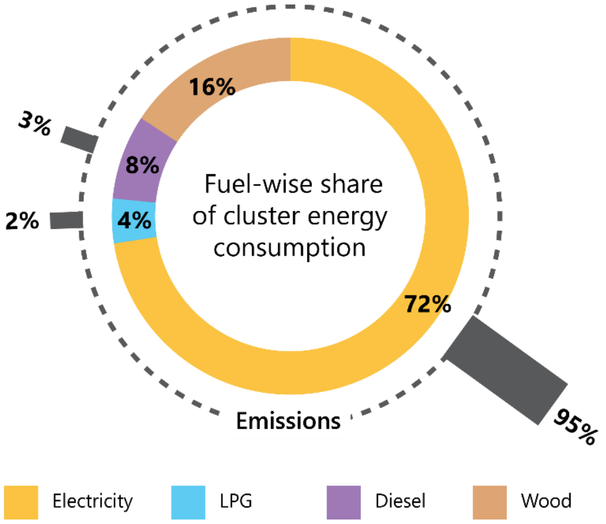


Figure 26: Energy consumption and emission profile for Alathur cluster

The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) were calculated, as shown in Figure 27.

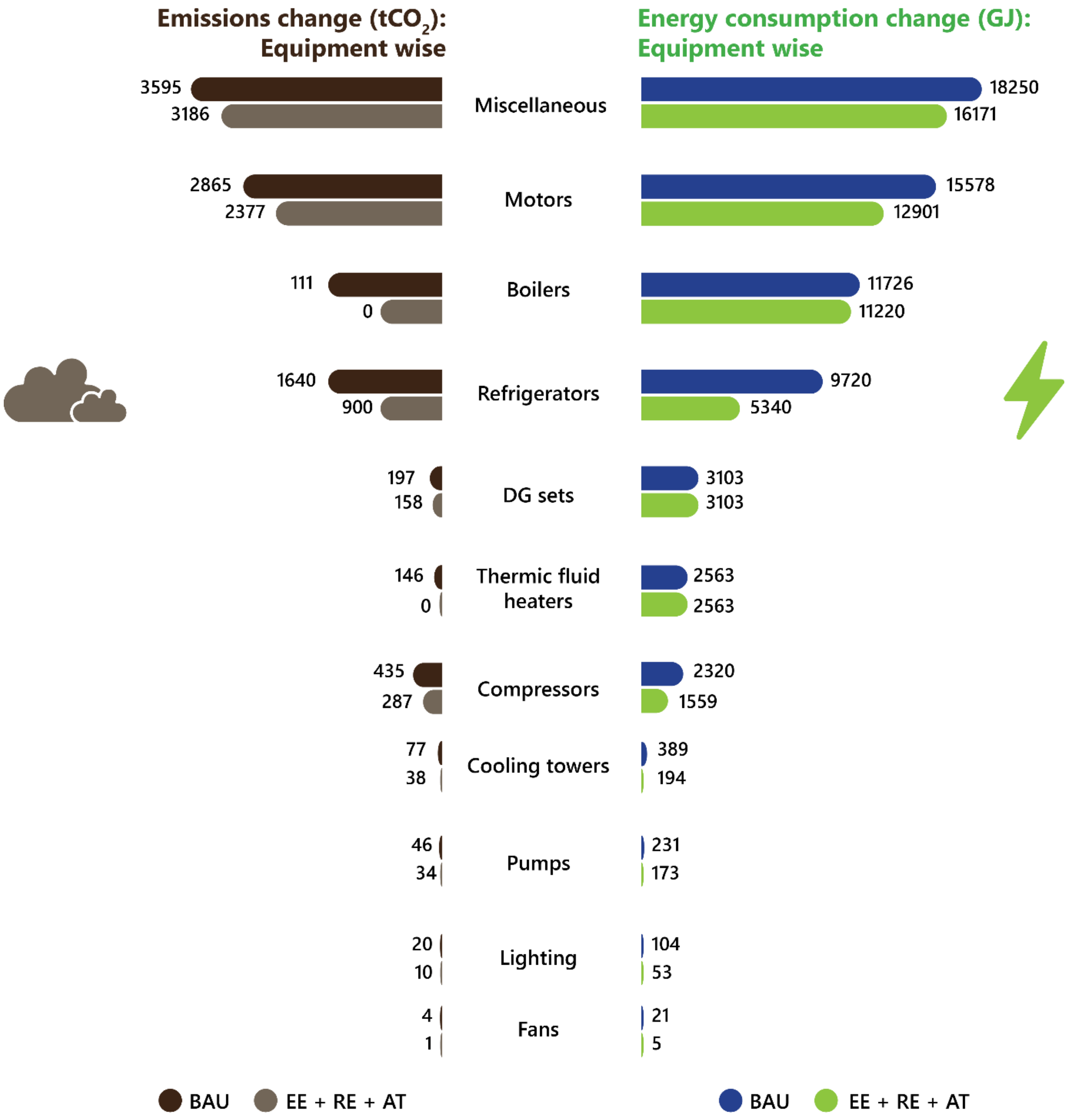


Figure 27: Equipment-wise difference in energy consumption and emissions in Alathur

Table 18 shows the reduction in energy, emissions, and energy costs for the Alathur cluster. The total investment required for decarbonising the units studied is INR 8.8 crore with a 3-year payback period.

Table 18. Total impact of decarbonisation measures in Alathur

Parameters	Observations
Percentage of energy savings	12.91%
Annual emissions savings (tCO_2/year)	2,308
Annual energy cost savings (INR crore)	2.98
Investment cost required (INR crore)	8.8

The changes in the SEC and emission intensity of one representative unit under the four scenarios are given in Figure 28.

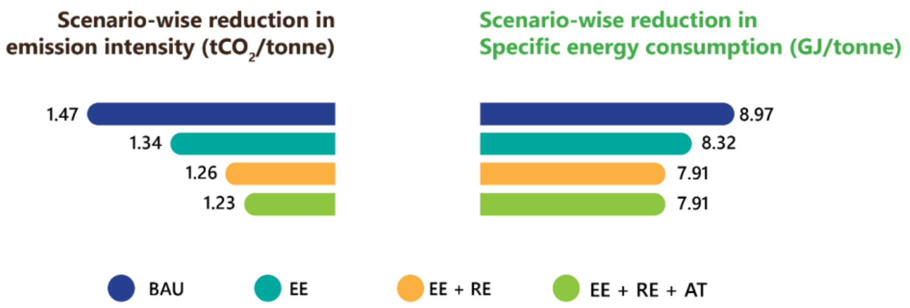


Figure 28: Difference in the specific energy consumption (SEC) and emission intensity of a representative unit in Alathur

3.4.2. Insights

The feasibility of the suggested decarbonisation technologies was assessed based on four important parameters, namely energy consumption, emissions, investment cost, and payback period. The scope for implementing each of the identified decarbonisation technologies for the pharmaceutical cluster was tabulated in the form of a feasibility matrix, as shown in Table 19.

Table 19. Renewable energy and advanced technologies considered for pharmaceutical sector

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from grid	-	High	Low	Immediate
DG set	Biodiesel blending (20%) in DG set	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years
DG set	Conversion of DG set to battery	Medium	None	High	Not feasible
Boiler	Diesel boiler to electric	Low	None	High	Not feasible
Boiler	Diesel boiler to biogas	Low	High	High	Not feasible
Boiler	Diesel boiler to green hydrogen	Low	High	High	Not feasible
Boiler	Diesel boiler to biomass briquettes	None	High	Low	*<4 years

**Due to low utilisation of boilers*

DG: Diesel generator

In the pharmaceuticals sector, changes can be made on multiple levels in order to reduce emissions. The following EE measures can be taken to reduce the energy consumption of the unit (and thereby emissions):

- Improvement in boiler insulation (short term)
- There is a significant heat loss due to poor insulation in the boiler. By improving the insulation in boilers of two pharmaceutical units, cumulative energy savings of 0.09% and cumulative GHG emission reduction of 0.16% are possible.
- Installation of BLDC fans (medium term)
- Replacement of V-belt drives with raw-edged cogged wedged belts (medium term)
- Installation of energy management systems (long term)
- Installation of screw compressors (medium term)
- Most units have installed reciprocating compressors in the facility. The baseline specific power consumption of compressors in 50% of the units was found to be above 0.21 kW/cfm for an operating pressure of 7 kg/cm^{2}g, against the benchmark SEC of 0.18 kW/cfm for screw compressors. The replacement of reciprocating compressors with screw compressors is expected to reduce energy consumption and GHG emissions of the sampled units.
- Reduction in the operating pressure of the compressors much closer to the required operating pressure (7–8 kg/cm^{2}g) to result in energy savings (immediate)
- Installation of adequate receivers to help optimise the compressed air generation pressure and reduce the running hours of compressors (short term)
- Switching to energy-efficient IE3 motors (long-term)
- Use of centralised HVAC systems (long term)
- Most pharmaceutical units have packaged chillers and split Acs, which have a higher SEC than a centralised HVAC system, as a result of improper planning of capacity addition in the pharmaceutical unit. Compared with packaged HVAC systems, centralised HVAC systems for individual buildings have three major advantages—better indoor air quality control, lower life cycle cost, and higher system efficiency.

Since electricity is the dominant form of energy used in the cluster, the most obvious decarbonisation option is the installation of distributed RE systems like RTPV and small wind. Three MSME units in the Alathur cluster have installed RTPV systems. The levelised cost of electricity (LCOE) of the RTPV systems (INR 5.5/kWh–6.2/kWh) is lower than the retail electricity tariff of approximately INR 10/kWh in Tamil Nadu. An alternative option is to avail green electricity through open access. The open-access tariff with annual escalation will still be cheaper than the Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) retail tariff over the years.

Boilers are used intermittently and have a lower utilisation rate in the Alathur cluster. The formulation manufacturing units use diesel for their boilers. A techno-economic analysis for replacing diesel-fired boilers with biomass briquette-based boilers was performed. The operating cost of a biomass briquette boiler is only 12% of the operating cost of a diesel boiler with a payback period of 4 years.

The use of electric boilers for the pharmaceutical units was also evaluated. An electric boiler is four times as expensive as a diesel boiler of the same capacity. Because the utilisation of boilers in formulation manufacturing units is very limited, the switch to electric boilers will have a very long payback period.

Another feasible decarbonisation measure is the introduction of biodiesel blending in DG sets. However, biodiesel has a higher viscosity and a higher cloud point of 15°C than diesel (1°C). This means that at lower temperatures (<15°C), biodiesel may rot or create clogging in DG sets. Because the temperature in Chennai typically does not decrease below 15°C, this is not a major concern. Nevertheless, this issue could be avoided by including additives to the blended fuel and by changing filters in the DG sets.

The use of natural refrigerants like hydrocarbons, water, and ammonia over synthetic refrigerants can reduce GHG emissions arising from refrigerant leakages as well as from electricity consumption in the HVAC systems. This is mainly due to their lower global warming potential and the difference in the thermal properties of the natural refrigerants. The use of hydrocarbons like propane, propylene, and butane is not only good for the environment but has also been proven to improve the coefficient of performance of refrigeration systems. Owing to limited secondary literature, the prospects of replacing the existing synthetic refrigerants with natural refrigerants need to be studied in detail. Further research is required to assess whether the existing synthetic refrigerants can be easily replaced with natural refrigerants or whether it would warrant a replacement of the refrigeration equipment.

Some of the challenges faced by the MSME units in the pharmaceutical sector preventing them from decarbonising their manufacturing process are described in Table 20.

Table 20. Challenges to decarbonisation faced by MSMEs in Alathur

Nature of challenge	Description
Technical	• Compressors operating at higher than required pressure • Lack of insulation along process heating equipment • Use of V-belt drives in motors • Air compressor leakage and use of compressed air in space cleaning • Use of split air conditioners, part load operations, and low efficiencies leading to high HVAC energy consumption
Financial	• Lack of low-cost, collateral-free financing for energy-efficient equipment and RE systems • Uncertainties in policy landscape affecting fuel and equipment costs
Organisational	• Preference towards short-term EE measures with less than 6-month payback period • Reluctance to divulge information regarding operational parameters during energy audits due to confidentiality • Improper monitoring of fuel usage

HVAC: Heating ventilation and air conditioning

EE: EE measures can decrease energy consumption and emissions by 12% and 15.4%, respectively. The EE measures for electric loads namely the HVAC systems, electric motors, and compressors can provide maximum energy and emission reduction in the pharmaceutical cluster. The following policies targeting these energy-intensive equipment can maximise impact:

- The Government of Tamil Nadu has introduced the Promotion of Energy Audit and Conservation of Energy (PEACE) scheme to promote EE in the state. According to the scheme, 75% of the energy audit costs up to INR 1 lakh and 50% of the energy-efficient machinery costs up to INR 10 lakh are reimbursed. The awareness regarding the PEACE scheme is very low in the pharmaceutical cluster. More awareness needs to be created to garner interest from the MSME units. In addition, capacity building of state auditors can have positive impacts on the implementation of the scheme.
- An additional line of credit should be created for the identified energy-intensive equipment like HVAC systems, compressors, and motors.
- Benchmarks need to be set for the energy consumption of different equipment as well as for different categories of pharmaceutical units.
- State government support can be leveraged through the upcoming RAMP scheme.

RE: As electricity is the dominant energy source in the pharmaceutical cluster, the emissions are relatively easier to abate. Distributed RE installations in the form of RTPV systems or small wind systems can effectively decarbonise the cluster. Another option for the industries is to avail open-access connections. The following suggestions are provided to improve the RE uptake in the pharmaceutical sector:

- The networking charges introduced by TANGEDCO are close to INR 1.25/kWh and are relatively high. This increases the LCOE of RTPV systems and reduces the financial viability of the business case. In addition, networking charges are also levied on units self-consumed. Suggestively, the networking charges can be reduced and levied only on units exported or imported.
- Across India, the gross metering regime allows RTPV installations only up to the sanctioned load of the unit. Because gross metering is beneficial for DISCOMs if the feed-in tariffs for gross metering are lower than the average power purchase costs of DISCOMs, it would be beneficial for the DISCOMs and customers if RTPV installations above the sanctioned load are permitted.
- In the gross metering regime, the power evacuation infrastructure is to be arranged by the customer. DISCOMs can support the customers by providing power evacuation infrastructure, thereby streamlining the process of RTPV installations.

Systemic measures beyond equipment-level changes are also potential solutions to decarbonisation in the clusters. In Alathur, there is a proximity of units with similar processes and resource requirements. There are existing schemes, such as the MSME Cluster Development Programme and the Integrated Processing Development Scheme, that can be utilised to a greater extent. These schemes provide funds for the following:

- Centralised RE systems (The possibility of centralised RE systems, such as shared solar or wind power installations, can be further explored. This can provide reliable, clean energy to multiple units within the cluster.)
- Centralised compressed air systems, HVAC, and compressed air systems (Due to economies of scale, the investment costs can be brought down with larger installations.)

The recommended advanced technologies for the cluster have longer payback periods (more than 3 years). The upcoming voluntary carbon market scheme can be used as a potential source to leverage carbon finance and reduce the payback period of the decarbonisation measures. However, for this to happen, further clarity is needed on the regulations and framework on market design. Sensitisation and capacity building will also be required for MSMEs, given the enhanced compliance and monitoring requirements for the carbon market. Lastly, common enabling strategies for MSMEs including pilots, demonstration projects, and enforcement of energy audits are important for units in any sector.

3.5 Bakeries

The bakery industry in India holds a significant share in the food-processing sector, with high consumption rates of the growing population. It is largely categorised into two major groups—baked goods and sweets and savouries. Coimbatore is one of the prominent bakery clusters in the country, with more than 700 establishments. Most of these units fall under the small and micro category spread across the city, whereas the medium-scale units are limited in number. The main products include pastries, bun, bread, cookies, biscuits, sweets, and savouries. Overall, six units were selected in Coimbatore as part of the study. The basic process flow of the baking industry is depicted in Figure 29.

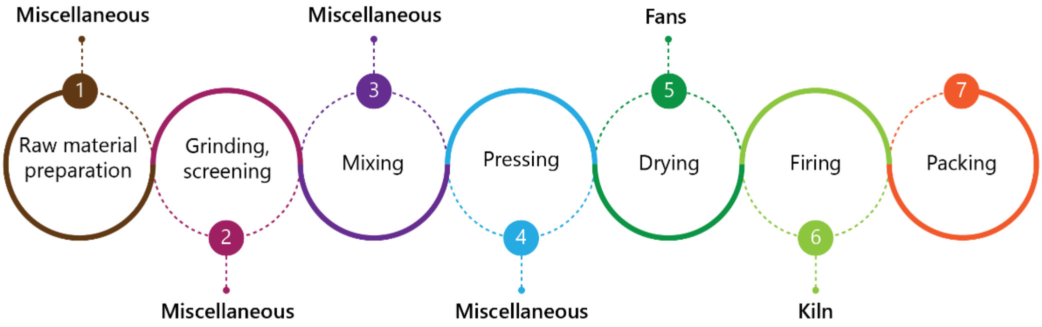


Figure 29: Generic process flow of the bakery industry

The major energy- and emission- intensive equipment in the units are as follows:

Baking ovens: Ovens are among the few equipment in the bakery cluster that operate on fossil fuels, primarily HSD and LPG, to bake goods. Although electric ovens are available in the market, there was only one surveyed unit that used it.

Cooking stoves: Unlike ovens, cooking stoves primarily use LPG as fuel, while some units still operate wood-fired stoves. Savouries are made on these type of cooking stoves, which require overhead exhaust fans to clear out the smoke.

Refrigerators: Food products like pastries and cakes require refrigeration to retain the freshness of the product. This equipment consumes the highest amount of electricity, as it operates round the clock.

Compressors: Air compressors are typical used for smaller mechanical operations, such as pneumatic compression and packaging.

Other equipment: Some of the other equipment in these units include slicers, kneaders, and blenders, which are used in the preparation process and are powered by electricity.

The decrease in energy consumption and emissions due to the implementation of decarbonisation technologies was modelled equipment-wise, highlighting the areas of maximum decarbonisation potential for the sector.

3.5.1. Cluster-wise observations: Coimbatore

The fuel usage was recorded, and based on the calorific value of the fuel and emission factors, the total energy consumption and emissions under the BAU scenario were calculated (Figure 30).

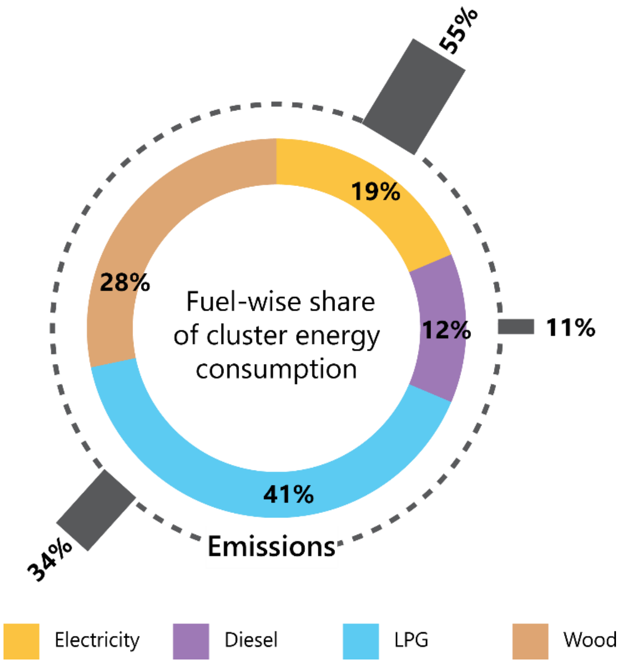


Figure 30: Energy consumption and emission profile for Coimbatore cluster

The energy consumption and associated emissions were also mapped equipment-wise to highlight the areas requiring decarbonisation interventions. The differences in energy consumption and emissions between the current scenario (BAU) and the final scenario (EE + RE + AT) are shown in Figure 31.

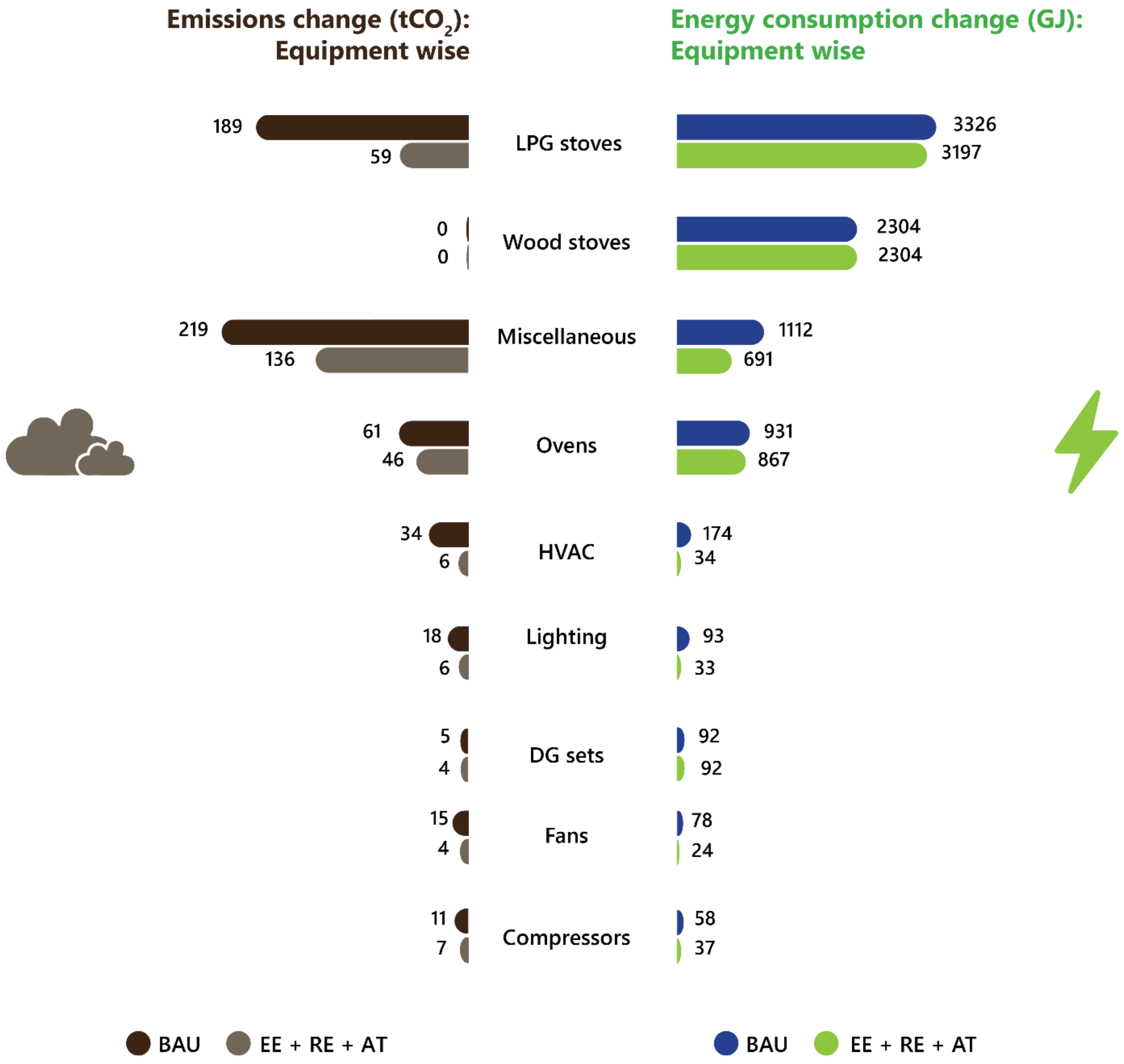


Figure 31: Equipment-wise difference in energy consumption and emissions in Coimbatore

The modelling was conducted according to the location, while measuring the overall impacts of implementing the decarbonisation technologies across technical and economic parameters (Table 21).

Table 21. Total impact of decarbonisation measures in Coimbatore

Parameters	Observations
Percentage of energy savings	5.5%
Annual emissions savings (tCO_2/year)	283
Energy cost savings (INR crore)	0.74
Investment cost required (INR crore)	1.36

Further, two other parameters, SEC and emission intensity, were calculated. These parameters normalise the energy consumption and emissions against the unit's annual production numbers and highlight the energy required and emissions produced while manufacturing a standard measured amount of the product. For units that provided production data, the SEC and emission intensity under all four scenarios were compared, and the differences for a representative unit in Coimbatore are shown in Figure 32.

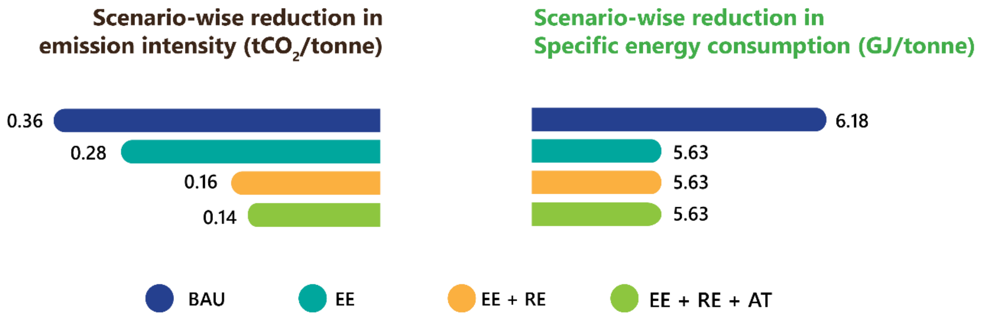


Figure 32: Difference in the specific energy consumption (SEC) and emission intensity of a representative unit in Coimbatore

3.5.2. Insights

The decarbonisation technologies identified for the bakery sector cater to its energy- and carbon-intensive equipment. The feasibility of these technologies was analysed based on four important parameters, namely energy consumption, emissions, investment cost, and payback period. The scope for implementing each of the identified decarbonisation technologies was tabulated in the form of a feasibility matrix, as shown in Table 22.

Table 22. Renewable energy and advanced technologies considered for bakeries

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from grid	-	High	Low	Immediate
DG set	Biodiesel blending (20%) in DG set	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years
DG set	Conversion of DG set to battery	Medium	-	High	Not feasible
Oven	Biodiesel blending (20%) in diesel ovens	-	Medium	Low	Immediate
Cooking stove	Electric heater instead of LPG stove	Medium	-		<2 years
Cooking stove	Biomass gasifier instead of LPG stove	-	High	High	<2 years

DG: Diesel generator; LPG: Liquefied petroleum gas

In the bakery sector, changes can be made on multiple levels to reduce emissions. The following EE measures can be implemented to reduce the energy consumption of the unit (and thereby emissions):

- Waste heat recovery to preheat the water in the proving oven (long term)
- Optimisation of electric heater operation with a proportional-integral-derivative controller (medium term)
- Use of energy-efficient air conditioners and freezers (medium term)
- Replacement of compact fluorescent lamps with light-emitting diode lights (medium term)
- Replacement of existing fans with BLDC fans (medium term)

Considering the high use of cooking stoves in bakery units, the dependency on LPG can be reduced by switching to electric heaters. Installation of biogas digester is another viable option, as most bakeries deal with inventories that include perishable goods. The use of RTPV systems can meet some of the electricity demand and reduce the emissions from grid electricity. Open-access RE can further decrease the grid emissions as a cleaner reliable source of electricity. In the bakery sector, DG sets are used to power the production facility during load shedding. Biodiesel blending (20%) in DG sets is an easy-to-implement recommendation, as it has immediate returns with low investment costs and can lead to considerable emission reduction. Replacement of existing DG sets with 100% biodiesel-powered DG sets requires certain investment cost, but owing to a low payback period (<3 years), it is another high-impact option for decarbonisation. Although the conversion of DG sets into battery electricity storage systems (for backup power) is technically feasible, it was not considered due to the high space requirements and the economic unfeasibility.

Some of the challenges faced by the MSME units in this sector preventing them from decarbonising their manufacturing processes are described in Table 23.

Table 23. Challenges to decarbonisation faced by MSMEs in the bakery sector

Nature of challenge	Description
Technical	• Significant heat loss in flue gases and no heat recovery systems installed • Use of inefficient air conditioners and freezers • Leakages in compressed air lines • Operation of compressors at a pressure higher than the required pressure • Use of compact fluorescent lamps for lighting
Financial	• Lack of low-cost, collateral-free financing for energy-efficient equipment and RE systems • High electricity tariffs for MSMEs
Organizational	• Rented and outdated machinery in small units • Lack of awareness on efficient operating practices and measures among working staff • Low awareness regarding energy efficiency measures and energy audits • No concept of using food waste as biofuels • Low focus on implementing energy efficiency in the units, with expenditure focus on increasing production

EE: There is limited scope for implementing EE measures in these units (potential reduction in emissions and energy consumption of only 5.5%). However, improving operational efficiency as well as installation of waste heat recovery systems and energy-efficient equipment such as freezers, lighting, and fans will be helpful. Other recommendations to aid EE changes are described below:

- Equipment likely to be eligible under the PEACE scheme can be installed. Under this scheme, the state government will reimburse 50% of the cost of conducting energy audits (cap of INR 75,000) and 25% of the cost of machinery and equipment installed or retrofitted (Micro, Small and Medium Enterprises Department, Government of Tamil Nadu, 2020).
- The state government in partnership with industrial cluster associations can set a local benchmarking framework for energy consumption in common process equipment.
- Financial institutions can introduce portfolios for energy-efficient technologies for MSME units.
- Programmes and workshops to create awareness regarding energy audits and EE measures among each MSME cluster and hub should be promoted.

RE: Electricity has a relatively lower share in the energy mix of the bakery cluster but is accountable for majority of the emissions. Owing to high grid emission factors, the need for RE solutions, primarily RTPV and open access, is essential. The potential for RE adoption in units can be increased through the following measures:

- Reduction in sanctioned load requirements for open access, as most bakeries have a sanctioned load of less than 50 kW
- Use of RE-specific financing schemes for RTPV installations (e.g. MNRE subsidy under Phase-II of grid-connected rooftop solar program)
- Reduction of networking charges for RTPV installations
- Allowing RTPV installations above the sanctioned load in gross metering regime to benefit MSME unit owners with sufficient rooftop space
- Provision of power evacuation infrastructure for gross metering by DISCOMs

Clean fuels: The bakery sector has a fuel mix of LPG, wood, diesel, and electricity, with a higher inclination towards fossil fuels. The use of biofuels is a key decarbonisation measure, as the industry works with defective and expired food products. Biogas from biogas digesters have the potential to replace LPG in cooking stoves. Integrating the use of biofuels such as biodiesel for DG sets is another suitable alternative, with the potential to reduce emissions and energy costs. Biomass such as food waste should be promoted as a clean fuel source for the food and beverage sector. Furthermore, biodiesel should be included under the Pradhan Mantri JI-VAN Yojana, given the high usage of HSD in industrial sectors (e.g. DG sets).

4 Conclusion

4.1 Insights

Based on the findings of this study, the effects of the decarbonisation measures—EE measures, RE solutions, and advanced technologies—are described below.

Impact of EE measures

- It is estimated that EE measures can reduce the energy consumption in Asansol and Chirkunda significantly by about 37%, with a 31% drop in GHG emissions. This is primarily because of the low efficiency of existing DD kilns.
- The scope for EE in aluminium die-casting clusters in Delhi-NCR and Bengaluru is 7.8% and 10.8%, respectively. The EE measures include installation of thyristors for temperature control in PDC machines, waste heat recovery for furnaces, and installation of energy-efficient motors and pumps.
- The potential for energy savings within the textile clusters of Ludhiana and Tiruppur stands at 6% and 14%, respectively, which equates to a reduction in GHG emissions by 5.81% and 15.6%, respectively. EE has a lower scope in Ludhiana because thermal equipment such as boilers and thermic fluid heaters in the textile units are functioning at an optimum efficiency of 80%. However, the boilers and thermic fluid heaters in Tiruppur operate at efficiencies of less than 50%.
- The energy and emission reduction estimated through EE measures in Alathur is 12% and 15.4%, respectively. There is considerable scope for EE improvements in HVAC systems, compressors, and electric motors. There is also significant scope for thermal energy savings through the insulation of thermal equipment and pipelines.
- The bakery units studied in Coimbatore can achieve energy and emission reductions of 5.5% and 4.37%, respectively, by implementing EE measures such as waste heat recovery.

The equipment providing the highest amount of energy savings in each cluster are described in Table 24. The potential for energy savings from these equipment alone was also calculated to highlight the focus for EE programmes.

Table 24. Energy saving potential through energy efficiency measures

Cluster	Equipment with the highest energy savings potential	Potential drop in energy consumption (%)
Bengaluru (*Aluminium die-casting*)	Pressure die-casting	4.36
Delhi-NCR (*Aluminium die-casting*)	Furnace	3.35
Ludhiana (*Textile*)	Boiler	5.34
Tiruppur (*Textile*)	Thermic fluid heater	8.22
Asansol–Chirkunda (*Refractories*)	Kiln	36
Alathur (*Pharmaceutical*)	HVAC	4.7
Coimbatore (*Bakery*)	Motors	1

HVAC: Heating ventilation and air conditioning

Impact of RE adoption

- There has been some progress in RE adoption in most MSME clusters. In the Tiruppur textiles cluster and Alathur pharmaceutical cluster, units have installed captive power consumption plants like wind farms. A few aluminium die-casting units in Bengaluru purchase solar power through open access, and the pharmaceutical units in the Alathur cluster have installed RTPV systems through the Renewable Energy Service Company model.
- In Asansol, the sole recommended RE option is RTPV, which can reduce GHG emissions by 5.4% compared with the EE scenario.
- In Alathur, by combining RTPV installation and the switch from diesel to biomass, GHG emissions can be reduced by 7.96% compared with the EE scenario.
- In Delhi-NCR and Bengaluru, RTPV installation can achieve emission reductions of 1% and 6%, respectively, compared with the EE scenario.
- The use of RTPV and producer gas from biomass gasifiers instead of LPG can reduce GHG emissions by 46% in the Coimbatore cluster.

In total, 8.3 MW of RTPV capacity can be installed in the MSME units studied. The MSME units in Coimbatore and Tiruppur had low rooftop space available, leading to a lower RTPV potential. The RTPV potential for the units studied in the different clusters is given in Table 25.

Table 25. RTPV potential across clusters

Cluster	RTPV potential (kW)
Bengaluru (*Aluminium die-casting*)	4,891.94
Delhi-NCR (*Aluminium die-casting*)	463.61
Ludhiana (*Textile*)	1,404.68
Tiruppur (*Textile*)	267.12
Asansol–Chirkunda (*Refractories*)	438.9
Alathur (*Pharmaceutical*)	782.62
Coimbatore (*Bakery*)	73.23

The RTPV capacity addition in the units is limited to the rooftop area available in the unit. While virtual net metering presents a viable solution to address the limitations imposed by limited rooftop areas, it is yet to be implemented in the states considered for the study. Green open access has the potential to mitigate all GHG emissions from the electrical loads in the MSME units. According to the recent modifications notified under the Electricity (Promoting Renewable Energy through Green Energy Open Access) Rules, 2022, the sanctioned load limitations for open access have been reduced to 100 kW, and there is no sanctioned load limitation for captive consumers. The open-access charges include cross subsidy surcharge, additional surcharge, wheeling charges, standby charges, load dispatch fees, and banking charges. The landed costs of open access are calculated as the sum of open-access charges and the average power purchase cost of renewables. Due to the exemption of cross subsidy surcharge and additional surcharge, the group-captive model stands as the preferred operational business model for open access at present.

However, there are many practical limitations to availing the third-party ownership open-access model, as mentioned below:

- Many states have not complied with the recent amendments by the Ministry of Power to the open-access regulations. Several states continue to maintain a sanctioned load limit of 1 MW for open access. Among the states included in the study, Karnataka, Haryana, and West Bengal have reduced the sanctioned load limit to 100 kW. Meanwhile, Jharkhand and Tamil Nadu have not yet made amendments to their open-access regulations.
- The third-party open-access models have not been widely accepted due to high open-access charges and difficulty in obtaining approvals. The cross-subsidy surcharge has also

been increased over the years. Haryana has introduced grid support charges, thereby increasing the landed costs of open access.

- States have either limited or withdrawn the carry-over of surplus power to the next month.
- The project developers are not compensated for the excess power generation.

The landed tariff for third-party open-access model, which includes the open-access charges and the energy charges for a few states, is listed in Table 26 (Gulia et al., 2022).

Table 26. Landed tariff for third-party open-access model

State	Landed tariff third-party model (INR/kWh)	Retail tariff (INR/kWh) inclusive of fixed charges
Tamil Nadu	6.4–6.98	9–10
Karnataka	7.4	8.4–9.4

Within the Ludhiana textile cluster, thermal equipment primarily relies on coal and furnace oil as energy sources. However, two units utilize rice husks, and one unit employs woodchips. By transitioning from coal to rice husk, it is possible to eliminate greenhouse gas (GHG) emissions from the thermal equipment entirely. Combining this fuel conversion with the use of RTPV can lead to a remarkable 77% reduction in GHG emissions compared to the EE scenario. In the Tiruppur cluster, two medium-scale MSME units rely on coal, a major contributor to GHG emissions within the cluster. The other units use groundnut shells and firewood for their thermal equipment. Replacing coal with either wood or groundnut shells can eliminate GHG emissions from the thermal equipment. Additionally, the adoption of RTPV and fuel switching can result in an impressive 83% reduction in GHG emissions.

Impact of advanced technologies

Process electrification options as a part of the advanced technologies were explored for a few sample units in each industrial cluster. It is imperative to note that the emission factor per kJ for the electricity grid is higher than that for the combustion of fossil fuels like diesel, coal, and pet coke. The viability of the process electrification measures is dependent on factors such as the efficiencies of the thermal equipment and the proposed electric equipment, the emission factor for the Indian grid, retail electricity tariff in the industrial area, existing fuel prices, capital investment required for the electric equipment, and operating hours of the thermal equipment.

- The electric resistance furnace emerges as a technically and financially sound alternative. The electric resistance furnace is an efficient and cost-effective option when compared to PNG-fired furnaces in the aluminium die-casting cluster. As the SEC and energy consumption of an electric furnace is 2–5-times lower than that of a natural gas (PNG) furnace, it is clearly an energy-saving option. While the cost of electricity per kilojoule (kJ) is 1.3-times higher than that of PNG, the overall operating cost of an electric furnace is roughly 3.5-times lower than that of a PNG-fired furnace, making it a financially prudent option. Moreover, the GHG emissions of electric resistance furnaces are around 23% lower than those generated by PNG furnaces.

- Electric boilers are not financially viable for the pharmaceutical cluster due to their higher capital costs and lower utilisation. In Ludhiana, electricity is six times more expensive than coal. Furthermore, the operating cost of electric boilers is roughly 3.3 times greater than that of coal-fired boilers. Due to the high emission factor per kJ of the Indian grid compared to coal, transitioning to electric boilers may lead to a 30%–40% increase in emissions, making the transition redundant in Ludhiana.
- The electric tunnel kiln boasts a much higher efficiency rate at 55%, whereas the pet coke-fired kiln operates at a less efficient range of 23%–34%. However, the capital cost of an electric kiln is 300% of that of a pet coke-fired tunnel kiln, and the fuel cost of an electric tunnel kiln is roughly 165% of that of a pet coke-fired kiln. While the electric kiln offers a promising 29% reduction in emissions, its financial feasibility is hindered by the substantial capital costs involved.

In addition to the process electrification options, the following other advanced technologies were explored:

- Bio-CNG is a viable alternative that can be used in the PNG-fired furnaces in the aluminium die-casting cluster. However, although bio-CNG costs less than PNG, the only bottleneck is the supply chain for bio-CNG, which is still at a nascent stage. The operating cost of a bio-CNG-powered boiler is roughly 80% higher than that of a coal-fired boiler. Further research is needed to explore the potential of using bio-CNG in DD kilns.
- Biodiesel blending is another viable fuel option for the MSME sector. Biodiesel can be blended with 80% diesel to be used in DG sets and diesel boilers.
- Green hydrogen is approximately 11.4 times more expensive per kilojoule (kJ) than coal, making it a less economically competitive option. To achieve fuel price parity and make hydrogen a more viable choice for MSMEs, its cost needs to decrease significantly, ideally falling below INR 79 per kg) (Krishna, 2023). Additionally, the cost of adopting hydrogen boilers is relatively high, which underscores the need for further cost reductions and advancements in hydrogen technology to enable its widespread adoption in MSMEs. Feasible decarbonisation measures have been suggested in Table 27.

Table 27. Feasible decarbonisation measures

Equipment	Decarbonisation measure	Energy reduction	Emission reduction	Investment cost	Payback period
All electric equipment	Installation of rooftop solar	-	High	High	<5 years
All electric equipment	Use of open-access green energy from grid	-	High	Low	Immediate
Boiler	Pet-coke boiler to biomass briquettes	None	High	Low	0.2–4 years*
Boiler	Diesel boiler to biomass briquettes	None	High	Low	<4 years**
Furnace	Conversion of gas to electric furnace	High	Medium	High	<4 years
Furnace	Use of bio-CNG in gas furnaces	-	High	Low	Immediate
Kiln	Downdraft to tunnel kiln (coal)	Medium	Medium	High	<5 years
TFH	Pet coke TFH to biomass briquettes	None	High	Low	0.2–4 years*
Tumbler dryer	LPG to biogas	None	High	Low	Immediate
Oven	Biodiesel blending (20%) in diesel ovens	-	Medium	Low	Immediate
Cooking stove	Electric heater instead of LPG stove	Medium	-		<2 years
Cooking stove	Biomass gasifier instead of LPG stove	-	High	High	<2 years
DG set	Biodiesel blending (20%) in DG set	-	Medium	Low	Immediate
DG set	Use of 100% biodiesel generator	-	High	Medium	<3 years

DG: Diesel generator; TFH: Thermic fluid heater; LPG: Liquefied petroleum gas

**Depending on pet coke prices*

The estimated changes in emissions, energy, and energy costs for the different clusters are given in Table 28.

Table 28. Total potential impact of decarbonisation measures

Cluster	Energy reduction (%)	Emission reduction (tCO_2)	Energy cost savings (INR crore)	Investments required (INR crore)
Alathur (*Pharmaceutical*)	13%	2,300	3	9
Delhi-NCR (*Aluminium die-casting*)	36%	3,123	11	9
Ludhiana (*Textile*)	6%	91,876	14	7.1
Asansol–Chirkunda (*Refractories*)	57%	3,583	-5.3	48
Bengaluru (*Aluminium die-casting*)	26%	4,106	6.5	15
Tiruppur (*Textile*)	13.5%	31,302	7.7	1.31
Coimbatore (*Bakeries*)	5.5%	283	0.74	1.36

The estimated reduction in emissions due to the implementation of a combination of the recommended EE measures, RE solutions, and advanced technologies is depicted in Figure 33, with potential savings in emissions of 1,36,581 tCO_2 and energy usage of 3,85,383 GJ and a reduction in energy costs of INR 37.01 crore. It is important to note that while all clusters experienced decreased energy costs, an exception was found in Asansol.

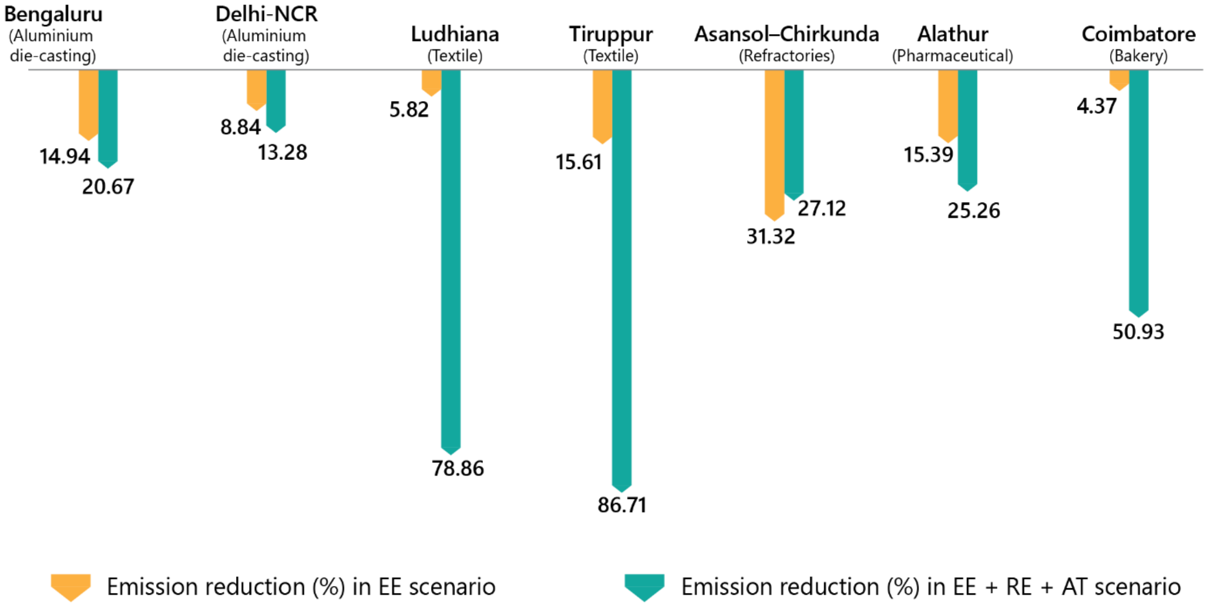


Figure 33: Difference in emission reductions from the BAU scenario

SEC and emission intensity

As part of the energy audits, the production values of some units were also tabulated, through which the normalised amount of energy and emissions required to make a product could be tabulated for every sector. The SEC and emission intensity for the units were calculated for the BAU scenario (Figure 34 and Figure 35).

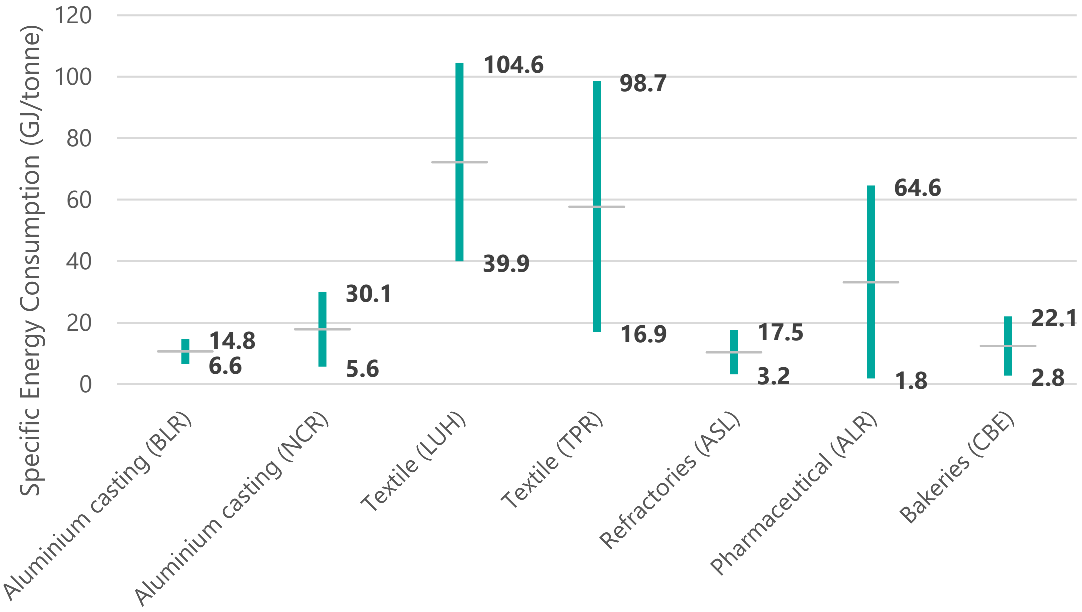


Figure 34. SEC Range for all clusters in the study

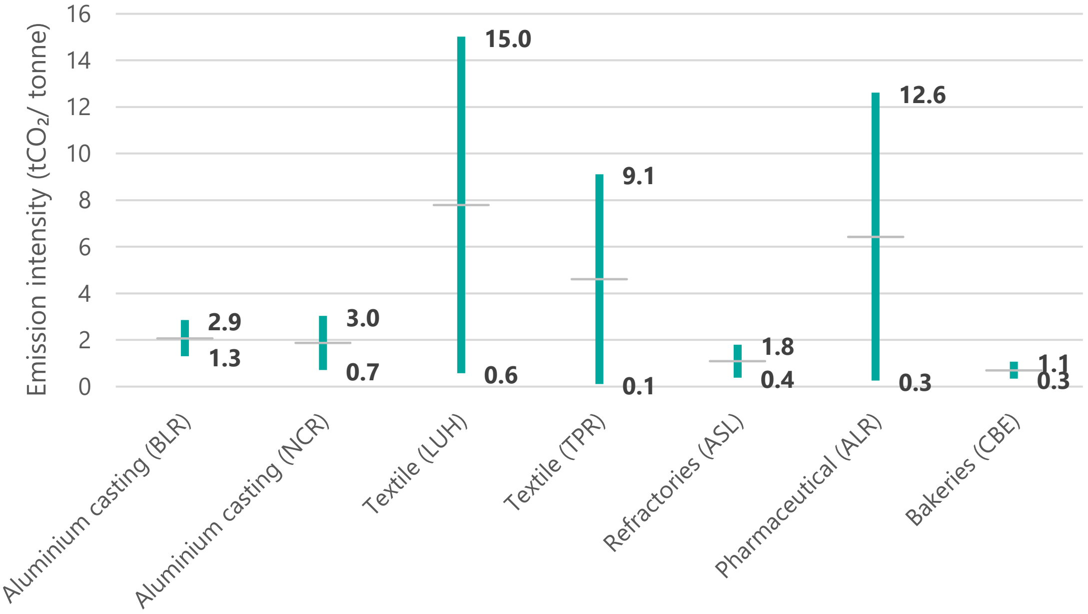


Figure 35. Emission intensity range for all clusters in the study

SEC is an important parameter of comparison of a unit/cluster's operational efficiencies with the overall sector. The recorded SEC values were compared against the existing literature (Table 29) (The Energy and Resources Institute, 2013).

Table 29: SEC comparison

Sector	Recorded SEC (GJ/tonne)	SEC in existing literature (GJ/tonne)
Aluminium die-casting	5.64–30.1	8.1–25.6
Textiles	16.9–104.6	20.52–124.7
Refractories	3.2–17.5	4.2–73.7
Pharmaceuticals	1.8–64.6	32.2
Bakeries	2.7–22.1	4.01

The recorded SEC range of the units were within the range of the reference SECs from the literature. While this helps validate the findings, it must be stated that the literature is over 5–10-years old. The lack of progress in reducing excessive energy usage highlights the need for greater efforts for decarbonisation in these sectors.

A high variance in SEC and emission intensity values was observed in every location. A large factor behind this is the heterogeneous nature of production for a given sector. Differences were observed in the operating processes, type and capacity of equipment used, working efficiencies for a given equipment, different grades of solid fuels used (coal and biomass), differences in fuel prices (which influence how responsibly fuel monitoring and consumption is conducted within a unit), etc.

4.2 Challenges

The challenges to decarbonising manufacturing are often localised to a cluster or a sector and have been detailed in the Results section. A few common themes were observed across the seven clusters, as described below:

- **Financing**

Access to adequate financing opportunities has consistently been flagged as a major challenge in the MSME sector. MSMEs seek debt financing for a range of technological upgrades and equipment changes, and this extends for the purposes of decarbonisation (in the form of EE replacements of equipment, solar panels, etc). However, large sections of the MSME sector are unable to receive such financing due to multiple reasons, such as

  - informal operation of units, with lack of identification/registration and other forms of documentation required for formal financing;
  - operation in rural/interior areas with lower access to financial institutions and suppliers;
  - lack of awareness of applicable government schemes;
  - stringent eligibility criteria (such as profitability for 3 years) and collateral requirements for financing; and
  - uncertainties of these MSME sectors, also affecting the bank's interest rates, which in turn affects financial viability of the financing.

- **Compliance**

Most of the large industries are subjected to energy conservation regulations (such as the Perform, Achieve and Trade scheme) or compliance requirements from their clients. However, most MSMEs do not have a mandate to shift towards efficient and clean manufacturing processes. Efforts are primarily only in the form of incentivising MSMEs.

- **Awareness**

Beyond financing, awareness within many units can also be improved. Greater levels of monitoring of fuel consumption and energy consumption of equipment are required to reduce operational inefficiencies. Knowledge of the latest available technologies and changes in government regulations or new schemes can help MSMEs manufacture at greater and more efficient levels.

- **Equipment oversizing**

In every sector studied here, several units were found to be running energy-intensive machinery (such as boilers, furnaces, and compressors) at partial loading. Due to a high variance in product demand and market uncertainties, equipment is often rated at higher capacities to cater to the rare peak demand. This results in partial loading (which typically results in lower operational efficiencies) as well as larger investment costs for any equipment replacements.

- **RE challenges** (RTPV/RE open access)

The introduction of RTPV/RE open access is not only a decarbonisation measure but is seen by the MSME sector as a means to save electricity costs. Adoption of such RE solutions were already observed in several units in clusters including Tamil Nadu and Delhi-NCR. However, the following constraints to their wider adoption remain:

  - bottlenecks in policy (net metering or net feed in eligibility, sanctioned load limits, additional open access charges) as well an overall changing policy environment leading to uncertainties for RE developers;
  - smaller system sizes for MSMEs leading to higher transactional costs; and
  - hesitation to finance due to concerns of MSME unit stability, defaults etc.

- **Apprehension of advanced technologies**

While replacement of standard EE equipment such as motors and lighting are more widely acknowledged by industries, uncertainties remain over several technologies that are not technologically or commercially mature in the local region. Concerns among units over disruption to production, expected benefits, and other logistical issues lead to hesitation in adopting newer technologies.

- **Workforce**

On most occasions, a lack of skilled workforce for operating high-tech machinery prevented the adoption of upgraded equipment. The lack of awareness and access to skill development programmes tailored to specific MSME sectors also affect the overall operational efficiency.

5 Recommendations

Based on the insights from the seven clusters, the key recommendations for decarbonisation measures in the MSME manufacturing sector are described here:

- There are schemes financing EE and RE solutions catering to the MSME sector (such as SIDBI 4E scheme, eGPS, and Surya Shakti schemes); however, currently, the overall uptake has scope for improvement. **Increasing financial access** for MSMEs can have sweeping effects on the wider implementation of decarbonisation measures. The following steps can be taken in this regard:
    - Collateral-free financing, lower interest rates, longer repayment periods, or relaxation of certain eligibility criteria can be provided. This would require financial support from state and central governments.
    - Indirect measures can be undertaken by providing increased assistance to finance institutions (credit guarantees and risk sharing) or through the upcoming RAMP scheme for state governments.
    - Capacity building of financial institutions can be done to better review EE/RE loans, which can lead to more favourable financing conditions for the units. Promising measures in this direction have already been taken in the form of BEE's Energy Efficiency Financing Platform for grading EE projects.
    - With limited details about the upcoming national carbon markets, the inclusion of MSMEs would be a positive move. The use of additional national/international carbon financing could help reduce the payback period of any decarbonisation measure taken by MSME units.
- The creation of an industrial and an **MSME policy** for every state/sector would be a necessary step in analysing the local clusters and identifying the challenges they face. This includes defining energy and emission reduction targets and charting a roadmap for achieving them. Important measures in such manufacturing policies should include the following:
    - R&D activities for advanced technologies should be amplified.
    - Conducting regular energy audits is extremely important for an efficient and clean manufacturing ecosystem. MSME policies must recognise this and highlight the means to increase energy audits being conducted (through mandates and subsidies on audit fees and by launching incentives and schemes conditional to performing energy audits such as the PEACE scheme in Tamil Nadu).
    - The number of pilots and demonstration projects in a cluster should be increased to build local confidence about a technology's suitability/benefits in their unit's production processes.
    - Aggregating the demand of common EE equipment in clusters can have mutual benefits for units and technology providers (a recent example being the National

Motor Replacement Program offered by Energy Efficiency Services Limited). Expansion of such schemes for other equipment would fall under MSME policies.

- The existing role of **bioenergy** in MSME clusters and its potential for expansion are highlighted in this study. Fuels such as biomass briquettes, bio-CNG, and biodiesel have immense potential for the direct replacement of fossil fuels in thermal equipment (such as boilers and furnaces). Importantly, units are interested in adopting these fuels owing to the immediate financial benefits and no/low equipment changes. However, issues remain in the production and reliable supply chains for such fuels. The following policy measures are suggested to increase the usage of biofuels:
    - Biomass briquettes/pellets policies currently focus on the usage in thermal power plants; however, there is potential for expansion in thermal equipment such as boilers/thermic fluid heaters (e.g. through clean fuel mandates).
    - Biodiesel should be included under the Pradhan Mantri JI-VAN Yojana.
    - While bio-CNG production is under focus (through schemes such as GOBARdhan and SATAT), supplementary measures are required to facilitate the sale to units/clusters.
- Apart from working towards the financial viability of decarbonisation solutions, **regulatory incentives** can be used to nudge MSME units towards clean fuel switching. This could include easing pollution control board's industrial procedures (extended consent to operate/expand time periods and reduction in consent fees) for units using cleaner fuels and introduction of Scope 3 emissions reporting and source of materials for customers and larger organisations downstream of MSME sectors. This could help create additional support mechanisms and compliance and monitoring systems for MSMEs.
- Increasing the usage of **renewables** such as solar is an important step in decarbonisation and in reducing electricity costs. However, considering rooftop availability constraints, reluctance of DISCOMs, and changing regulatory environments, further steps are required to continue the progress:
    - The recent reduction in the minimum sanctioned load of 100 kW for open access raises the number of eligible MSME units. Ensuring rationalisation of other charges (such as transmission and cross-subsidy) is essential for encouraging adoption. For units with lower sanctioned loads, aggregating the demand is a potential solution.
    - Allowing gross metering arrangements beyond unit sanctioned loads can help in utilising larger rooftop spaces.
    - Awareness of existing RE schemes for MSMEs (including Surya Shakti scheme and SIDBI Tata Power scheme) should be increased.
    - Existing Cluster Development schemes should be used to finance common RE systems in clusters.
    - For RTPV systems, networking charges should be lowered, considering net billing/net feed-in tariff arrangements.

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7 Appendix

7.1 Appendix A

This section provides the glossary, energy conversion factors, fuel emission factors, and units and measures employed in the study as well as images from field visits.

7.1.1. Glossary

Calorific value: Calorific value is the amount of heat energy present in a unit value of a fuel, which is typically released by combustion of the fuel.

Carbon market: A carbon market is a trading system wherein entities can gain 'credits' due to actions that results in their emission reductions. These credits have a monetary value and can be traded in a marketplace with other entities that are compliant to buy credits due to insufficient emission reduction.

Coefficient of performance (COP): It is a measure of the performance of a heating ventilation and air conditioning system and refrigeration system. It is the ratio of useful heat/cooling provided to the net input work required to run the system. The higher the COP, the higher the efficiency of the system.

Contract demand: In an electric billing cycle, contract demand is the power demand agreed to be provided by the electric utility to a consumer while setting up of a connection.

Levelised cost of electricity: It is the averaged net present cost of providing electricity from a source (e.g. solar PV systems, which have a lifetime of 25 years). It is an important parameter in determining financial feasibility from different energy generation sources.

Scope 1 and Scope 2 carbon emissions: Greenhouse gas emissions reporting categorises Scope 1 emissions as the direct emissions associated with an organisation, through process emissions or emissions from combustion of fuels on-site. Scope 2 emissions are the indirect emissions resulting from import of heat and electricity from external sources (e.g. electricity purchased from the Indian grid having a high associated emissions due to the widespread use of thermal power plants).

Time value of money: It is a financial concept highlighting that money provided today has a greater value than at a point in future because the money can be used to earn additional profit in the form of interest etc. It is an important precursor to understanding the financial feasibility of several decarbonisation measures, which require high upfront costs and provide cash savings over a course of years.

7.1.2. Units and Measures

Short Form	Full Form
°C	Degree Celsius
CFM	Cubic feet per minute
cm^2	Centimetre square
GJ	Gigajoule
kg	Kilogram
kg/cm^2	Kilogram of force per square centimetre
kJ	Kilo Joule
kV	Kilo volt
kW	Kilowatt
kWh	Kilowatt hour
MJ	Megajoule
MPa	Megapascal
MT	Metric tonne
Mtoe	Million tonnes of oil equivalent
SCM	Standard cubic meter
T	Tonne
tCO_2	Tonnes of carbon dioxide
TPH	Tonne per hour
W	Watt

7.1.3. Conversion Factors

Units	Conversions
1 kWh	0.0036 GJ
1 ToE	41.868 GJ
GCV of high-speed diesel	38.6 GJ/KL
GCV of piped natural gas	0.0397 GJ/SCM
GCV of furnace oil	39.26 GJ/KL
GCV of liquefied petroleum gas	52.3 GJ/MT
GCV of biodiesel	37.3 GJ/MT
GCV of biogas	0.0397 GJ/SCM
GCV of pet coke	31~33 GJ/MT
GCV of coal	19~25 GJ/MT
GCV of woodchips	12.55 GJ/MT
GCV of rice husk	13.39 GJ/MT
GCV of tamarind wood	19.2 GJ/MT
GCV of coconut shell	20.27 GJ/MT

GCV: Gross calorific value

7.1.4. Emission Factors

Units	Emission factor
1 MWh	0.71 tCO_2
1 KL - high-speed diesel	2.6 tCO_2
1 SCM - piped natural gas	2.04 $kgCO_2$
1 KL - furnace oil	2.9 tCO_2
1 MT - liquefied petroleum gas	2.98 tCO_2
1 MT - pet coke	3.7 tCO_2
1 MT - coal	~1.9–2.62 tCO_2

7.2 Appendix B

Advanced technology cases

For decarbonisation measures such as use of renewable energy, process electrification, and switching to other clean fuels, techno-economic studies were conducted. This involved sizing of the new equipment and estimation of their financial viability.

Evaluation of the equipment is first required to estimate technical feasibility. The evaluation process consisted of literature review, case studies of existing usage of the technology, and consultation with technology service providers and advisors with industrial experience. The criteria include (but are not limited to) the following:

Technical criteria	Example
Meeting the capacity requirements of the existing equipment	Most **electric boilers** are limited in size to provide up to 1–1.5 tonnes per hour (TPH) of steam, while textile and pharmaceutical units often have requirements exceeding 4 TPH
Meeting the temperature requirements (process heating equipment)	In refractories sector, use of **direct firing of rice husk and wood** is insufficient to meet the temperature requirements (>900°C) for firing bricks
Disruptions to existing production processes	In aluminium die-casting sector, several units have in-built common lines connecting the furnace (melting/holding) to the die casting machines. Disruptions in the distribution of molten metal must be considered before **changing furnaces.**
Emission reduction	Due to the grid emission factor associated with electricity, shifting from fossil fuels does not always result in emission reduction. An example of this is shifting from a coal-fired thermic fluid heater (TFH) to an **electric-powered TFH**.
Power supply parameters (electric equipment)	**Induction electric furnaces** are a more efficient technology than conventional furnaces but have higher maintenance costs, unless a 33 kV power supply with no disruptions is available.
Lack of data on unit's production	Technologies such as **backpressure turbines** have been utilised in the textile industry; however, its applicability is highly dependent on the unit's desired final pressure. These data are not always provided by the units.

Once the equipment was considered suitable, the financial viability of the decarbonisation measure was determined by calculating the savings and payback period. An example of a feasible decarbonisation measure is given below:

Conversion of gas-based furnace to electric resistance furnace

Annual production (in tonnes): 2,914.3

Working hours per year: 3,720

Energy consumption

Gas furnace	Electric furnace
Annual consumption of piped natural gas (PNG): 6,60,000 SCM Calorific value of PNG: 0.0397 GJ/SCM Current energy consumption: 26,202 GJ SEC of the current gas-based furnace: 9 GJ/tonne	Electric resistance furnaces have SECs ranging from 450–550 kWh/tonne (or 1.62–1.98 GJ/tonne). Taking a mean value of **1.8 GJ/tonne**, the new energy consumption with usage of electric resistance furnace is 5,240 GJ (or 14,55,555 kWh).

Emission reduction

Gas furnace	Electric furnace
Emissions from piped natural gas: 2.04 kg CO_2/SCM Emissions from the existing gas furnace: 1,346 tonnes of CO_2	Emissions from electricity: 0.71 kg CO_2/kWh Emissions from the new electric resistance furnace: 1,033.4 tonnes of CO_2
Reduction in emissions: 312.6 tonnes CO_2/year (**23% drop** in emissions)	

Cost savings

Gas furnace	Electric furnace
Piped natural gas cost per SCM: 65.34 Annual fuel costs (gas furnace): INR 432 lakh	Grid electricity tariff: INR 8.3/kWh Annual fuel costs (electric furnace): INR 120 lakh
Annual reduction in fuel costs: INR 311 lakh	

Payback period

Estimated investment cost (capital expenditure [CAPEX]): INR 307 lakh

Discount rate: 9.61%

Annual operation and maintenance costs kept at 0.5% of CAPEX costs

Payback period: 3 years

7.3 Appendix C

Image A1. Wood-fired boiler for which an energy audit was performed during a field visit in Tiruppur

Image A2. One of the refractory units for which an energy audit was performed during a field visit

Image A3. Refractory unit with DD kiln and chimney for which an energy audit was performed during a field visit

Image A4. (a and b) Pharmaceutical unit operators are seen explaining the operating parameters to the energy auditors during a field visit in Alathur

Image A5. (a) Batter mixing process and (b) prebaked product

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