



Working Paper

Electrification of Textile Heat

Evidence and Insights from Textile Wet
Processing Units in Tamil Nadu and Gujarat



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LIST OF Abbreviation

MSME	Micro, Small, and Medium Enterprises
GAR	Gross As Received
LCoH / LCoS	Levelised Cost of Heat / Steam
TPH / TPD	Tonnes Per Hour / Day
MMF	Man-Made Fibres
GVA	Gross Value Added
T&A	Textile & Apparel
CETP	Common Effluent Treatment Plant
MEE	Multiple Effect Evaporator
ATFD	Agitated Thin Film Dryer
CUF	Capacity Utilization Factor
LT	Low Tension
HT	High Tension
CNG	Compressed Natural Gas
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
COP	Coefficient of Performance
BEE	Bureau of Energy Efficiency
ETP	Effluent Treatment Plant

MT	Metric Tonne
FY	Financial Year
GIDC	Gujarat Industrial Development Corporation
SIPCOT	State Industries Promotion Corporation of Tamil Nadu
MEE	Multiple Effect Evaporator
ATFD	Agitated Thin Film Drying
CETP	Common Effluent Treatment Plant
SEP	Solar Evaporation Pans
NVA	Net Value Addition
ASI	Annual Survey of Industries
CUF	Capacity Utilization Factor
GAR	Gross As Received
HTO	Heat Transfer Oil
IEA	International Energy Agency
GHG	Green House Gases
EPC	Engineering Procurement and Construction
LT-LEDs	Long-Term Low Emission Development Strategy

Executive Summary



India's textile and apparel sector contributes around 11% of manufacturing gross value addition and remains one of the country's largest sources of industrial employment. Gujarat and Tamil Nadu have emerged as two of the most important textiles manufacturing states, together hosting globally competitive clusters spanning spinning, weaving, wet processing and garment manufacturing. Textile processing activities are dominated by micro, small and medium enterprises (MSMEs), which account for the overwhelming majority of units in both Surat and Perundurai. Wet processing operations such as dyeing, bleaching, drying, and finishing are highly energy-intensive, with thermal energy, accounting for the bulk of energy consumption. Steam, hot water and hot air are indispensable to these processes, making industrial heat one of the most critical yet least addressed dimensions of textile decarbonisation.

At the same time, evolving buyer expectations, increasing fuel price volatility, improving cost-economics for clean energy with growing emphasis on supply-chain sustainability are creating a strong imperative to rethink thermal infrastructure and transition towards more efficient and resilient heating systems.

This study assesses pathways for decarbonising industrial heat in textile wet processing clusters in Surat in Gujarat and Perundurai in Tamil Nadu, based on field engagements with process houses, thermal energy profiling, techno-economic analysis and interactions with industry stakeholders. Rather than treating electrification as a simple fuel-switching exercise, the study finds that the transition requires rethinking thermal and grid infrastructure, improving energy productivity, and enhancing long-term competitiveness and resilience of textile manufacturing.

Cluster-level assessments reveal distinct transition contexts

The two clusters represent fundamentally different market structures and fuel-use patterns.

Perundurai, embedded within western Tamil Nadu's export-oriented textile ecosystem is characterised by cotton processing, strong environmental compliance, early adoption of Zero Liquid Discharge (ZLD)¹ systems and increasing sustainability expectations from international buyers. Most units are MSMEs established in the mid-2000s and rely heavily on firewood (*Prosopis Juliflora*) and some coal-based systems. The widespread use of *Prosopis Juliflora* has been facilitated by its official recognition as an invasive species in Tamil Nadu, supporting an established supply chain for industrial fuelwood with relatively favourable calorific value. However, continued dependence on firewood is increasingly constrained by rising fuel costs, variable moisture content and fuel quality, increasing transportation distances, growing traceability and sustainability requirements from global brands and retailers for biomass sourcing, and the substantial land footprint required for fuel storage and handling. Moreover, a significant number of firewood-fired boilers are approaching or have exceeded their typical twenty-year operational life, creating a natural replacement opportunity in the cluster. This makes decarbonisation of the cluster even more critical from a sustainability lens to avoid any inefficient lock ins for the coming decades. This transition window is further strengthened by western Tamil Nadu's proximity to some of India's largest wind resource regions and a mature renewable energy ecosystem, which enables relatively favourable access to low-cost renewable electricity through open-access and group-captive procurement models.



In contrast, **Surat** caters predominantly to India's vast domestic market and is India's largest synthetic textile hub, processing mainly polyester and man-made fibres. Polyester processing requires relatively higher temperatures, increasing the dependence on conventional combustion systems. Unlike Tamil Nadu, where biomass resources are readily available, Surat has limited access to industrial fuelwood and has historically relied on lignite, imported coal and natural gas. The cluster's proximity to Gujarat's lignite reserves and major western ports has facilitated access to domestic lignite as well as imported Indonesian coal, making these fuels the predominant energy sources for textile processing. However, their dependence has also increased manufacturers' exposure to international fuel price volatility and geopolitical disruptions. The recent West Asia conflict² significantly affected the cluster, with sharp increases in fuel costs compounded by labour shortages as prolonged and partial production shutdowns prompted many migrant workers to leave. Consequently, decarbonising the Surat cluster is not only a climate imperative, but also a strategic priority for improving energy security, strengthening industrial resilience and enhancing long-term economic competitiveness.

These contrasting characteristics imply that industrial heat transition

pathways cannot follow a "one-size-fits-all" approach and must reflect differences in product mix, export orientation, fuel dependencies, and thermal requirements. Some of the study findings presented below unpacks these attributes in more details.

First, textile heat demand within a facility is heterogenous, but existing thermal systems are designed around peak loads and high-temperature requirements

Based on our assessments, steam, hot water and hot air together form the backbone of textile wet processing. Heat is required across dyeing, bleaching, washing, drying, stentering, heat setting and effluent treatment operations, each operating at different temperatures and exhibiting distinct load characteristics.

However, existing thermal infrastructure is typically centred around oversized boilers generating high-pressure steam, much of which is subsequently reduced to meet lower-temperature requirements. Moreover, boiler utilization remains lower than its installed capacity at around 40 percent in Surat and approximately 65 percent in Perundurai indicating substantial underutilization of installed thermal capacity for a few years now. In Perundurai, steam demand from dyeing operations is highly intermittent and batch-dependent, whereas

effluent treatment processes such as Multiple Effect Evaporator³ (MEE) and sludge drying⁴ exhibit relatively stable loads. Similarly, in Surat, boilers often generate steam at higher pressures and temperatures than required by downstream applications, leading to energy losses.

These findings indicate that the opportunity for transition extends beyond fuel switching. Industrial heat systems can be redesigned by matching technologies with process temperature requirements, right-sizing equipment, improving load matching, recovering waste heat and deploying modular heating solutions, thereby cutting inefficiencies embedded across the thermal chain.

Second, levelised cost of heating analysis highlights the importance of electricity costs and system integration

The techno-economic analysis demonstrates that the cost of heating for different conventional and advanced technologies cannot be assessed solely on the basis of fuel prices. Levelised Cost of Heat (LCoH) comparisons show that heating costs are influenced by several independent factors, including fuel quality, operating hours, system utilisation, equipment efficiency, electricity tariffs and access to low-cost renewable power.

Unlike conventional combustion systems, the economics of electrified heating technologies are highly sensitive to proper system sizing and process integration. Their competitiveness improves

considerably in applications dominated by low- and medium-temperature heat, where waste heat streams can be recovered, simultaneous heating and cooling loads coexist, and high-capacity utilisation can be maintained.

The comparative LCoH estimates presented below illustrate the range of heating costs associated with different fuel and technology pathways and underscore the importance of affordable renewable electricity in improving the economics of electrification. For instance, heat pump already makes economic sense when compared with LPG burner. At INR 6 per kWh, heat pump can become economically the most-preferred technology over coal, firewood, oil or gas due to their rising costs, fuel availability and sustainability/traceability concerns.

Table 1: Summary of LCoS for different heating technologies and Sensitivity of LCoS to electricity tariffs for electric boilers and industrial heat pumps

Technology	Annualised CAPEX (INR lakh)	Annualised OPEX (INR lakh)	Estimated Annual Costs (INR lakh)	Levelised Cost of Steam (INR/Kg steam)
Coal boiler	34.4	460	494.4	1.96
Firewood boiler	14	533	546	2.17
LPG burner	2.4	284	286.3	3.41
CNG burner	2.6	224	226.5	2.70
Electric boiler	20.4	1210	1229.4	6.35
Heat pump	31.4	74.2	105.5	2.09

Technology	Levelised Cost of Steam for Electricity Tariffs in INR/kWh		
	INR 8.5	INR 6.5	INR 6
Electric boiler	8.28	6.35	5.87
Heat pump	3.1	2.09	1.88

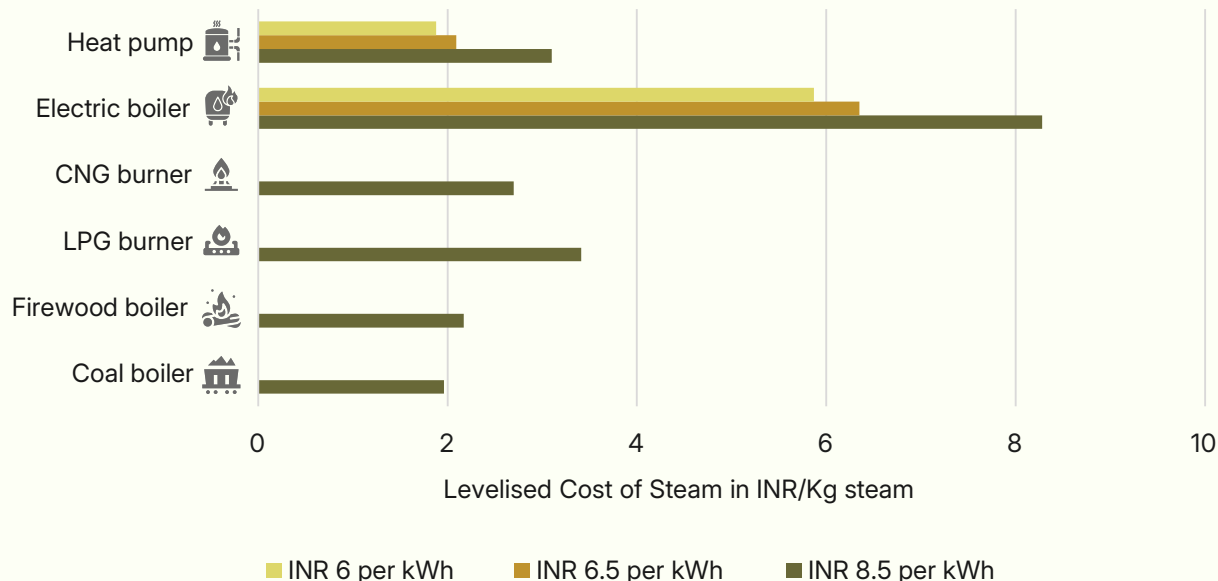


Figure 1: Levelised Cost of Steam for Different Electrification Technologies

Third, ageing infrastructure presents a natural transition opportunity

Based on our field interactions, many textile units are approaching major reinvestment cycles. In Perundurai alone, nearly fifty units operate boilers that have completed their normal operational life and are evaluating replacement decisions. Such replacement cycles provide an important window for redesigning thermal infrastructure instead of locking industries into another two decades of combustion-based systems. Greenfield facilities, in particular, offer opportunities to treat electrified heating as the default design option, while existing facilities can adopt phased approaches centred around waste heat recovery and process integration.

Fourth, ecosystem and policy barriers continue to constrain adoption

Industrial heat electrification is not solely a technology challenge. The study identifies several ecosystem gaps:

- ◆ **Limited process-level steam and thermal data (temperature and flow profiles⁵):** Most MSME units do not have adequate instrumentation to capture hourly

temperature and flow profiles across heat sources and process loads. The absence of steam flow meters, hot-water flow meters, condensate return-meters, temperature sensors, pressure transmitters and machine-level energy monitoring limits the ability to identify actual demand patterns, quantify waste heat availability and assess source-sink matching for technologies such as heat pumps;

- ◆ **Absence of business models suitable for MSMEs:** MSMEs face constraints related to upfront capital, credit access, credit term, technology risk and payback expectations. There is a need for service-based models such as heat-as-a-service, ESCO-led deployment technology leasing, etc. that can reduce upfront investment burden and align payments with usage;
- ◆ **Challenges in accessing affordable renewable electricity:** For example, in Surat, high particulate emissions and soot deposition from coal firing reduce the performance and increase the maintenance of rooftop solar installations and open-access procurement entails additional transaction costs of around INR 1.1-1.5 per kWh in Gujarat. The requirement

for 15-minute energy accounting and balancing adds further complexity for smaller consumers.

- ◆ **Lack of demonstration projects in the sector and performance benchmarks:** There are limited to no cluster-level demonstrations of industrial heat pumps, electric boilers, thermal storage and integrated waste-heat recovery systems in textile wet-processing applications. As a result, MSMEs lack reliable benchmarks on performance, system uptime, steam/hot-water output, operating cost, maintenance requirements, payback periods and integration challenges under Indian operating conditions.
- ◆ **Fragmented supply chains and technology ecosystems:** The ecosystem for industrial heat electrification remains dispersed across technology suppliers, boiler vendors, heat pump manufacturers, EPC contractors, renewable energy developers, utilities, financiers and process-house operators. Limited coordination among these actors makes it difficult to develop bankable projects, standardise designs, after-sales service networks and cluster-level deployment models.

- ◆ **Absence of dedicated policy frameworks for industrial heat decarbonisation:** Existing policy support remains focused on capital subsidies, with limited emphasis on operational incentives such as preferential renewable electricity tariffs, relief from open-access transaction costs, and mechanisms to improve the long-term competitiveness of low-carbon heat. There is a need for dedicated India industrial electrification strategy with clear targets and cluster roadmaps unpacking differing industrial priorities across sectors, incentive structures, technology options and readiness levels for industrial electrification across clusters
- ◆ **Misalignment between brands and suppliers:** Manufacturers have repeatedly highlighted a structural contradiction that while international brands increasingly demand low-carbon production and traceability of fuel, purchasing decisions continue to prioritise lowest cost. This disconnect limits the ability of suppliers to recover investments required for decarbonisation. Greater cost-sharing and stronger engagement across value chains will therefore be critical.

Fifth, electrification offers benefits extending far beyond decarbonisation

The transition to cleaner thermal systems has important co-benefits for textile clusters. These include:

- ◆ **Energy security and import dependence:** Electrification reduces the dependence on imported coal and gas and improving energy security. For clusters like Surat; exposure to imported coal and gas markets has increased vulnerability to international price fluctuations and supply disruptions.
- ◆ **Operational Simplification:** Conventional thermal systems carry hidden operational burden that extends beyond fuel prices. Industries incur substantial expenditures associated with fuel handling, storage, labour, maintenance, ash disposal, pollution control systems and periodic overhauls. Electrified systems eliminate most of these complexities.
- ◆ **Industrial Electrification as RE energy demand anchor:** Cluster level electrification can lead to increased utilisation of new renewable energy getting planned at the state/district level. In effect, industrial clusters that electrify become demand anchors for the green grid, improving the utilisation and financial viability of renewable energy investments.
- ◆ **Worker Health and air quality:** Coal firing in boiler leads to higher emissions and high ambient temperatures that creates heat stress for the workers and poor air quality in and around the cluster. Cleaner thermal systems directly improve the working conditions for the workers and community-level air quality impact as a whole; making the transition as much a public health intervention as an energy one.

Industrial heat electrification should be viewed not merely as an emissions reduction strategy but as an opportunity to redesign thermal infrastructure, enhance energy productivity, strengthen energy security and improve the long-term competitiveness and resilience of India's textile manufacturing clusters.





1 Background

India's Textile and Apparel (T&A) sector is considered to be the second most significant economic driver in terms of employment generation after agriculture, accounting for about 11% of India's manufacturing Gross Value Addition (GVA)⁶ during 2024-25. With about 4 per cent share of T&A global market, India is looking to diversify its export basket (traditionally dominated by cotton textiles) by focusing on Man Made Fibres (MMF). Today, more than 70% of the worldwide garments are made from MMFs⁷ and the shift from natural fibres is being driven by its affordability, durability, strength, consistency in quality, versatility, and weather resistance⁸. Polyester is the most predominant MMF constituting about 57% of all fibres being used globally in 2023⁹. In India, presently, the per capita fibre consumption is 5.5 kg of which MMF consumption stands at 3.1 kg (one of the lowest in the per capita consumption). Historically, India's textile fibre consumption has been positively linked with GDP and it is certain that consumption and demand for MMF is bound to increase in the coming years.

In India, Gujarat has been an important centre of textile production and trade, contributing 60% to India's total exports in the textile sector.¹⁰ Domestically, Gujarat produces 65% of the country's denim fabric¹¹, and 28% of country's cotton¹². Gujarat hosts one of the country's largest MMF hub with daily production of 30 million meters of processed fabric¹³, accounting for 45% of country's MMF production.¹⁴ Surat is the largest centre for production of synthetic fabrics, mainly nylon and polyester. There are over 650,000 power looms and 350 fabric processing (or wet processing that includes textile dyeing, finishing and drying) units. Globally, Surat is set to emerge as a major textile hub as brands seek stability away from Bangladesh, which in turn relies on fabrics from Surat for ready-made garments (RMG).¹⁵ Surat's integrated textile value chain (from power looms to dyeing, embroidery, and garmenting) ensures scalability and cost efficiency which are key to meeting both, its local dominance and increasing international opportunities.

Alongside Gujarat, Tamil Nadu represents one of India's most integrated and export-oriented textile ecosystems, with strong clusters centred around Coimbatore, Erode, Tiruppur, and Karur that span the entire value chain from spinning and weaving to wet processing, garment manufacturing and exports.¹⁶ The State has historically occupied a leading position in India's textile industry and continues to be one of the country's most industrialised manufacturing centres.¹⁷ Supported by one of the world's largest spinning capacities and a well-established cotton-based value chain, Tamil Nadu has built a globally competitive textile sector specialising in cotton yarn, knitwear, home textiles and value-added apparel products. Clusters in Tamil Nadu have evolved into internationally recognised production centres, with Tiruppur serving as India's knitwear capital, Coimbatore functioning as a major spinning hub and Erode emerging as an important fabric processing and dyeing centre.

In recent years, Tamil Nadu has emerged as India's leading textile exporting state, surpassing Gujarat and Maharashtra, with textile exports valued at approximately USD 8 billion during FY 2024-25 and accounting for nearly 22 per cent of India's total textile exports.¹⁸ The State's textile exports have increased nearly 29 per cent over the last four years, reflecting the strength of its cluster-based manufacturing ecosystem and deep integration with global supply chains.¹⁹ Erode district alone exported T&A products worth INR 22.9 billion during April 2025 – January 2026, highlighting the growing importance of western Tamil Nadu's processing clusters in India's export economy.

The export-oriented textile clusters of western Tamil Nadu are increasingly responding to global demand for low-carbon and sustainable manufacturing, creating opportunities for resource efficiency, circularity, and the decarbonisation of industrial heat in textile processing operations.

The rise in MMF consumption and the continued expansion of export-oriented textile manufacturing are reshaping the global textile landscape, but they also raise critical sustainability concerns. Among these, energy-intensive processing and water-use in dyeing and finishing operations contribute significantly to sector's environmental footprint. Across textile processing clusters in Gujarat and Tamil Nadu, while wastewater management has increasingly been addressed through interventions such as Common Effluent Treatment Plants (CETPs)²⁰ and Zero Liquid Discharge (ZLD) systems, thermal energy requirements for process heating and steam generation continue to rely heavily on coal, lignite, biomass, and other combustion-based fuels, resulting in substantial greenhouse gas emissions and exposure to fuel price volatility.

Process electrification is recognised as long-term low-carbon emission development strategies, especially in manufacturing industries.²¹ In this aspect, electrification of industrial operations through power generated by renewables will be prioritised. Studies suggest that electrification of industrial heat (<200°C) is practically achievable today using mature technologies such as industrial heat pumps and electric boilers²². When coupled with renewable energy, electrification technologies can deliver higher energy efficiencies while providing a sustainable alternative to combustion-based thermal systems.

Both Gujarat and Tamil Nadu are well positioned to leverage their growing renewable energy ecosystems to decarbonise their industrial heat and steam requirements in the textile sector. Gujarat currently leads the country in installed renewable energy capacity and has set a target of achieving 100 GW by 2030.²³ Tamil Nadu, meanwhile, has historically played a pioneering role in India's renewable energy transition and remains one of the country's leading renewable energy states, with a mature wind power ecosystem and rapidly expanding solar capacity. The State has been actively strengthening its renewable energy infrastructure through repowering of ageing wind assets, grid modernisation, and investments aimed at transforming itself from a wind-energy leader into a broader renewable energy powerhouse.²⁴ Furthermore, Tamil Nadu has set a target for the State to meet 43.33 per cent of its energy requirements from renewable sources by FY 2030.²⁵ With both States placing increasing emphasis on green growth and the global competitiveness of their textile industries, the transition towards cleaner thermal infrastructure offers an opportunity to enhance energy security, reduce carbon emissions, and future-proof India's textile manufacturing clusters against evolving sustainability requirements and international market expectations.

2

Objective

The primary objective of this study is to assess technical and economic feasibility of decarbonising industrial heat and steam generation in textile processing clusters in Gujarat (Surat) and Tamil Nadu (Perundurai). The Surat analysis specifically focuses on mapping fuel-use patterns, coal dependence and electrification opportunities across the wet-processing cluster.

The study compares existing combustion-based systems such as coal-fired boilers, firewood boilers and thermic fluid heaters with electrified alternatives such as industrial heat pumps and electric boilers. The analysis aims to estimate the levelised cost of steam or useful heat under different technology configurations, fuel prices, electricity tariffs, operating loads, boiler efficiencies, heat pump COPs, capital costs and renewable electricity integration scenarios. The objective is to identify commercially viable pathways for replacing or supplementing conventional boilers and thermic fluid heaters in textile dyeing, drying, finishing and effluent-treatment applications.



3

Methodology, Scope and Limitation

The study focuses on understanding the energy use patterns of textile processing units within the Surat cluster. While there is scope for clean energy integration across the value chain including both upstream and downstream activities, like, weaving, garmenting, raw material procurement, the analyses focus only on applications of industrial heat and steam i.e., textile dyeing, drying and finishing. These activities primarily are carried out in a textile process unit.

There are close to 331 textile process units in Surat operating in GIDC (Gujarat Industrial Development Corporation) governed estates. Textile processing activities in Surat are concentrated within a few major²⁶ (GIDC) estates. Figure X illustrates the spatial distribution of textile process units and highlights the principal processing clusters located at Pandesara, Sachin, Kadodara and Palsana. These clusters formed the primary focus of field visits and data collection undertaken as a part of this study.

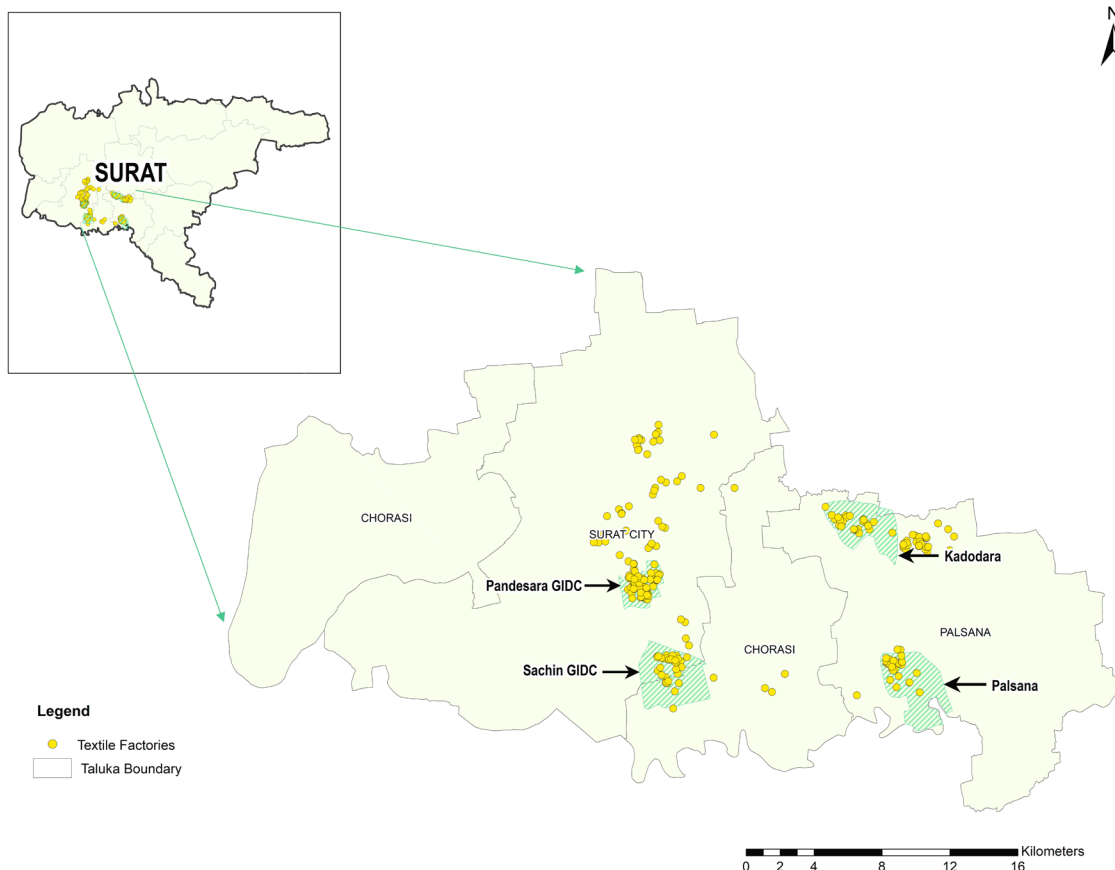


Figure 2: Location of textile processing facilities in GIDC estates and non-GIDC estates in Surat

The study involved physical visits to textile processing units to collect data on both thermal and electrical energy consumption. For data collection, we followed a stratified sampling technique where the segmentation of the textile units was based on two characteristics:

1	Type of processing operation	Only printing
		Both printing and dyeing
2	Cost of operation	High-cost dyeing or both printing and dyeing
		Low-cost dyeing or both printing and dyeing

Each of the four stratum is more internally homogenous, and data was collected from each group more efficiently. While auxiliary equipment in a textile processing unit such as motors, pumps, blowers, compressors, fans, etc. can contribute significantly to electricity consumption, its optimisation falls outside the scope of this analysis.

In addition to evaluating the technical and economic aspects of fuel switching and electrification, the study also assessed the localized environmental impact of existing coal-fired boilers, with a focus on NO₂ (nitrogen dioxide) concentrations in GIDC areas. For this, monthly average values of NO₂ for the year 2024 were calculated using data from Sentinel-5P satellite, specifically, the NO₂ tropospheric column number density bands, extracted and processed via the Google Earth Engine platform.

For Tamil Nadu, the study involved field-level engagements with textile processing units and industry associations across Perundurai SIPCOT, Tiruppur and Salem. The field visits focused on collecting unit-level technical and operational data related to steam generation, thermic-fluid heating, fuel consumption, process temperatures, steam pressure requirements, electricity tariffs, renewable energy access and existing heat-recovery practices.

In Perundurai, detailed data was collected from a medium-scale export-oriented cotton dyeing unit processing around 15 tonnes of dyed fabric per day. The analysis examined the fuel mix, process-level thermal demand across dyeing, bleaching, drying, stentering, heat setting, steam compacting, MEE, ATFD and sludge drying. In addition to Perundurai, indicative data was collected from a large textile processing unit in Salem using Indonesian coal-fired boilers and firewood-based thermic-fluid heaters. The study also considered cluster-level insights from Tiruppur, where dyeing units are served both by individual and common CETPs. Based on field data and excel-based techno-economic modelling, the study the estimated levelised cost of steam/heating for multiple pathways, including existing boilers, thermic fluid heaters, electric boilers and heat pumps. The analysis used parameters such

as fuel price, calorific value, boiler efficiency, steam-to-fuel ratio, operating hours, electricity tariff, heating capacity, capital expenditure, supporting infrastructure, and emission factors.

The scope of analysis in Tamil Nadu clusters, however, were limited to industrial heat and steam applications within textile processing units. Upstream spinning, weaving, sizing, and downstream garmenting operations are not assessed in detail. The assessment is based on a limited number of field interactions and unit-level data points rather than a statistically representative sample of the entire State textile sector. The Perundurai analysis is more detailed because of the availability of steam-metered data. Therefore, the results should be interpreted as techno-economic case studies rather than cluster-wide estimates.

The levelised cost of steam estimates are sensitive to assumptions on fuel prices, fuel quality, boiler efficiency, electricity tariffs, heat pump COP, operating hours, capacity utilisation, etc. In particular, biomass and firewood systems are affected by variation in moisture content, calorific value, seasonal availability and local logistics costs. Similarly, heat pump economics depend strongly on source temperature, sink temperature, process integration, operating hours and whether both heating and cooling benefits can be captured.

Further, the analysis does not include a full engineering design of heat pump integration, piping modifications, heat exchanger sizing, control systems, plant shutdown requirements, or process-level redesign. It also does not include detailed electrical load-flow studies, open access charges, banking charges, demand charges or renewable power procurement constraints, although these factors may significantly affect project viability.

Further, the study identified a broad spectrum of key stakeholders for electrification of industrial heat and steam. These include industry associations, policymakers, electricity utilities, renewable energy developers, technology manufacturers and financial institutions as each play a distinct role in enabling the transition through policy support, infrastructure development, technology deployment, and investment facilitation.

4

Textile Processing

Textile processing units are also referred to as dyeing and finishing units as they impart the yarn and/or fabric with the required colours, textures, resilience, and other characteristics through a range of processes that can be grouped as:

- 1 Preparation process such as scouring (washing), shrinking and bleaching
- 2 Dyeing or wet processing
- 3 Finishing processes such as squeezing, drying and pressing

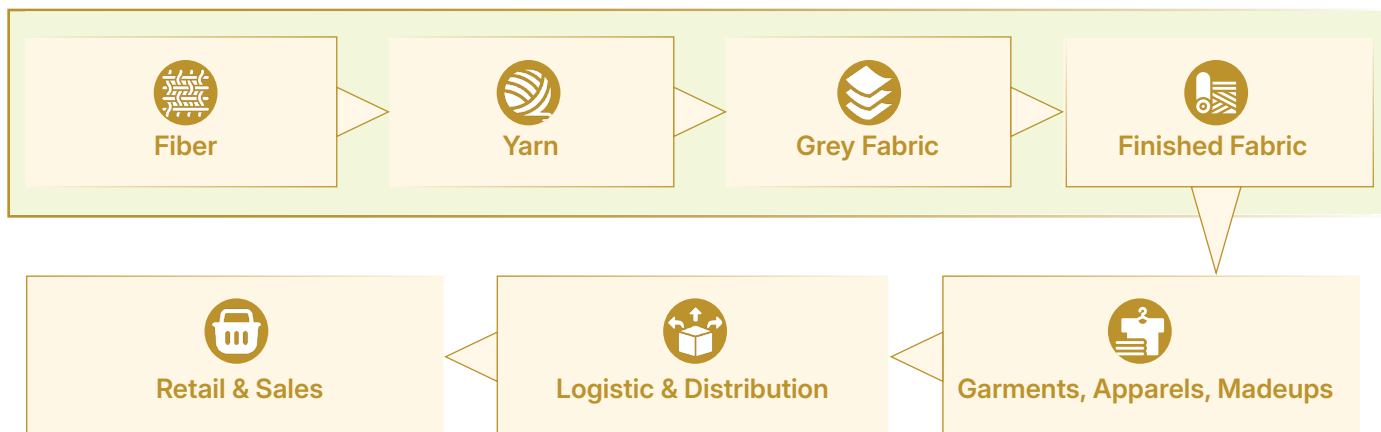


Figure 3: Textile value chain from fibre to retail

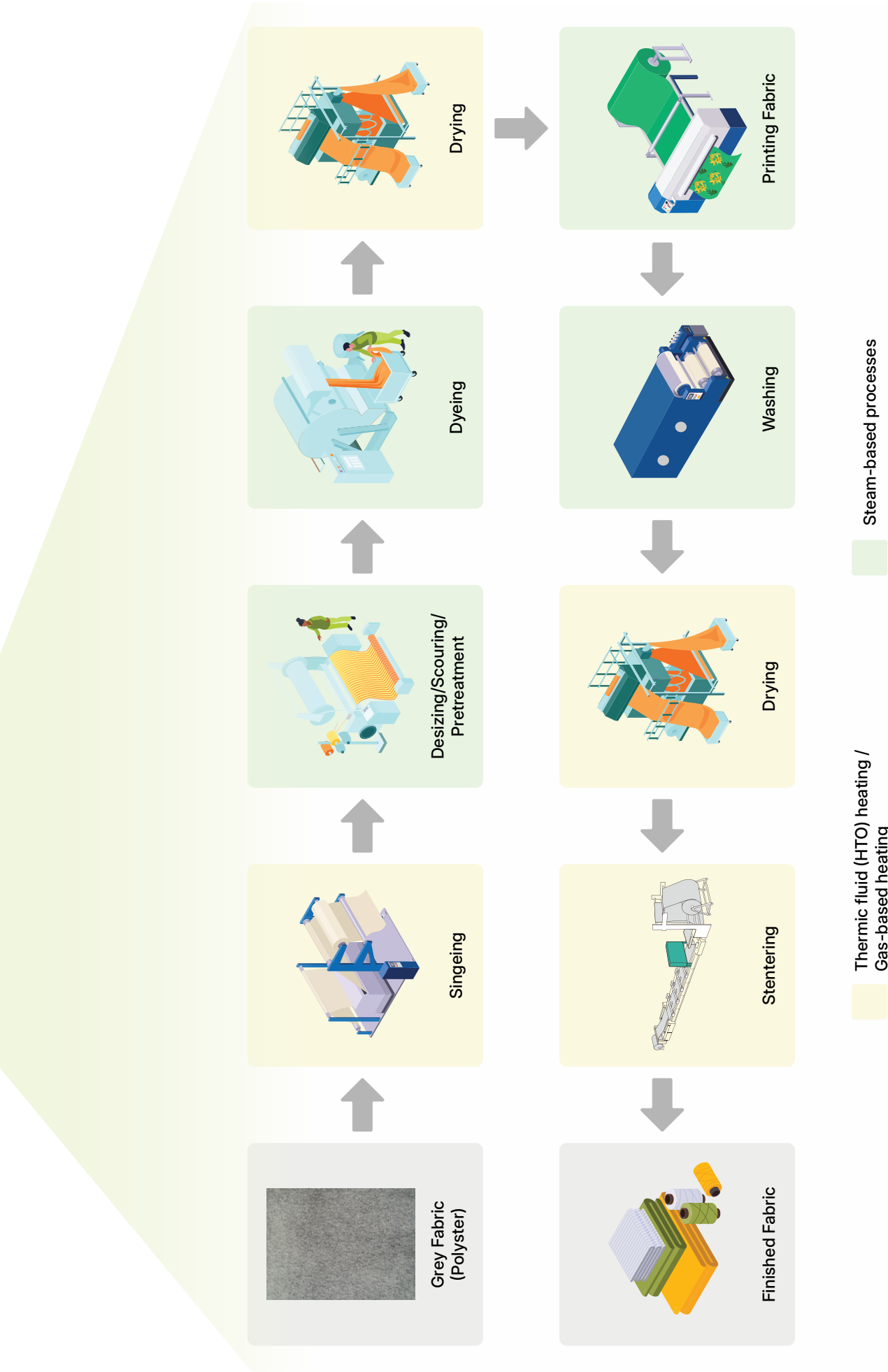


Figure 4: Major heat-intensive wet processing stages in textile manufacturing

5

Erode-Perundurai Textile Hub

Alongside Tiruppur and Coimbatore, Erode forms an integral part of western Tamil Nadu's textile ecosystem and hosts India's leading textile wet-processing clusters. The Perundurai SIPCOT Industrial Growth Centre was developed with a dedicated focus on textile processing industries and houses bleaching and dyeing units. The cluster forms part of a broader cotton-based textile value chain integrated with spinning mills in Coimbatore, knitwear manufacturers in Tiruppur and home textile producers in Karur.

The cluster provides direct employment to around 15,000 workers, nearly one-third of whom are women. The units are predominantly MSMEs and cater to both domestic and export markets through value-added textile processing operations. The cluster primarily processes cotton fabrics sourced from neighbouring textile centres and specialises in dyed and finished fabrics used in garment manufacturing.

Perundurai SIPCOT occupies a unique position among textile clusters in India owing to its early adoption of environmental infrastructure. The cluster became the first textile processing cluster in Tamil Nadu to migrate to Zero Liquid Discharge (ZLD) systems in 2006 and was also the first to voluntarily integrate with the Tamil Nadu Pollution Control Board's Water Quality Watch Centre, enabling online monitoring of effluent treatment operations. Further, all textile processing units in the cluster have transitioned from conventional Solar Evaporation Pans (SEP) to Agitated Thin Film Dryers (ATFD), making it one of the few clusters in the country to achieve complete migration towards advanced sludge management systems.



From an energy perspective, Perundurai SIPCOT represents one of the largest concentrations of industrial heat demand in Tamil Nadu. The cluster has an estimated steam requirement 150 TPH, with steam generated at approximately 8.5 bar and utilised at 6 bar pressure within textile processes. Thermal energy is consumed across dyeing, bleaching, dyeing, stentering, heat-setting and effluent-treatment operation, with fuels such as firewood, biomass, coal and LPG currently meeting most of the heat demand.

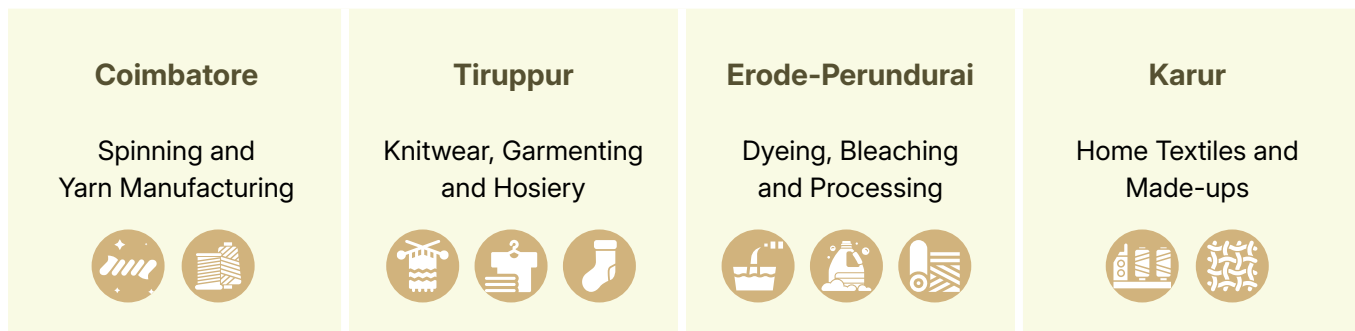
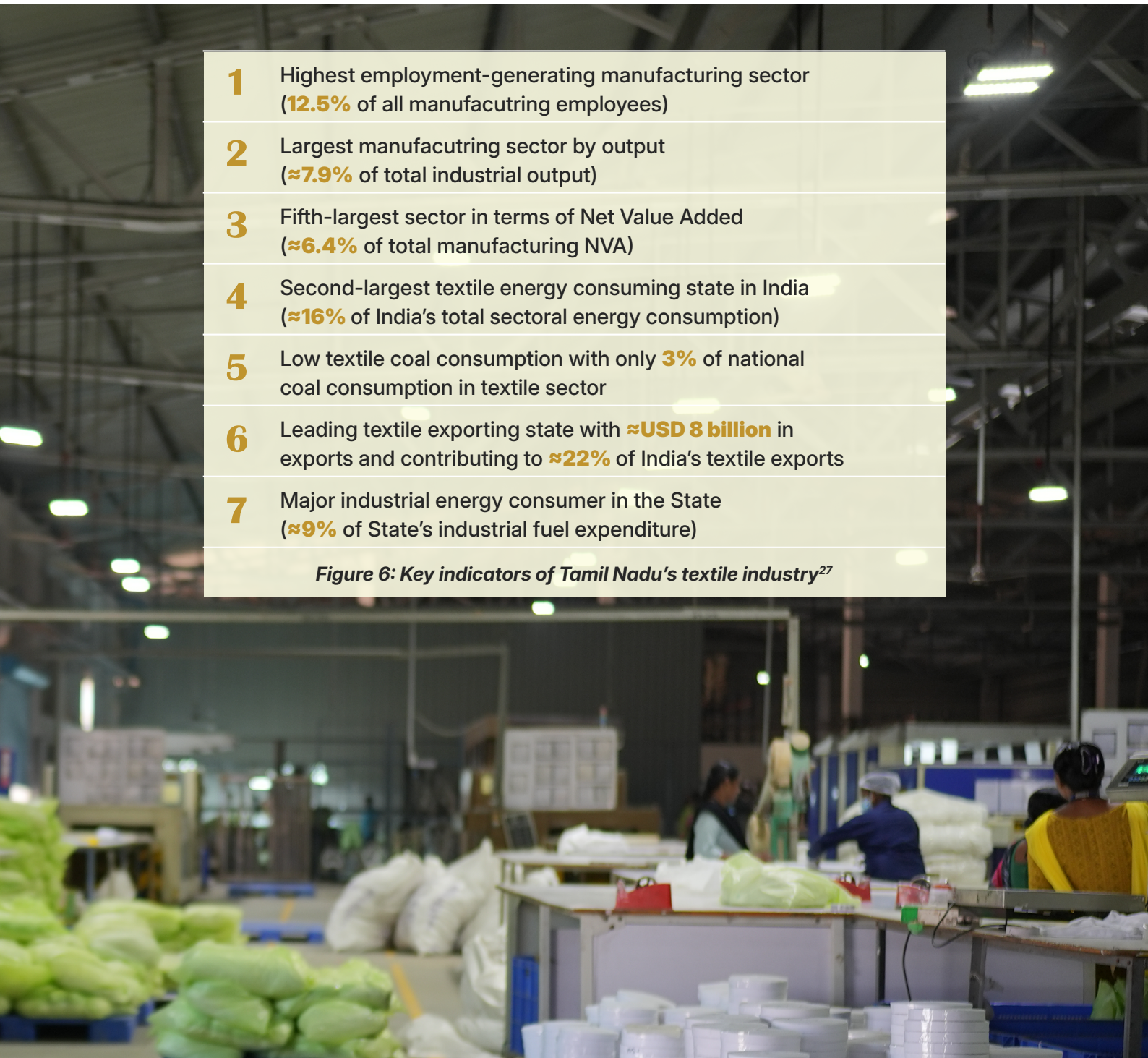


Figure 5: Major Textile Manufacturing Hubs in Western Tamil Nadu

- 1** Highest employment-generating manufacturing sector (**12.5%** of all manufacturing employees)
- 2** Largest manufacturing sector by output (**≈7.9%** of total industrial output)
- 3** Fifth-largest sector in terms of Net Value Added (**≈6.4%** of total manufacturing NVA)
- 4** Second-largest textile energy consuming state in India (**≈16%** of India's total sectoral energy consumption)
- 5** Low textile coal consumption with only **3%** of national coal consumption in textile sector
- 6** Leading textile exporting state with **≈USD 8 billion** in exports and contributing to **≈22%** of India's textile exports
- 7** Major industrial energy consumer in the State (**≈9%** of State's industrial fuel expenditure)

Figure 6: Key indicators of Tamil Nadu's textile industry²⁷



5.1 Inside Textile Processing Factories in Erode-Perundurai

Textile processing units located in Perundurai were set up mostly in mid-2000s almost 90% of the units are MSMEs engaged in the processing of grey knitted cotton fabric sourced from Tiruppur. Within the cluster, a sample unit that we analysed produces dyed cotton fabric for captive garment manufacturing and processes approximately 15 tons of processed fabric per day, operating for nearly 300 days a year. The production process is centred around wet processing operations, with dyeing and steam compacting constituting core thermal applications. In addition, the unit operates an in-house effluent treatment facility to comply with environmental requirements.

The unit relies predominantly on firewood, supplemented by LPG and electricity, with peak solid fuel consumption reaching nearly 30 tonnes per day. Fuel is procured on a weekly basis with a minimum storage inventory equivalent to one month. Firewood is sourced primarily from districts of Ramanathapuram and Tiruchirappalli at an average cost of approximately INR 5,400 per ton. The unit has already invested in energy monitoring infrastructure and is equipped with eight steam flow meters distributed across dyeing applications, steam generation systems, sludge dryers, ATFDs, MEE systems, and steam compacting operations. Heat recovery measures have also been implemented through recovery of flue gas heat, effluent heat, and cooling water from process machines.

The overall thermal requirement of the facility in terms of steam amounts to approximately 75 tons per day. Of

this, nearly 30 tons is consumed by textile processing operations, particularly dyeing and steam compacting, while the remaining 45 tons is utilised by effluent treatment plant. Accordingly, the unit operates two independent steam systems. A manually fired 3-TPH firewood boiler supplies steam for the core textile processes, whereas a separate 2-TPH boiler caters to steam requirements associated with ETP. Both systems have been operational for more than eighteen years and continue to serve as the backbone of thermal infrastructure. The boilers operate at pressures of 9 kg/cm² and 7 kg/cm² respectively, while process requirements are generally lower, indicating scope for improved load matching and thermal optimization.

Besides steam, the facility employs a thermic fluid heating system rated at 20,00,000 kcal/h to provide high-temperature heat for drying, stentering and heat-setting operations. The thermic fluid heater delivers up to 240°C and incorporates air preheating using recovered flue gas, thereby improving overall thermal efficiency.

Process mapping indicates that steam and industrial heat are delivered at different temperature levels depending on the application. Dyeing operations are carried out at 130°C and 6 kg/cm² steam pressure, while bleaching applications operate at approximately 120°C. Steam compacting requires saturated steam at around 3.5-4 kg/cm² pressure. High-temperature applications such as drying, stentering and heat setting are served through thermic fluid heating systems. The unit employs soft-flow dyeing technology, which represents one of the most energy-intensive operations within the plant.

Understanding Steam Demand in Batch Dyeing Processes: Need for Micro-level Load Profiling

Unlike a continuous process, thermal demand in the dyeing section is highly dynamic and batch-dependent. Steam consumption is not uniform throughout the cycle, nor is saturated steam at 6 bar pressure is required continuously. Initial filling and chemical addition stages rely largely on hot water recovered from process condensate and pre-heating tanks, while steam is withdrawn intermittently to raise the liquor temperature from ambient conditions to around 55-60°C and subsequently to higher temperature levels in the range of 80-90°C. Steam effectively acts as a temperature top-up medium, supplementing the available recovered hot water whenever the temperature ramp cannot be achieved solely through heat recovery. Consequently, steam demand is characterized by short-duration, high-intensity withdrawals rather than steady consumption. Analysis of a representative dyeing recipe for a single machine indicates that, steam is required only for a total duration of 264 minutes in a day. Peak steam withdrawal therefore occurs only during certain stages of the batch cycle and at particular times of the day, resulting in highly intermittent and instantaneous loads.

This behaviour highlights that the design basis for thermal systems should be derived from process-level and batch-wise load profiles rather than assuming a constant steam requirement, thereby creating opportunities for right-sizing of heating infrastructure, thermal storage integration, and deployment of modular heating systems.

Analysis of hourly steam consumption profiles (See Figure 7) reveals distinct variations between core textile operations and the effluent treatment systems. The 3 TPH boiler dedicated to textile processing experiences fluctuating steam demand corresponding to batch-wise dyeing and finishing schedules. Steam consumption peaks during dyeing and steam compacting cycles, resulting in intermittent load patterns. In contrast, the 2 TPH boiler serving the ETP (See Figure 7) exhibits a comparatively stable profile owing to the continuous operation of multiple-effect evaporators (MEE), agitated thin film dryers (ATFD), and sludge drying systems. The combined steam demand profile highlights the importance of understanding process-level load variations for appropriate sizing of alternative heating technologies.

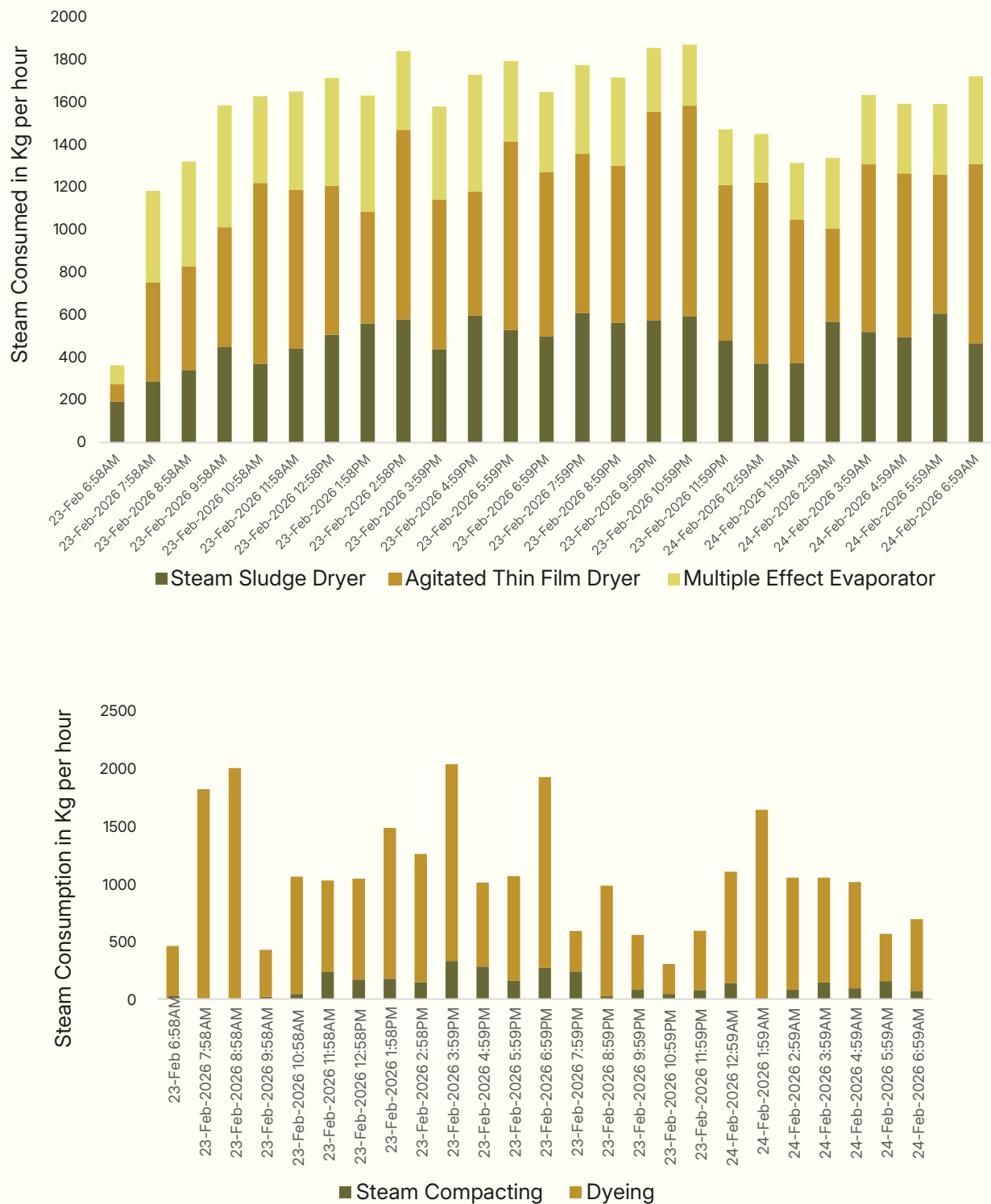


Figure 7: Hourly steam demand across core and non-core (effluent treatment) textile processes

Production and hot water consumption profiles (See Figure 8) indicate a strong correlation between fabric throughput and process water requirements. As daily production increases, hot water demand correspondingly rises, reflecting the water-intensive nature of wet processing operations. Dyeing operations require substantial quantities of hot water for washing, rinsing and process preparation, resulting in large fluctuations in hot water consumption over time. The data also show that production schedules are not uniform across days, with periods of low or zero production corresponding to proportionately lower steam and hot water requirements. These variations reinforce the importance of considering batch-wise production patterns while designing electrified heating systems.

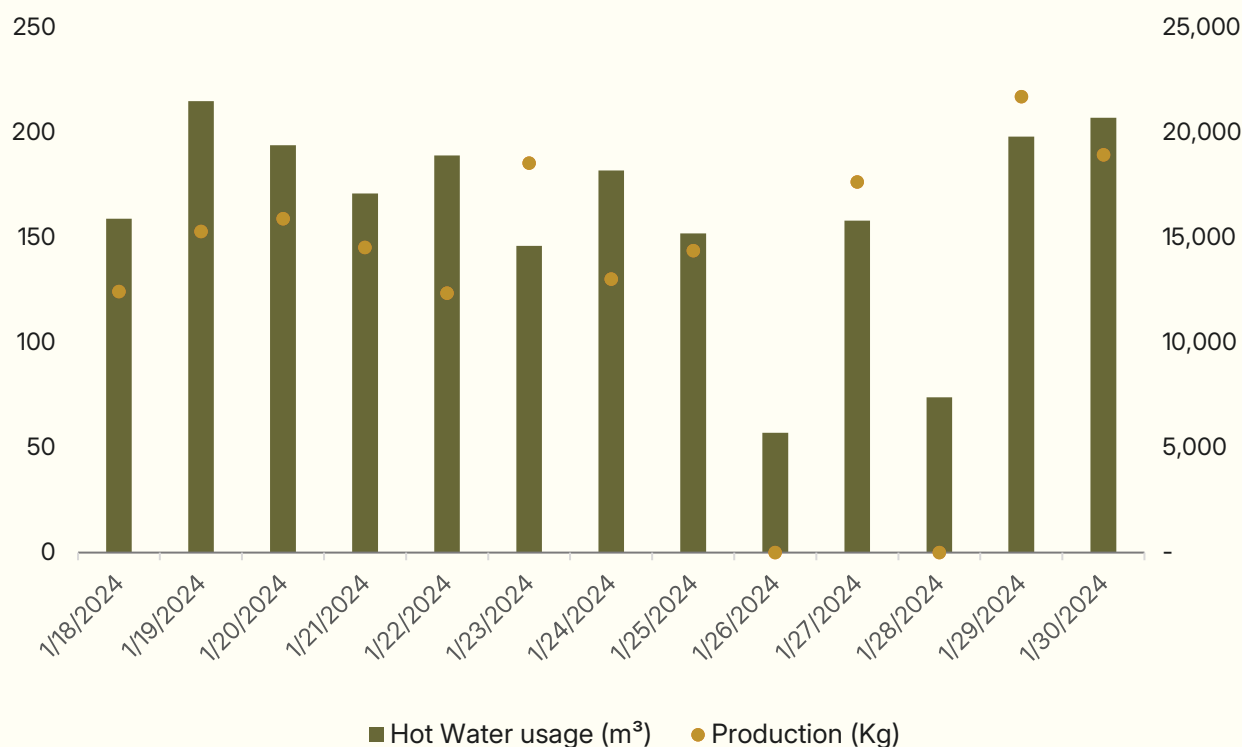


Figure 8: Daily hot water consumption relative to fabric production

The cooling return water profiles indicate the presence of significant quantities of low-grade waste heat circulating within the facility. The availability of return water streams from process cooling systems provides a potential heat source that can be upgraded through industrial heat pumps. Such streams represent an important opportunity for waste heat recovery and can improve the economics of electrification by reducing the temperature lift required for heat pump operation.

The data further suggest that thermal energy dominates the facility's energy consumption, with steam and process heat accounting for the overwhelming majority of energy requirements. Existing heat recovery systems and the availability of detailed steam metering provide a strong foundation for data-driven energy management. The presence of separate steam systems for production and effluent treatment also presents opportunities for phased interventions and targeted decarbonisation strategies.

5.2 Biomass Fuel Quality, Traceability and Sustainability Considerations

Fuel quality is an important operational variable in biomass-fired systems. The reported calorific value of 3,000 kcal/kg is consistent with a relatively low-grade or moderately moist biomass fuel. In practice, firewood with higher moisture content will have lower useful heat value because a portion of the combustion energy is consumed in evaporating water contained in the fuel. Higher moisture content can therefore increase specific fuel consumption, reduce boiler efficiency, increase smoke and particulate emissions, and create greater variability in steam generation. This is particularly relevant for manually fed boilers, where combustion control is already limited and fuel heterogeneity can result in fluctuating steam pressure and incomplete combustion.

Prosopis Juliflora (Juliflora) may offer certain advantages as a locally available woody biomass, particularly where it is sourced from managed removal of invasive growth. However, its use cannot be treated as automatically sustainable unless sourcing is documented and monitored. If a commercial market develops without safeguards, it may create incentives for continued propagation or unmanaged harvesting. Therefore, any use of Juliflora or firewood should be accompanied by farm-to-fuel traceability systems that document the origin of biomass, harvesting permissions, species type, moisture content, transport distance, supplier details and storage practices.²⁸

Overall, the Perundurai unit-level analysis demonstrates that biomass-fired steam systems remain central to textile processing and effluent treatment, but also carry significant operational, emissions and traceability challenges. The derived specific fuel consumption values indicate that each kilogram of dyed fabric may require approximately 1.4 kg of firewood under normal plant-level operations, rising up to 2 kg/kg under peak fuel-use conditions. While biomass may appear cheaper than fossil fuels on a delivered cost basis, its long-term sustainability depends on fuel quality, moisture control, verified sourcing and ecosystem safeguards. Therefore, future decarbonisation should not rely solely on fuel switching within biomass categories, but should prioritise demand reduction, waste heat recovery, electrified heat pumps, thermal storage and renewable electricity-backed process heating.



5.3 Other Findings

Discussions with industry stakeholders, including representatives of dyeing units in the Perundurai SIPCOT cluster, provided several insights into current steam demand, boiler replacement cycles, and emerging approaches to thermal energy supply. A significant number of industrial units in the cluster currently rely on steam boilers for their process heat requirements. It was observed that nearly 50 units in the cluster operate boilers that have already completed their typical 20-year operational cycle. As these units approach equipment replacement decisions, they are evaluating options to either replace the existing boilers with similar systems or transition to alternative technologies.

At the same time, several units in the cluster are undergoing capacity expansion, which is prompting discussions around shared thermal infrastructure which are biomass-based steam generation systems. Agro-waste boilers require frequent maintenance shutdowns, typically once every 7-15 days, which necessitates the installation of multiple units to ensure uninterrupted steam supply. While a few larger units in the cluster continue to rely on fossil-fuel-fired boilers, there is increasing pressure from international buyers and export markets to transition toward lower-carbon fuels, reflecting sustainability expectations in global textile supply chains.

Industry stakeholders also highlighted several challenges associated with the increasing shift from coal to firewood and other biomass-based fuels. While biomass is often considered a lower-carbon alternative, its adoption presents practical challenges related to fuel quality, supply reliability, and cost stability. One of the key concerns raised by units in the cluster relates to the traceability and consistency of firewood and biomass supply. Ensuring reliable documentation of fuel origin and sustainability is increasingly important as global buyers place greater emphasis on supply chain transparency and environmental compliance. However, the existing biomass supply chains are largely informal, which makes traceability verification difficult for many units.

Operational challenges were also reported in relation to fuel quality, particularly the high moisture content commonly observed in firewood which can go up to 70 per cent during peak monsoon periods. Higher moisture levels reduce combustion efficiency and can increase operational variability in boiler performance. In addition, industries noted the presence of supply-side risks, including fluctuations in biomass availability and price volatility.

The availability of agro-based fuels such as paddy residues is also constrained in several regions. Stakeholders indicated that multiple industries, including power generation, brick kilns, paper and pulp, and other manufacturing sectors are increasingly

competing for the same biomass resources. The growing demand has contributed to supply shortages and upward pressure on biomass prices, creating uncertainty for industries that rely on such fuels for their thermal energy needs. Furthermore, the procurement and handling of biomass fuels often involve additional logistics costs, including aggregation, transportation, drying, and storage infrastructure. These activities can require specialized handling and storage facilities to maintain fuel quality and ensure continuous supply. For industries operating with relatively thin profit margins, these additional costs can significantly affect the economic viability of biomass-based fuel switching.

Stakeholders also noted the evolving expectations of international buyers and brands, particularly in export-oriented sectors such as textiles. While buyers increasingly emphasize environmental compliance, traceability, and low-carbon production, procurement practices within supply chains continue to prioritize cost competitiveness in finished products. This creates a complex operating environment for manufacturers, who must simultaneously meet stringent sustainability expectations while maintaining cost competitiveness in global markets. Greater alignment between sustainability requirements and commercial procurement practices across supply chains could therefore play an important role in enabling a smooth transition toward cleaner energy solutions.

6

Surat Textile Hub

6.1 Economy and Sectoral Overview

Surat is an industrial city and a leading contributor to the State's industrial output and Net Value Added alongside Bharuch, Jamnagar, Ahmedabad and Vadodara. Correspondingly, it has the highest number of workers among all districts in the State, highlighting its pivotal role in employment generation and economic activity. Key manufacturing sectors in the district include textiles, machinery and equipment,

chemicals and chemical products, and food products, with textiles being one of the most fuel-intensive sectors.²⁹ Industries in Surat are the largest consumers of electricity and petroleum products, second-highest consumers of coal, and the third-highest consumers of natural gas after Morbi and Bharuch.³⁰ Various parameters defining the size and contributions of the textile manufacturing sector, both at the State-level and in Surat are described in the figures X and X below.

Table 3: Key indicators of the Surat textile cluster

Number of Textile Industries ≈38000	Business Dyeing, printing, garment, weaving, wholesale markets
Daily Production 30 million metres of processed fabric	Cluster Size Second largest textile hub in India, after Tiruppur
Annual Turnover INR 40,000 Crore	Products Yarn, fabrics, saree dress materials, and ethnic wear
Export Market Volume INR 500 Crore	Industrial Segment 95% of units are MSMEs (excluding large textile integrated units)
Employment 1.6 million	Domestic Market Volume 45% of Man-made fabric, 65% of denim fabric and 28% of cotton consumed in India

 Highest number of workers (21.17%) and employees (20.09%)	 Third-largest district in terms of its contribution of Net Value Added by manufacturing sector (13.79%)	 Second highest in terms of total fuel consumed (15.99%) by Industries
 Maximum number of textile manufacturing units (1693 units) in the State (56.98%)	 Second-highest coal consuming district (17.73%)	 Highest consumer of electricity (63.27%) and petroleum products (10.69%) and third-highest consumer of gas (13%)

Figure 9: Industrial and textile profile of Surat³¹

1	Second-highest coal consuming industrial sector (23.38%)	
2	Top-five industrial sector (9.57% of total factories)	
3	Sixth-largest industrial sector in terms of Net Value Added (6.07%)	
4	Highest number of workers (17.54%) and employees (16.17%)	
5	Third-highest in total fuel consumed by any industrial sector (11.34%)	
6	Second-highest coal consuming sector (21.60%)	
7	Fourth-highest electricity consuming sector (13.07%)	

Figure 10: Gujarat's textile manufacturing sector at a glance³²

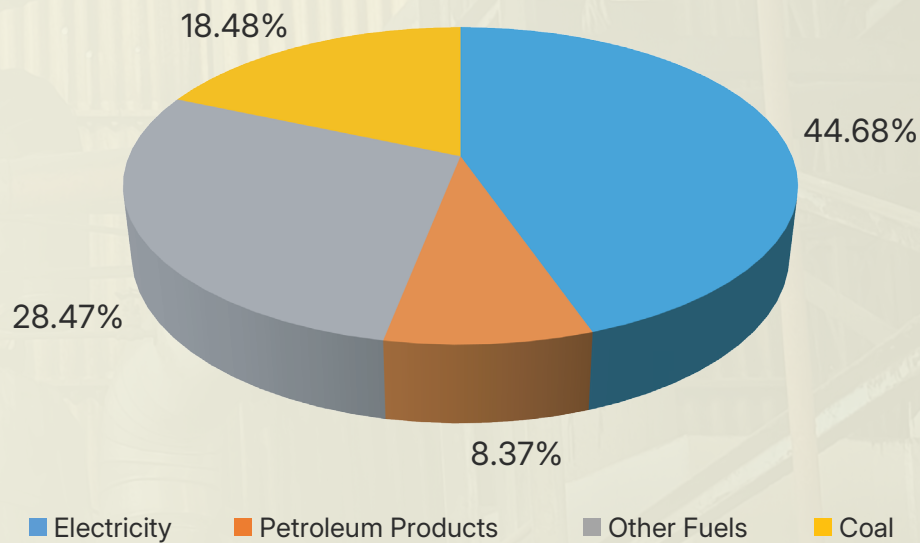


Figure 11: Composition of industrial fuel consumption in Gujarat (2020-21)

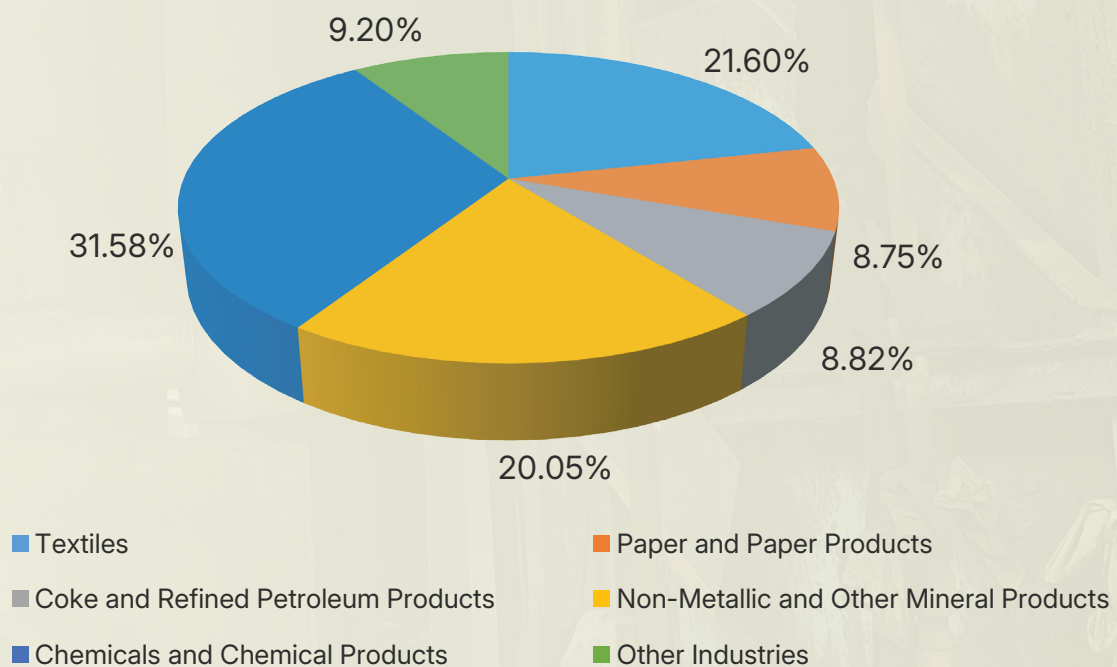


Figure 12: Sector-wise distribution of coal composition in Gujarat's manufacturing sector

6.2 History and Growth of Surat's Textile Sector and other key Industries

6.2.1 Textile Value Chain and Processing Characteristics

Surat is largely known as the MMF capital of India, with over 90% of fabric processed in Surat being polyester-based MMF fabric (including blends with viscose, nylon, etc.). Cluster accounts for a total production of 40 million metres of fabric per day consisting of polyester. Surat dominates domestically in fibre, yarn and finished fabric. Textile processing involves textile bleaching, dyeing, printing and finishing fabrics.

Textile value chain in the cluster include:

Power looms	Garments	Embroidery and Design	Spinning	Dyeing and Finishing	Other
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Surat hosts 57% of textile manufacturing units in the State with more than 80% of them engaged in wet processing or in the production of grey fabric with power looms.

6.2.2 Inside Surat's Textile Processing Factories

Textile processing units in the Surat vary significantly in their daily production capacity. According to the Bureau of Energy Efficiency (BEE) cluster study, units can be broadly classified into three categories based on the amount of fabric processed per day. Small units process less than 50,000 metres per day, medium units process between 50,000 and 100,000 metres per day, while large units process more than 100,000 metres of fabric per day.³³

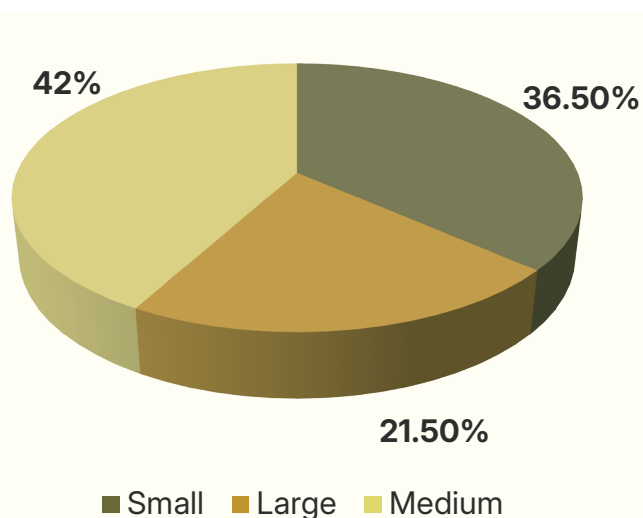


Figure 13: Production capacity distribution of dyeing and printing units in Surat

Analysis of textile manufacturing processes shows that the highest energy intensity occurs in wet processing stages such as dyeing, drying, and finishing³⁴. These stages rely heavily on thermal energy and therefore represent the most promising entry point for electrification. Among these, dyeing is the most energy-intensive operation, accounting for nearly 40% of the total energy use. The dyeing process requires hot water or steam with 45-50 litres of water

being consumed per kg of cloth dyed. Hot air stenters account for another 18-20% of the remaining energy while the rest are utilised in powering air compressors, and pumps. Generally, energy costs account for 16-20% of the total manufacturing cost. Besides energy, water and chemicals add a significant cost to the overall manufacturing cost.³⁵

6.2.3 Business and Exports (Job-work basis)

Majority of the units in the cluster are of integrated type, where grey cloth (raw material) is purchased from outside and the same is processed for dyeing and printing. The main products manufactured in cluster units are synthetic sarees and dress materials and cotton dress materials. More than 80% of the units are engaged in job works wherein, local traders provide the design and raw material (grey cloth) and the units process the raw material for dyeing and printing as desired by the traders.

6.2.4 Policy and Governance

In Gujarat, the textile sector is governed and administered by the Industries and Mines Department, as the state does not have a separate Textile Department, unlike states such as Maharashtra and Tamil Nadu.

The erstwhile 2012 Textile Policy focussed on full value-chain approach i.e. Farm-Fiber-Fabric-Fashion-Foreign securing jobs, capital inflow into the sector, alongside other benefits. It was then revised in 2019 with inclusion of interest subsidy and power tariff subsidy. In 2024, the state got a new textile policy with enhanced capital investment subsidy, support for energy conservation and technology upgradation, alongside other support mechanisms. The latest policy offers an additional 15% capital subsidy on top of other capital incentives for sustainability-focused investments.

Further, textile units in Gujarat can leverage complementary incentives under both the 2024 Policy and the Gujarat Industrial Policy 2020. While the 2024 policy offers targeted support for green technologies, resource-efficient equipment, the 2020 policy supplements these efforts through capital subsidies for cleaner production measures and infrastructure support for common environmental infrastructures. By strategically structuring the investment plans, textile units can access non-overlapping incentives under both policies – maximising financial support for environmental compliance, green manufacturing, etc.

6.2.5 Industrial Heat and Steam

We break down the steam and temperature range along with heat source for each of the finishing processes in a typical textile unit (considering processing of cotton, polyester fabric). Coal boiler generates high temperature high pressure steam which is reduced to a level below 3.5 kg/cm² pressure through Pressure Reduction Valves³⁶. However, at the boiler end, saturated steam is generated at a higher-pressure range between 6-12 kg/cm² with temperatures between 170-195°C.

Steam is an integral component of textile processing, serving not only as a carrier of heat but also as a medium that facilitates dye fixation and penetration into the fibre. The combined action of heat and moisture promotes the formation of dye-fibre bonds and enhances the diffusion of dye molecules into the fabric, ensuring uniform colouration and wash fastness. Inadequate or inappropriate steam conditions can lead to uneven dyeing and poor colour retention. A typical textile processing unit in Surat operates with an average thermal load of approximately 4.1 MWth to meet its industrial heat and steam requirements. Such units generally consume around 3-4 tonnes of steam per hour, with steam being used across multiple operations including dyeing, printing, washing, drying and finishing. In addition to facilitating dye fixation, steam is required for washing off excess dyes and chemicals from the fabric. The temperature and quality of steam required for dyeing and printing vary considerably depending on the fibre type, its chemical structure and the affinity of the dyes being used.

Table 4: Operating conditions and thermal requirements of major textile processing operations

Process	Pressure (bar)	Required Process Temperature (°C)	Medium	Function
Desizing	2.0-2.5	95-105	Steam	Removes size materials before dyeing and finishing
Scouring/ Bleaching	3.0-4.5	110-130	Steam	Removes natural impurities and oils
Dyeing (Jet)	Up to 4.5	130-140	Steam	Removes natural colour
Dyeing (Jigger)	3.0-4.5	90-130	Steam	Impart colour uniformly using closed machines
Pad Steam Dyeing	2.5-3.5	100-105	Steam	Applies dye using a padder followed by steam to fix the dye
Printing (Loop Steam)	2.0-3.5	100-105	Steam	Localized application of dye and pigments in patterns
Finishing (Drying)	1	100-140	Hot Air	Removes moisture, softens hand feel
Heat Setting (Polyester)	1	180-200	Hot Air	Stabilize synthetic fibres by exposing them to high temperature
Curing	1	150-180	Hot Air	Colour fixation
Calendar Rolls (Finishing)	1	120-180	Heated Roll (Steam/ Hot Air)	Surface finishing and smoothness
Drum Dryers	1	120-170	Steam-Heated Cylinders	Fabric drying
Stentering	1	160-200	Hot Air	Fabric drying and width setting

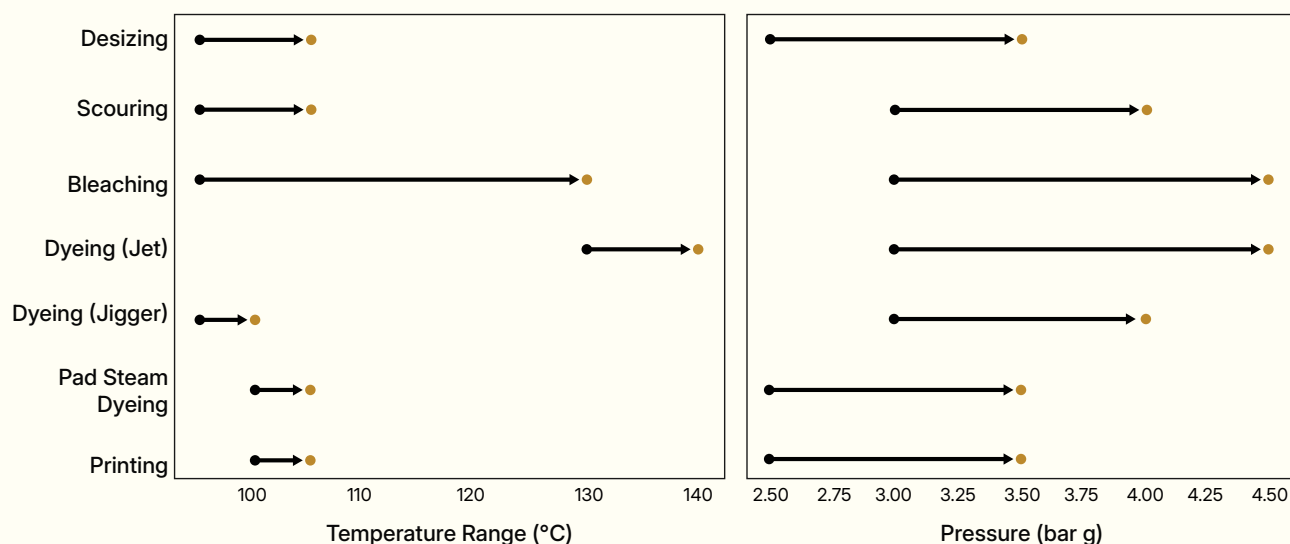


Figure 14: Operating temperature and steam pressure ranges for major textile processes

On the other hand, thermic fluid heaters are deployed specifically to deliver high-temperature heat (without suffering any pressure vessel regulations, as the heat transfer medium is oil). In a textile unit, thermic fluid heaters deliver non-pressurized heat between 180-280°C with rated capacity between 3,00,000 kcal/h to 10,00,000 kcal/h and beyond.

Table 5: Typical maximum process temperature range for different textile fibres

Fiber	Maximum Process Temperature
Cotton	130-150°C (Steam)
Nylon	120-140°C
Polyester	190-210°C
Rayon	120-130°C

Table 6: Typical processing temperature requirements of major textile fibres

Fiber	Typical Process Temperature Range	Remarks
Polyester	120-130°C (dyeing)	Needs high-temperature, high-pressure dyeing using disperse dyes
Viscose	85-105°C (dyeing)	Usually dyed with reactive or direct dyes at atmospheric pressure with the need of moderate to high-temperature steam
Nylon	100-120°C	Requires moderate to high-temperature steam under slightly elevated pressure
Cotton	60-105°C	Processed at lower temperatures although steam is required for fixation in printing

7

Data Collection, Analysis and Insights

7.1 Solid Fuels

Textile units in Surat use high-grade Indonesian coal. As per our estimates, a typical textile unit in Surat consumes 25-40 metric tons of coal per day based on its production size. Coal of high-grade quality (≥ 5000 GAR) and medium-grade quality (3600 GAR) is widely preferred across the cluster.

Any textile mill in Surat is highly sensitive to the prices of imported coal and lignite and any fluctuation in its price and availability can affect its working capital, production, and hence, daily operations. For example, in 2022, nearly 15 textile dyeing and printing mills in Surat have shut down, unable to maintain due to high

costs and shortages in supply of lignite and imported coal on the account of low production from the lignite mines and global geopolitical disruptions that hit the international coal supply. This is also reflected in the increase in price of international coal during the same period.³⁷ More recently³⁸, similar pressures have re-emerged with rising international coal prices affecting the operating costs of textile processing units.

Since a significant portion of the coal used in the cluster is imported, international factors such as geopolitical tensions, trade restrictions, shipping disruptions, and volatility in global energy markets can directly influence the landed cost and availability of fuel for industrial users.

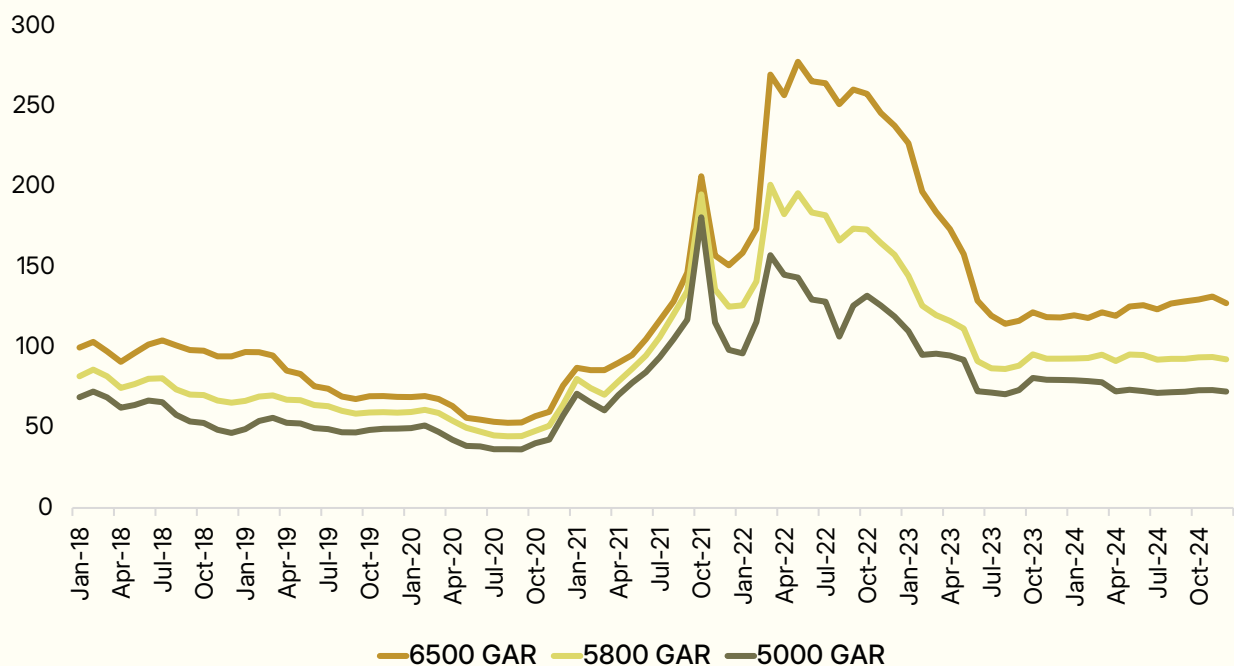


Figure 15: Indonesian Coal Price Index (Argus) for different coal grades during 2018-2024

For textile processing units operating on thin margins, fuel costs constitute a significant share of operating expenditure. Industry observations suggest that a 30-35% increase in coal prices can raise overall processing costs by approximately 8-12%, often forcing units to increase job-work processing charges or absorb the costs through reduced margins. In practical terms, this implies that a 1% increase in coal prices may translate into an approximate 0.25-0.35% increase in processing costs, depending on the share of fuel expenditure in the overall production.

Surat's proximity to the sea ports (namely, Hazira, Dehej Sea, and Magdalla) makes imported coal a cost-effective fuel than other solid fuels including biomass. Biomass, in particular is limited in its availability in Surat in comparison to other districts in the State.³⁹

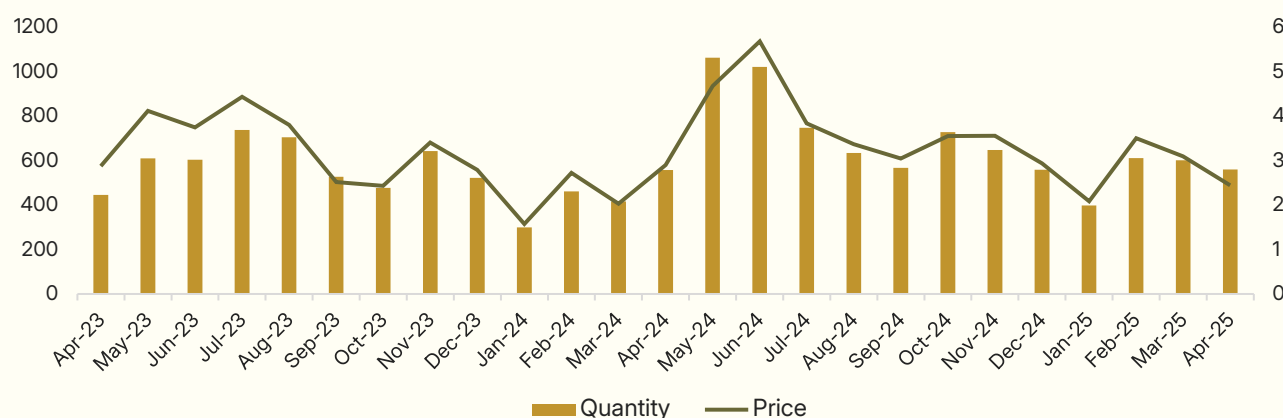
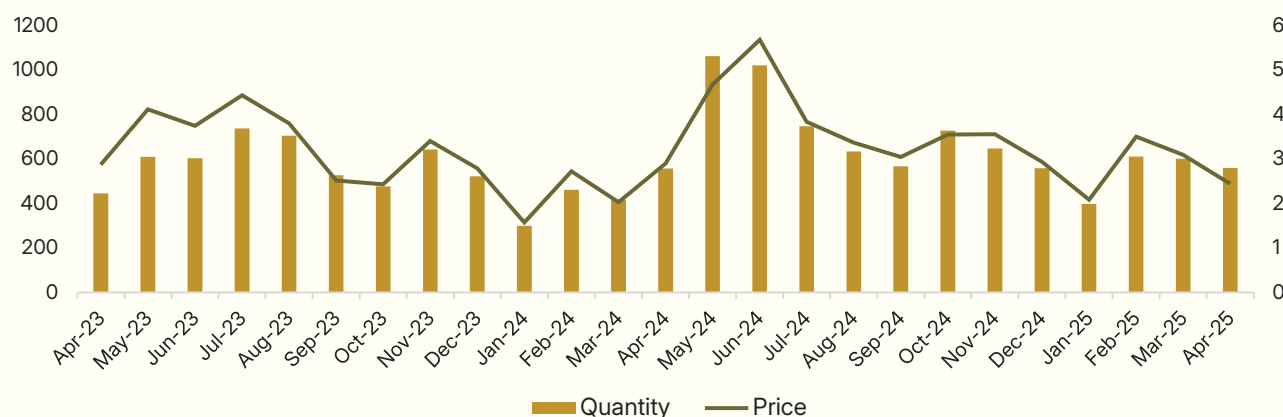
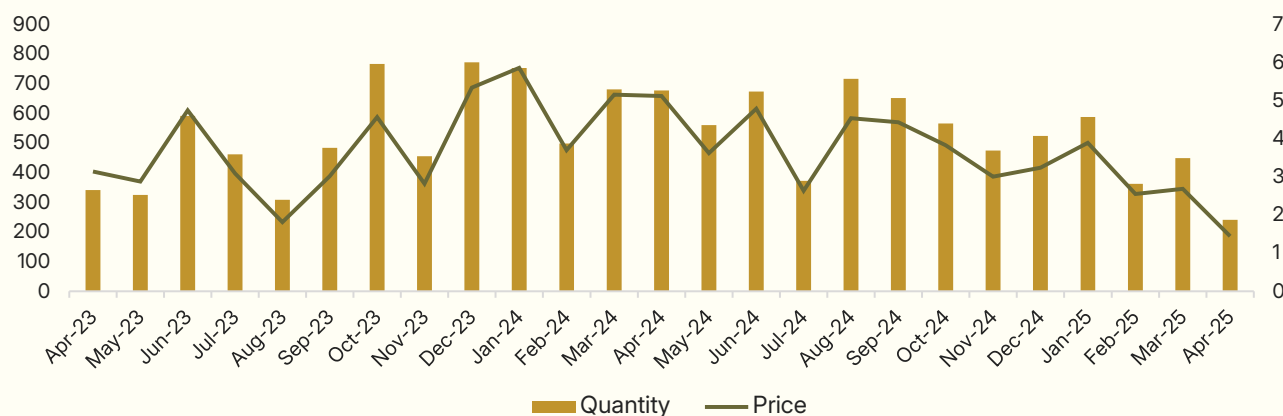


Figure 16: Monthly imported coal quantity and import value through three major ports: Dahej, Hazira, and Magdalla

The quantities of coal imported⁴⁰ (in '000 MT) and price (in INR billion) are described in the graphs below (Figure 16). During 2023-24, a total of 19.946 MMT of Indonesian coal was imported via these three ports. According to DGCI&S, during 2023-24, 19.94 MMT of coal was imported and this figure rose to 23.09 MMT during 2024-25. As per our unit analysis, the cluster annually consumes between 4.9-6.3 MMT of coal and lignite with specific coal consumption of 0.5-0.6 Kg per metre of fabric processed. The high specific coal consumption can be attributed to reasons, which include:

- ◆ Steam is often employed indirectly for generating hot water, maintaining vessel or tank temperature, heating air or surfaces, rather than being directly applied to process material.
- ◆ Additionally, the legacy boilers are typically oversized to meet peak steam demand during certain finishing operations, but routine operations require only 30-40 per cent of the boiler capacity (See Figure 19), reducing boiler efficiency, increasing fuel consumption and maintenance costs

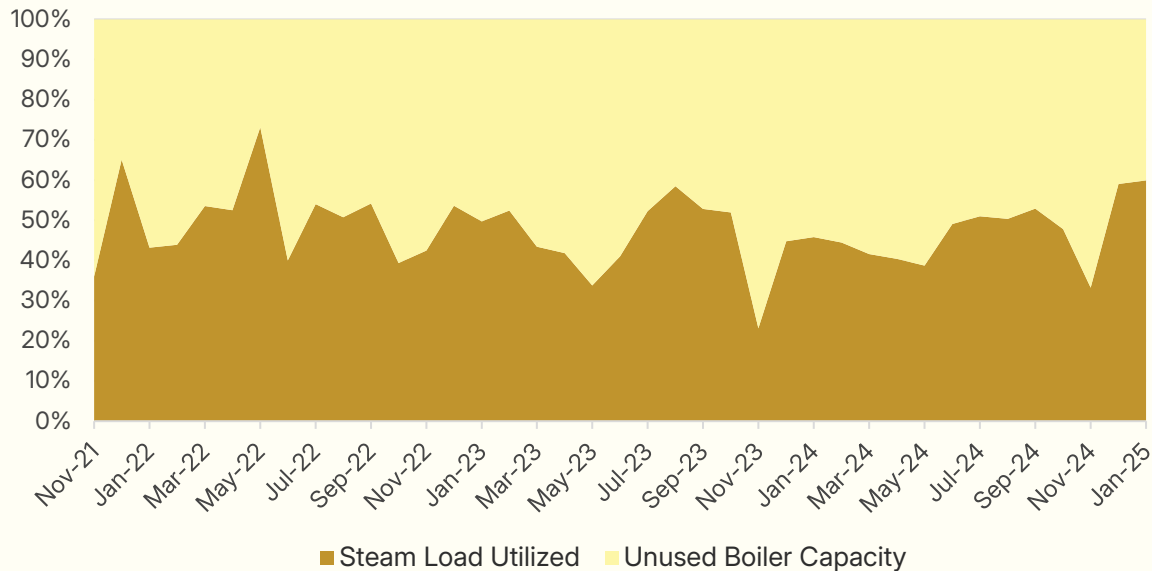


Figure 17: Boiler capacity utilisation profile at a textile unit

These conditions present a strong opportunity to integrate electrified heating systems that can recover low-grade waste heat in the facility or ambient water or air and pre-heat feedwater or process streams, thereby reducing dependence on steam for indirect heating. Such an integration should be subject to evaluation of

thermal suitability (that includes temperature range, process compatibility), as well as measurement of temperature lift, flow rate and pressure of circulating fluids, along with operational constraints and process-specific heat delivery requirements.

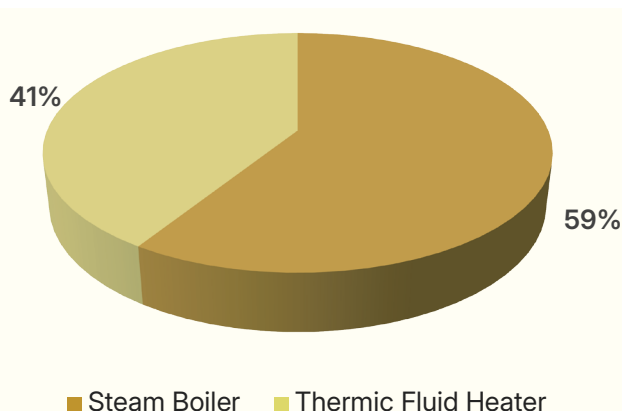


Figure 18: Breakdown of thermal and electrical energy demand in a textile unit

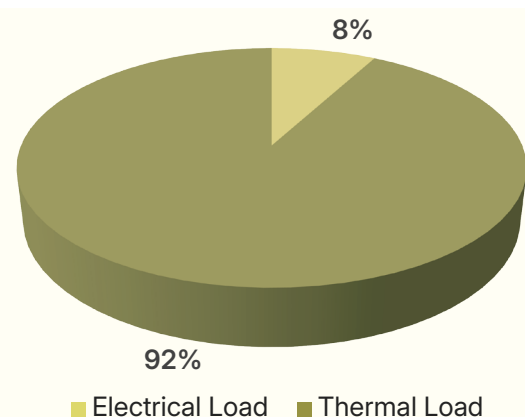


Figure 19: Distribution of useful thermal output by heating technology

Based on the above data and as well as the daily fuel statistics at the reference unit, it is observed that $\approx 92\%$ of the energy load is thermal in nature, in the

form of steam and industrial heat. This thermal load is delivered by solid fuels like coal, lignite and the heat transfer medium are water and heat transfer oil (HTO).

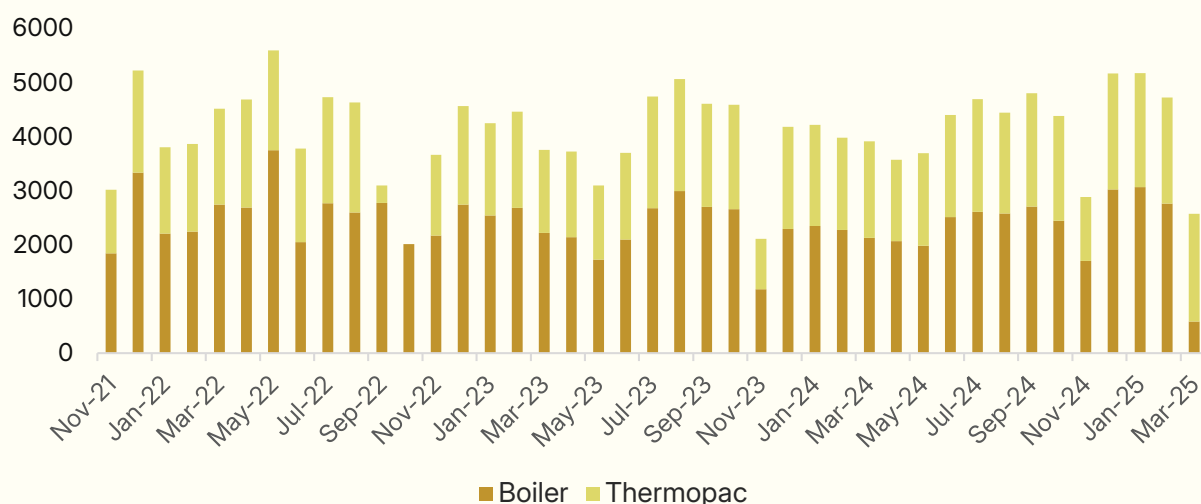


Figure 20: Monthly useful thermal load delivered by the steam boiler and thermic fluid heater (kWth)

While coal (of various grades) is imported from Indonesia, lignite is procured domestically from the mines controlled and operated by Gujarat Mineral Development Corporation (GMDC)⁴¹. Indonesian coal consistently forms a significant part of steam coal imports for the textile units in Surat. Among the solid fuels, the unit consumes on an average of 11% of lignite

and the rest, imported coal. However, the consumption of lignite was as high as 53% of the total solid fuel consumption (See Fig. XX) during June 2022 with the rise in imported coal prices (See Fig. XX). Kindly note that the coal prices as per the Price Index represents only the base market price for coal at a specified grade.

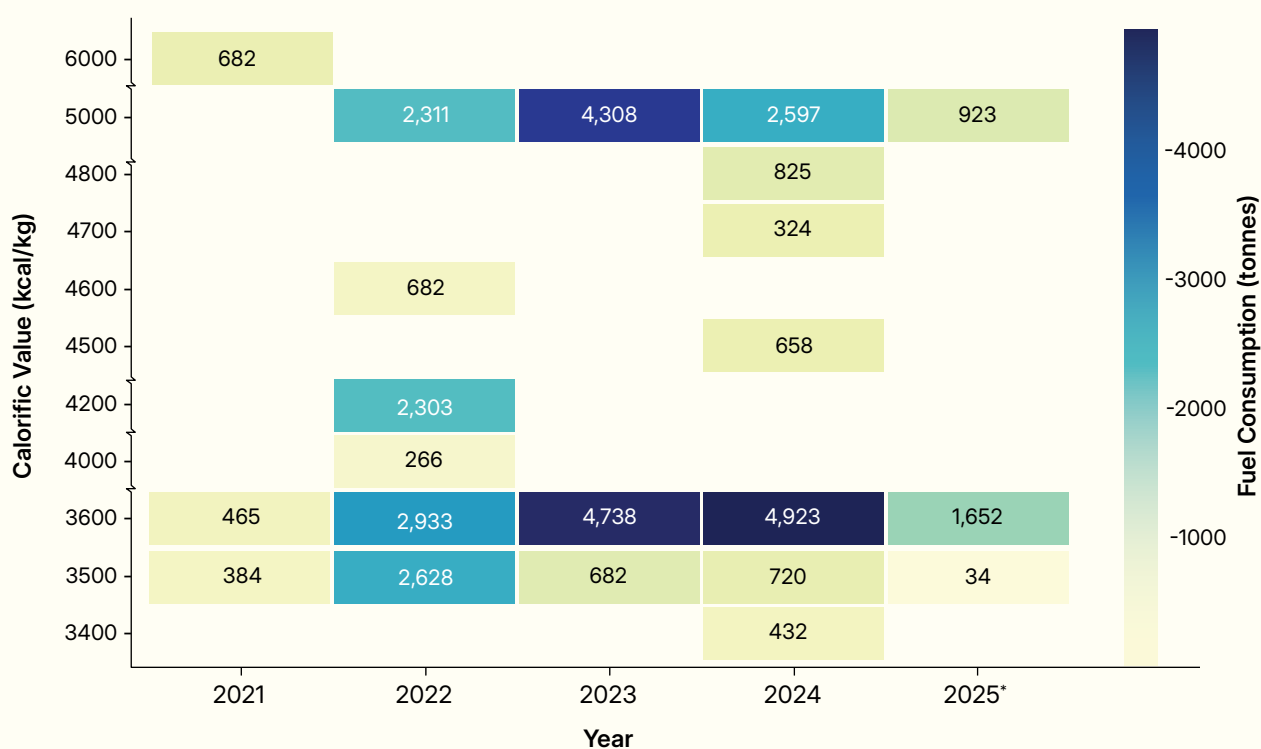


Figure 21: Annual coal consumption by calorific value grade during 2021-25

Speaking of daily fuel consumption, during 2022-24, the unit on an average consumed ≈ 25 MT of coal with ≈ 35 MT as the maximum daily coal consumption. It generated 3.05 MT of steam per hour (≈ 2408.01 KWth eq.) and 1732 KWth industrial heat from the thermic fluid heaters.⁴² It is evident that thermic fluid heaters cater close to 41% of the total thermal demand while coal boilers (both, primary and support boiler) together meet 59% of demand. The unit is selective in terms of

using high-grade coal in its primary boiler and a blend of lignite and imported coal in its support boiler. The most commonly used grade is 5000 GAR⁴³ for primary boiler and 3600 GAR for support boiler and thermic fluid heater. The unit switched to using biomass during Apr-24 to meet its additional thermal load in that particular month. Otherwise, the choice of solid fuel has been limited to coal and lignite.

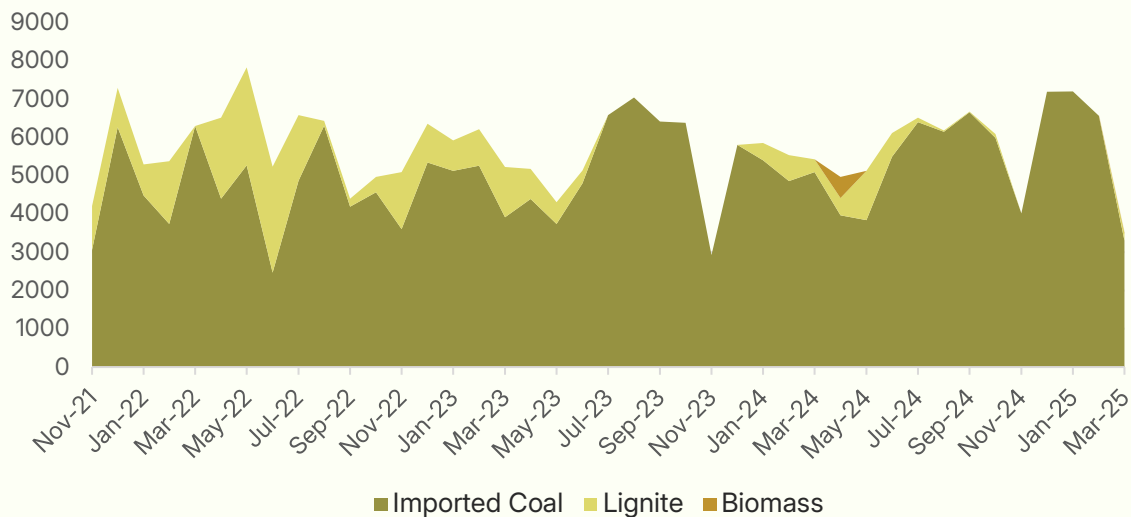


Figure 22: Monthly fuel-wise thermal load profile (kWth)

7.2 Price and availability of international coal as against lignite

The rise and fall of the values in Fig XX correspond to the peak and off-peak periods. Further, the sharp decline in certain months mark the season of festivities where the unit shuts majority of its operations. It can

be inferred from Fig XX that imported coal is preferred over lignite to for industrial heat and steam due to its high calorific value, low moisture and ash content, etc. provided that there is a stable import supply chain. During 2021-25, coal boilers generated 3.52 TPH of steam, on an average.

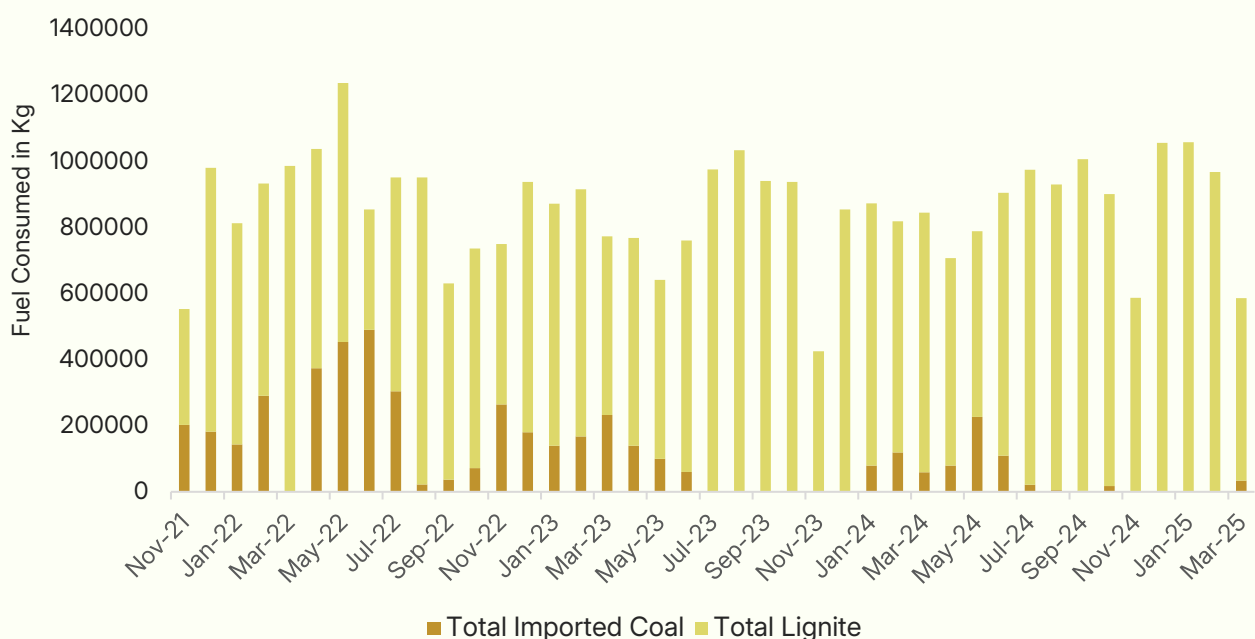


Figure 23: Monthly fuel consumption by fuel type for heating systems (Kg)

Using the above fuel consumption data, we can observe that to produce 1 m of finished fabric, the unit consumes ≈ 0.42 kg of coal and ≈ 0.06 kg of lignite emitting close to 0.785 kg of CO₂ cumulatively⁴⁴. This corresponds to 11-14 MMT CO₂e emissions annually from the cluster. A typical textile unit in Surat spends INR 7.7 million on coal and lignite.

7.2.1 Sustainability Journey so far

Textile processing units in and around Surat embarked on a sustainability journey that began with pilot Emission Trading Scheme (ETS) initiatives led by the Central Pollution Control Board and Gujarat Pollution Control Board around 2013. More than 300 mills were fitted with continuous emissions monitoring systems (CEMS) to measure particulate matter, SO₂, NO_x in real time, allowing them to trade emissions permits under a market-based system. That experiment is said to have resulted in a 20-30% reduction in particulate matter emissions among participating units, with abatement costs dropping approximately 11%.⁴⁵

Surat was also identified as one of the eight major textile clusters in India under the GEF-UNIDO-Ministry of Textiles programme initiated around 2023-24. This project targets cleaner production, chemicals reduction, innovative materials, circular business models, and sustainable lifecycle practises across 320 factories in Surat, aiming to mitigate CO₂e emissions and reduce persistent organic pollutants and greenhouse gases at scale.⁴⁶

On effluent management, Surat's textile mills which generate high-strength industrial effluents with dyes, chemicals, and organic loads are served by a Common Effluent Treatment Plant. Treatment processes include primary, secondary, and tertiary treatment for water reuse and zero liquid discharge goals.

On fuel switching, nearly all textile processing units shifted from coal/lignite to natural gas during the early 2000s incurring substantial investments. Starting around 2011 and into early 2013, many units shifted back to coal and lignite owing to steep gas price increases and supply shortages which made gas economically unviable.⁴⁷

7.3 Emissions

Surat is one of Gujarat's largest industrial centres and has been identified as one of the non-attainment cities under the National Clean Air Programme (NCAP). The city's air quality is influenced by the concentration of pollution-intensive industries, including chemicals, textiles and textile processing, engineering, and other manufacturing activities, alongside emissions from transport and construction. Figure 27 presents the monitoring locations and the corresponding spatial distribution of PM₁₀ and PM_{2.5} concentrations⁴⁸.

Source apportionment studies for Surat (Figure 26) indicate that elevated PM₁₀ concentrations are strongly influenced by road dust, soil and construction activities during summer, while industrial emissions become the dominant contributor during winter. Across several monitoring locations, including industrial areas, industry and power plants contribute substantially to both PM₁₀ and PM_{2.5} concentrations. The industrial monitoring station located near the Pandesara industrial corridor also records among the highest PM_{2.5} concentrations during both monitoring seasons.

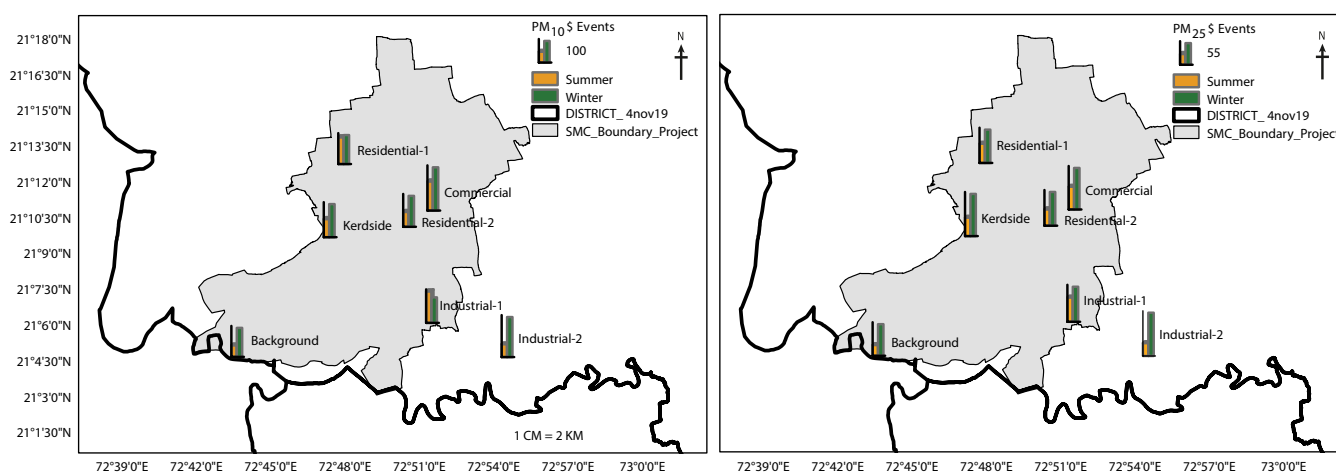


Figure 24: Spatial distribution of monitoring locations and seasonal PM_{2.5}/PM₁₀ concentrations during 2021

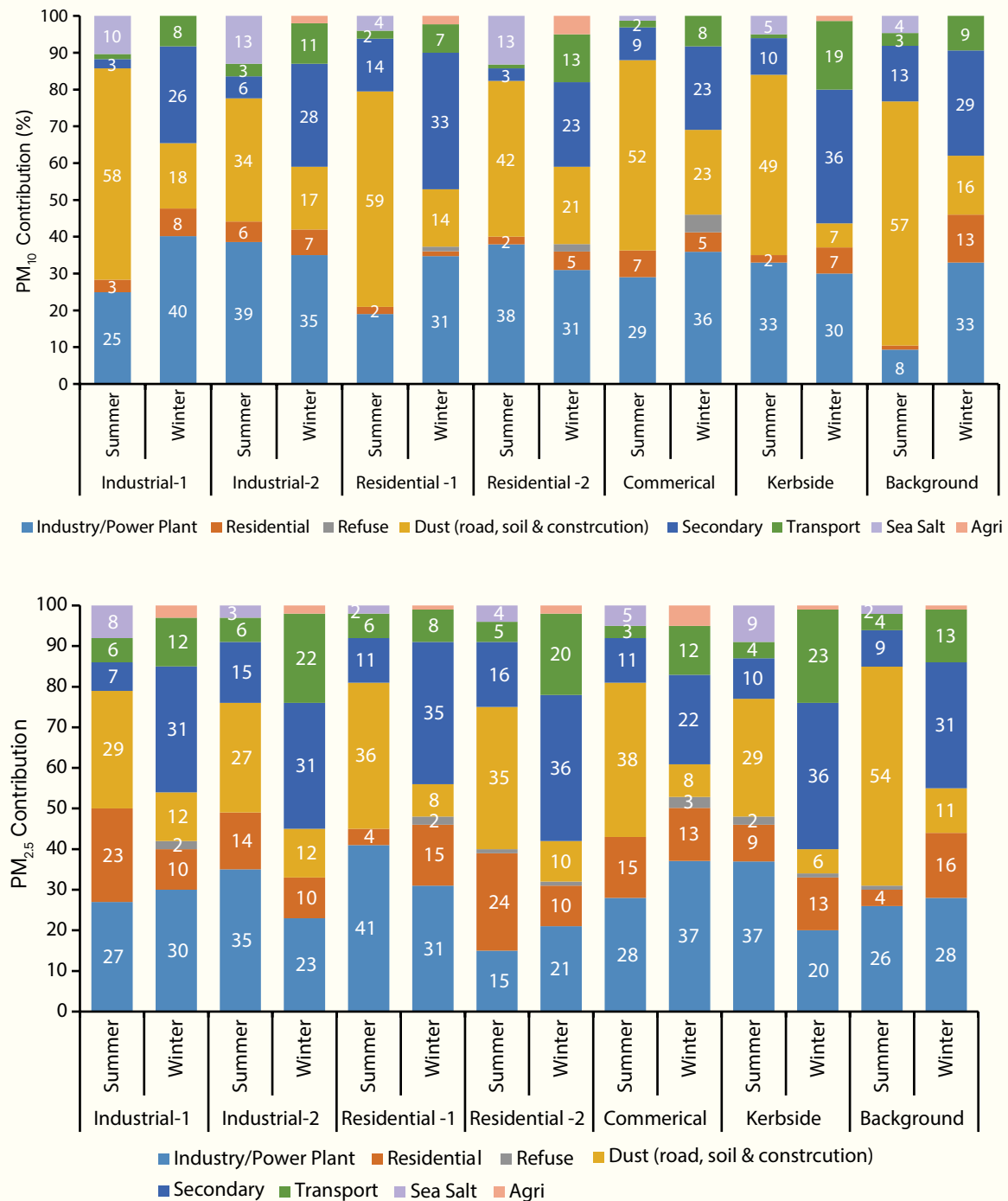


Figure 25: Seasonal source apportionment of ambient PM₁₀ and PM_{2.5} concentrations across different monitoring locations in Surat

In addition to particulate matter, the monthly mean spatial distribution of NO₂ concentrations during 2024 (Figure 28) indicates consistently higher concentrations in and around the Pandesara and Sachin GIDC industrial areas, particularly during the winter months. These locations coincide with dense industrial activity and a concentration of textile

processing and other manufacturing units, suggesting the influence of industrial combustion and associated urban emissions on ambient NO₂ levels. The observed seasonal increase during winter is also consistent with less favourable atmospheric dispersion conditions, leading to higher pollutant accumulation.

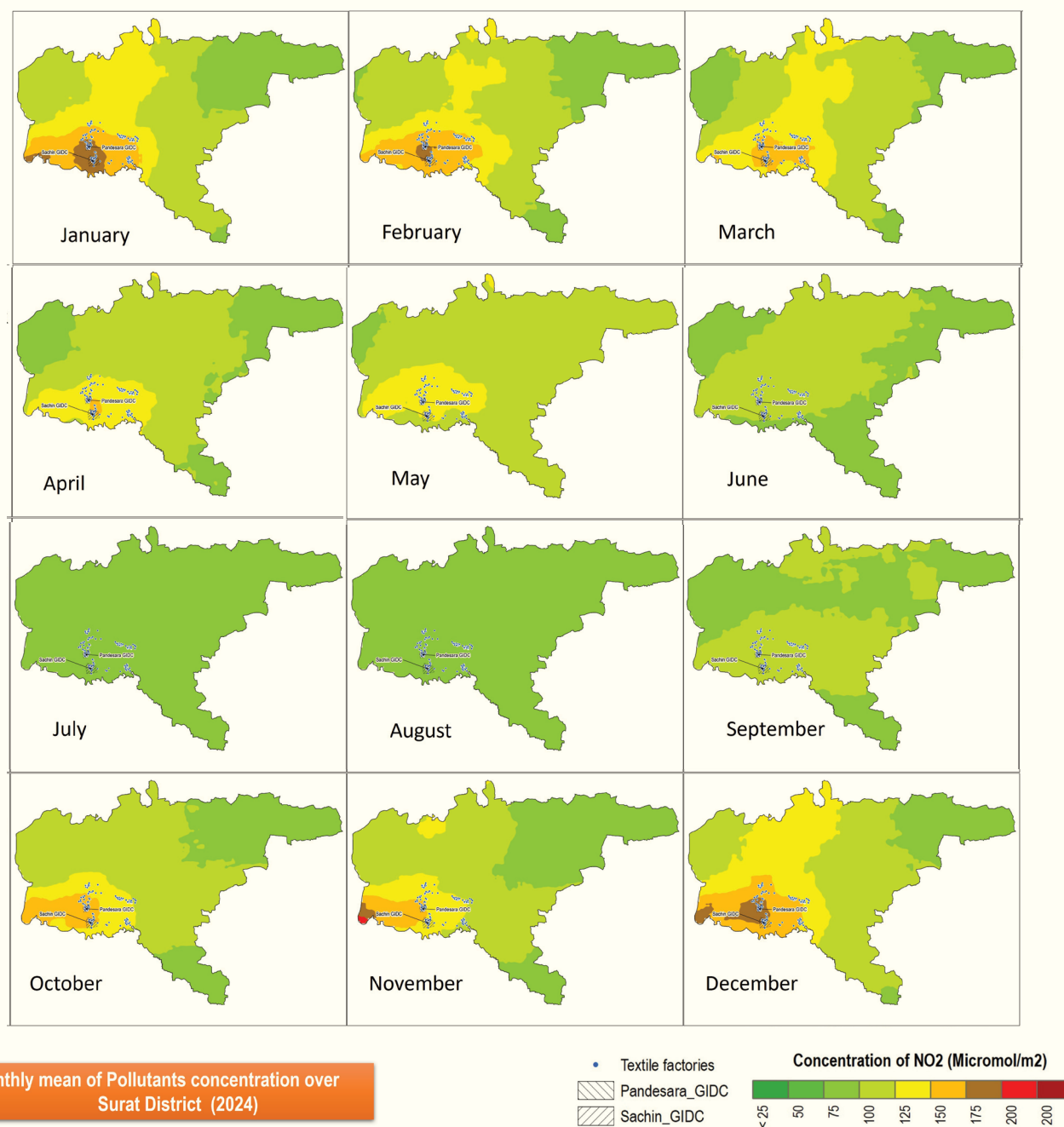


Figure 26: Monthly spatial distribution of NO₂ concentrations over Surat district during 2024, indicating the locations of the Pandesara and Sachin GIDC industrial estates

The spatial distribution of pollutant emissions across Gujarat (Figure 29) further highlights southern and central Gujarat, including Surat district, as major emission hotspots. District-level emission inventories for PM_{2.5}, PM₁₀, NO_x and SO₂ consistently show higher emission loads in districts with dense industrial

activity. These patterns suggest that industrial fuel combustion, together with associated urban activities, contributes substantially to regional air pollution, reinforcing the importance of targeted interventions in industrial clusters to improve air quality.

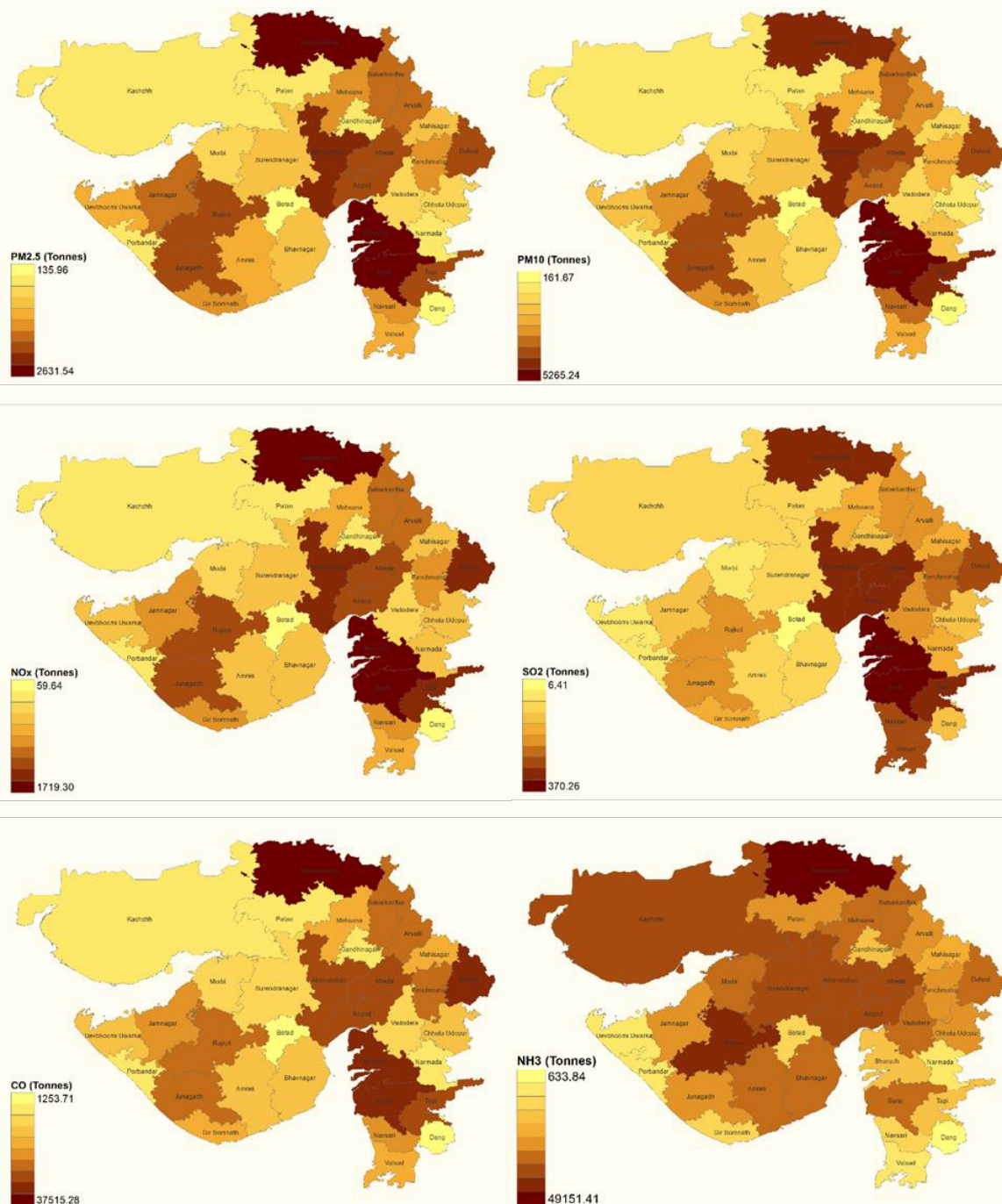


Figure 27: District-wise annual emission inventory of PM_{2.5}, PM₁₀, NO_x, SO₂ and CO across Gujarat in 2021⁴⁹

7.4 Key Findings

The Surat textile cluster, a key hub for MMF production and exports, is predominantly composed of informally operated units employing medium- to low-skilled labour. The cluster faces several structural and operational challenges, including suboptimal energy use arising from over-sized and individually operated process heat boilers that are often not aligned with actual thermal requirements. The absence of common infrastructure further limits opportunities for economies

of scale, while high land prices constrain new investments and reduce the cluster's competitiveness relative to other textile regions. Adoption of captive renewable energy also faces unique barriers, including high dust and pollution levels that limit rooftop solar deployment, as well as grid-related constraints associated with capacity and availability. In addition, banking charges and existing policy gaps adversely affect the financial viability of renewable energy procurement.

From a governance perspective, improved data availability through measures such as process- and machine-level steam flow metering can enable better-informed operational and investment decisions. Stronger institutional coordination among agencies including Gujarat Energy Development Agency (GEDA), Gujarat Pollution Control Board (GPCB), Surat Municipal Corporation (SMC), MSME-District Industries Centre (MSME-DIC), and South Gujarat Textile Processors' Association (SGTPA) will be essential to facilitate sustainable transformation. At the enterprise level, MSME sector's limited risk-bearing capacity, weaker credit profiles, and exposure to intense competition are further compounded by low awareness, poor working conditions, and inadequate skilling. Addressing these challenges requires a multi-stakeholder approach, with institutionalisation of energy efficiency, particularly through thermal energy optimisation, offering substantial operational and economic benefits. Strengthening textile sector governance, enhancing Surat's role in India's MMF export competitiveness, and fostering deeper integration with global markets will be critical for ensuring the cluster's long-term sustainability and resilience.

From a decarbonisation perspective, low- and medium-temperature processes such as washing, pre-treatment, and dyeing should be prioritised for early deployment of industrial heat pumps, where the potential for carbon emission reduction and cost competitiveness is greatest. Project assessments should also account for avoided cooling credits in cases where heat pumps simultaneously provide cooling services or reduce chiller loads. To build confidence and demonstrate technical and economic feasibility, pilot cascade or hybrid industrial heat pump installations should be undertaken in representative wet processing units, thereby creating pathways for wider replication across the cluster.

Stakeholder consultations in Gujarat indicate that the adoption of industrial heat electrification is shaped as much as by institutional trust and operational risk considerations as by technology readiness. MSMEs expressed reluctance to reinvest in new energy systems without credible long-term policy signals, informed by past experiences with abrupt reversals in fuel transition pathways, such as the earlier shift to Compressed Natural Gas (CNG).

Production continuity emerged as a dominant concern, with firms emphasizing the need for redundancy, modular system design, and the ability to operate electrified heating systems in parallel with existing infrastructure to avoid single-point failures that could disrupt operations. Grid readiness was identified as a binding constraint, as several local substations are already operating close to capacity, underscoring that feeder-level planning and early coordination with utilities must precede electrification rather than follow it. Importantly, industry participants highlighted that early demonstration projects and peer effects play a decisive role in building confidence, often carrying greater influence than formal incentives. Operational experience further revealed that non-energy benefits including improved product quality, reduced material wastage, lower factory-floor heat, and minimum civil works due to compact and modular equipment are critical drivers of acceptance, particularly among MSMEs.

8

Electrification and Levelised Cost of Heating Framework

This section presents a scenario-based Levelised Cost of Heating (LCoH) framework to evaluate partial or full electrification (industrial heat pumps and electric boilers) of thermal processes in wet-processing textile units. It compares techno-economic metrics as well as thermal suitability (temperature ranges and process compatibility) and key operational considerations.

But before we explore the LCOH for different heating technologies, it becomes important to understand how does boiler systems work, what comprises the maintenance costs, and other operational risks that are not really accounted for while estimating LCOH.

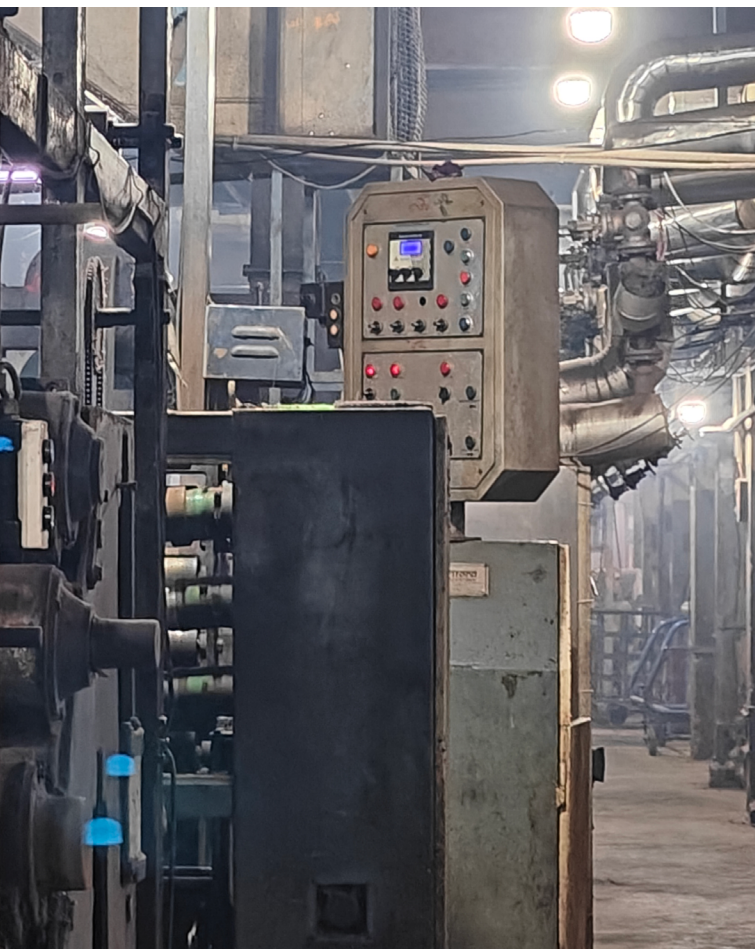
8.1 Understanding the Cost Structure of Legacy Boiler Systems

One of the most common arguments against electrification in industrial clusters is that steam produced from existing coal-fired boilers appears significantly cheaper than heat produced from electrified heating systems. However, this comparison often reflects an accounting artefact rather than a true economic advantage.

Most existing boilers in textile processing units have been in operation for many years, and in several cases their initial capital investment has already been fully amortized. As a result, the cost of steam from these boilers is typically calculated based only on ongoing operational expenses such as fuel consumption, labour, and routine maintenance.

This approach significantly underestimates the true economic cost of heat generation because several important cost components remain unaccounted for, including:

- ◆ Replacement of ageing boiler infrastructure
- ◆ Periodic overhauls and major maintenance
- ◆ Pollution control equipment such as electrostatic precipitators and bag filters
- ◆ Fuel storage and handling infrastructure
- ◆ Compliance costs associated with tightening emission standards
- ◆ Operational risks associated with fuel price volatility and supply disruptions



When these factors are considered, the cost advantage of existing boilers becomes far less pronounced. Consequently, comparisons between existing boilers and electrified heating systems should not be based solely on short-term operational costs. A more appropriate comparison requires a levelised cost of heating framework, which accounts for capital expenditure, operating costs, system lifetime, and efficiency over the full operational life of the equipment.

Successful electrification requires a deep understanding of process-level heat flows within industrial facilities, rather than simply replacing existing boilers with electrified heating systems. Industries like textile processing plants consist of complex systems where heat demand varies by process step, temperature requirement, and operational schedule. Process-level modelling (or Process archetypes) helps identify where electrification is technically feasible and economically optimal by analysing mass and energy flows across production stages.

Electrification tends to be easier in industries where energy costs represent a relatively small share of total production costs. In such sectors, even if electrification increases heating costs slightly, the impact of final product prices is minimal⁵⁰. Installing electrified heating systems today helps future-proof industrial assets against future climate policies and energy transitions. If facilities continue investing in fossil infrastructure, they risk stranded assets as decarbonisation policies tighten. Electrification investments help avoid premature equipment retirement and align industrial infrastructure with long-term decarbonisation trajectories.

The structure of electricity tariffs plays a significant role in determining the economics of electrified process heat⁵¹. Alternative rate designs such as time-differentiated tariffs, dynamic pricing or reduced demand charges can significantly improve the economics of electrification by enabling industries to shift electricity consumption to periods when electricity is cheaper.

Industrial electrification analysis is difficult due to limited data availability on:

- ◆ Process heat requirements
- ◆ Technology performance
- ◆ Industrial energy use patterns

This data gap creates challenges for designing policies and evaluating electrification pathways⁵². Because electrified heating systems are capital-intensive technologies, new deployment models are emerging to reduce adoption barriers, including:

- ◆ Heating-as-a-Service (HaaS) models where the technology provider installs and operates the heat pump and charges users based on heat delivered
- ◆ Leasing or energy performance contracting models, where repayment is linked to realized energy savings

Such models can help MSMEs adopt electrified heating systems without bearing the full upfront investment. Despite the maturity in space heating, cooling, and low-temperature hot water applications, awareness of heat pump use for industrial process heating remains limited among textile units. This lack of familiarity contributes to hesitation among industrial buyers despite favourable economics in certain applications.

Operating conventional solid-fuel boilers presents occupational safety and labour availability challenges, including risks associated with manual fuel handling, ash management, and boiler operations. These challenges are becoming more pronounced in industrial clusters where skilled boiler operators are increasingly difficult to find.

Industrial process heat is not categorized as a distinct energy category in energy policy and planning, which tend to focus primarily on electricity. Developing dedicated policies, financing frameworks, and market mechanisms for process heat decarbonisation could help accelerate adoption of cleaner technologies.

Industrial fuel-use data is primarily available through regulatory permit records rather than direct monitoring of unit-level consumption. Regulatory authorities maintain datasets linked to production permits and environmental filings submitted by industrial units, from which indicative estimates of fuel consumption can be derived. However, these records typically reflect permitted values rather than actual real-time fuel consumption at the unit level, particularly in MSME clusters. Access to such datasets can nevertheless provide an important starting point for estimating the fuel mix, understanding cluster-level energy use patterns, and developing baseline assessments for industrial heat decarbonisation strategies including electrification.

8.2 Calculating the Levelised cost of heating

LCoH is expressed as the delivered cost of usable thermal energy, annualised over equipment lifetime (expressed in INR/kWh of useful heat convertible to INR/Kg of steam, where required). For electrification options, efficiency plays a central role: electric boilers convert electrical energy to heat at a factor of nearly 1.0, while industrial heat pumps deliver higher efficiency depending on the temperature lift, expressed through

COP. In contrast, conventional fuel-based boilers operate at lower thermal efficiencies, typically ranging from 0.8 for firewood to 0.9 for gas-fired systems. By using COP ranges instead of single values, the framework captures the variability in real-world performance of industrial heat pumps across different process temperatures.

Process mapping within the textile sector shows three major temperature bands:

- 1** Low-temperature process such as washing, rinsing and certain pre-treatment steps ($\leq 100^{\circ}\text{C}$) are highly compatible with heat pumps
- 2** Medium-temperature processes such as scouring, bleaching and dyeing can also be partially electrified, often requiring cascade heat pump systems or hybrid configurations
- 3** High-temperature processes above $160\text{--}180^{\circ}\text{C}$, including fixation and stenter finishing, remain challenging for current heat pump technology, and are more suited to electric boilers

Operational conditions are also critical in determining the LCoH outcome. Many textile boilers in Surat are oversized to meet occasional peak loads, which reduces efficiency and increases fuel cost per unit of steam. Moreover, in multiple processes, steam is only an indirect carrier of heat – for instance, in roller heating or jacketed vessels – where direct electrification with heat pumps or electric heating could yield higher efficiency and lower distribution losses.

Electrification also introduces co-benefits that improve the LCoH economics. Heat pumps can provide simultaneous cooling, which is valuable in textile operations where chilled water is used in dyeing or finishing. The framework allows avoided cooling energy or cost to be credited against the total cost of heat, improving competitiveness compared to fuel-based boilers.

The following data points are required to build the framework as well as map the scenario inputs:

◆ Process inventory by unit & by cluster – list of processes (scouring, bleaching, dyeing, printing, finishing) and their typical operating temperatures
◆ Steam load profile (hourly or daily) – to map the demand and frequency of peaks
◆ Boiler fleet inventory – sizes, rated capacities, actual measured loads, fuel types, and measured or manufacturer-reported efficiencies
◆ Fuel and electricity tariffs – energy costs, demand charges, time-of-use structure that is essential for accurate LCoH
◆ Grid constraints and reliability – hours of outages, available feeder capacity, potential for additional dedicated feeders or substations
◆ Existing on-site/off-site Renewable Energy Sources and rooftop solar photovoltaic potential – current capacity, available rooftop area, willingness for captive generation
◆ Emissions baseline – current fuel consumption and CO_2 /PM emissions for the cluster
◆ Space and piping layouts – to assess feasibility of heat pump installations and retrofits
◆ Operation practices – number of shifts, maintenance schedules, availability of trained staff (to estimate maintenance and O&M cost assumptions)

The calculation of LCoH/LCoS is a critical metric for evaluating the cost of generating steam or heat over the operational life of the system. In our calculation, we took both the capital investment (CAPEX) and the operational and maintenance (OPEX) costs into account, all adjusted for inflation and time value. The formula for CAPEX is represented as:

$$CRF = \frac{r(1+r)^n}{(1+r)^{n+1}-1}$$

$$\text{Annualised CAPEX} = \text{CAPEX} \times CRF$$

Where, CRF is the Capital Recovery Factor, r is the discount rate and n are the number of years for which the capital expenditure is spread. On the other hand, OPEX consists of both Fixed (labour, management, regular maintenance) and Variable costs (fuel, consumables, and other resources).

$$\text{Annualised OPEX} = \text{Total NPV (OPEX)} \times CRF$$

To determine the Annualised OPEX, both fixed and variable O&M are considered and adjusted for inflation over the projects' life. These along with the Annualised CAPEX, are summed to calculate the Estimated Annual Cost (EAC).

$$\text{Effective Annual Growth (g)} = \{(1+i) \times (1+d) - 1\}$$

Where, i is the annual inflation of costs, d is the annual degradation or the performance loss for the particular technology, and g is the effective annual growth rate for OPEX

$$\text{Adjusted OPEX}_0 = \text{Variable}_0 \times \left(\frac{\text{Present Price}}{\text{Base Price}} \right)$$

Where, OPEX_0 is the total annual operating cost in the first year of operation, CAPEX_0 is the initial capital expenditure (in other words, investment at year 0) and Variable_0 is the base-year variable OPEX

$$\text{NPV}_{\text{Fixed}} = F_0 \times \frac{1 - \frac{(1+g)^n}{(1+r)^n}}{r - g}$$

Where F_0 is the base-year fixed O&M, r is the discount rate and n is the lifetime in years

$$\text{NPV}_{\text{variable}} = \text{O\&M}_{\text{variable}} \times \left(\frac{1 - \left(\frac{1+g}{1+r} \right)^n}{r - g} \right)$$

$$\text{EAC} = \text{Annualised CAPEX} + \text{Annualised OPEX}$$

8.3 Results

At an electricity tariff of INR 8.5 per unit, heat pump-based steam generation results in a Levelised Cost of Steam (LCoS) of INR 3.10 per kg, which remains higher than the LCoS of coal and firewood-fired boilers, but lower than LPG-based steam generation. Electric boilers, however, exhibit the highest LCoS. Sensitivity analysis indicates that the economics of heat pumps are strongly influenced by electricity

tariffs, among other factors. As electricity tariffs decline, the LCoS of heat pumps decreases substantially and approaches parity with coal-fired boilers. At an electricity tariff of INR 6.0 per unit, the LCoS of heat pump-based steam generation declines to INR 1.88 per kg, making it economically competitive with coal-fired boilers.

Table 7: Levelised Cost of Steam for various heating technologies

Technology	Annualised CAPEX (INR lakh)	Annualised OPEX (INR lakh)	Estimated Annual Costs (INR lakh)	Levelised Cost of Steam (INR/Kg steam)
Coal boiler	34.4	460	494.4	1.96
Firewood boiler	14	533	546	2.17
LPG burner	2.4	284	286.3	3.41
CNG burner	2.6	224	226.5	2.70
Electric boiler	20.4	1210	1229.4	6.35
Heat pump	31.4	74.2	105.5	2.09

Table 8: Sensitivity of LCoS to electricity tariffs for electric boilers and industrial heat pumps

Technology	Levelised Cost of Steam for Electricity Tariffs in INR/kWh		
	INR 8.5	INR 6.5	INR 6
Electric boiler	8.28	6.35	5.87
Heat pump	3.1	2.09	1.88

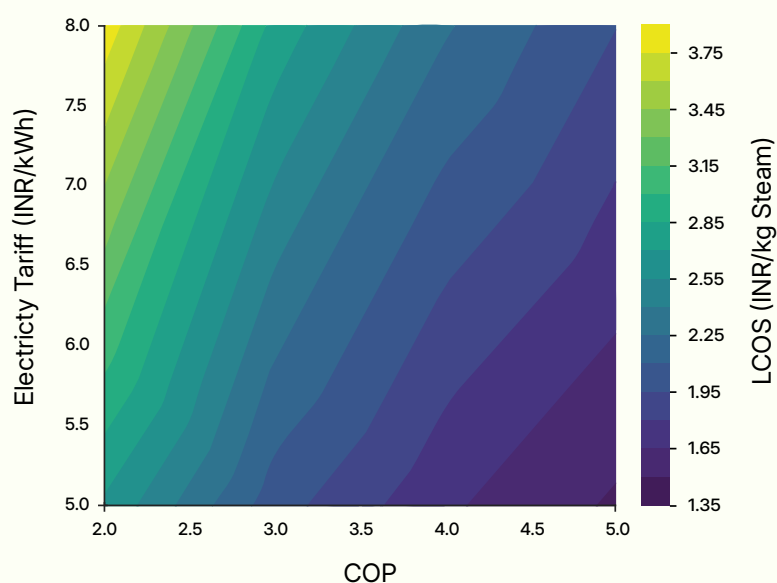


Figure 28: Comparison of the LCoS across conventional and electrified heating technologies under different electricity tariff scenarios (top) and contour plot illustrating the sensitivity of heat pump LCOs to variations in electricity tariff and COP (below)

8.4 Assumptions underlying the techno-economic analysis

- ◆ Pre-war prices of LPG and CNG have been considered to provide a conservative basis for comparison and to avoid overstating the cost advantage of electrification under recent geopolitical disruptions;
- ◆ Heat pump performance has been evaluated assuming a COP of 3, corresponding to relatively modest temperature lifts;
- ◆ Levelised cost calculations are based on prevailing fuel prices, estimated operating costs, and Annualised capital expenditure for each technology; and
- ◆ Analysis excludes carbon pricing and does account for the additional costs associated with environmental compliance, ash disposal, fuel handling.

8.5 Renewable Power Procurement for Electrifying Industrial Heat

Industrial electrification only delivers sustained emissions and cost benefits when firms can reliably procure low-carbon electricity at predictable prices. For Commercial and Industrial (C&I) consumers, this increasingly means treating renewable power procurement as an integral part of the electrified heating investment decision using open access procurement, rooftop solar, and contract structures such as long-term Power Purchase Agreements (PPAs) to reduce tariff volatility and policy risk. Rising grid tariffs and evolving regulations are pushing firms toward open access and rooftop solar as procurement choices.

8.6 Ecosystem gap for industrial heat electrification

One of the major challenges identified in the stakeholder discussions is the absence of a well-developed ecosystem for electrification of industrial heat in MSME clusters. Unlike renewable electricity markets, where procurement mechanisms, financing models, and technology suppliers are well established, the ecosystem for electrified heating systems remains fragmented. This creates information gaps between technology providers, equipment manufacturers, and MSME users, making it difficult for units to evaluate the feasibility, costs, and operational implications of such technologies.

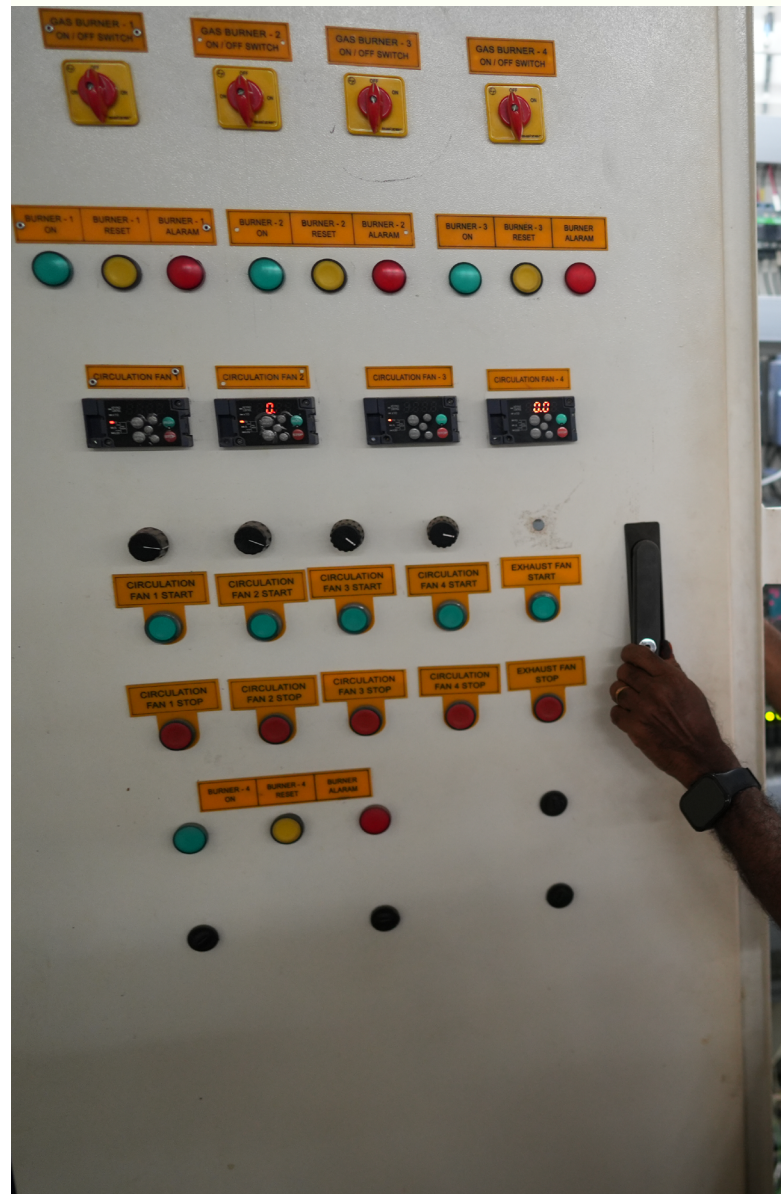
Stakeholder consultations highlighted the importance of creating collaborative platforms that bring together industry associations, MSME units, technology manufacturers, regulators, Energy Service Companies (ESCOs), financiers, and policymakers, etc. Such

platforms can help address critical knowledge gaps around technology performance, capital costs, operational reliability, and emission reduction potential. Cluster-level engagement mechanisms can also help accelerate market confidence and support the development of scalable deployment models for electrified heating systems.

8.7 Renewable Energy Procurement Challenges

Renewable energy procurement for industrial consumers requires detailed consumption profiles, typically measured in 15-minute intervals across the year, to determine appropriate system design and technology selection. Such granular load data helps determine whether renewable energy should be procured through open-access, hybrid systems, or on-site installations.

While renewable energy supply options are increasing, practical constraints remain in industrial clusters due to banking limits, transmission availability, wheeling charges, and grid infrastructure limitations. These factors influence the share of renewable electricity that can be integrated into industrial energy consumption.



For MSME clusters, renewable energy procurement may require an intermediary or aggregating entity capable of purchasing electricity on behalf of multiple units and redistributing it within the cluster. Such institutional arrangements can simplify contractual arrangements and improve participation of smaller units in renewable energy markets.

8.8 Green Finance

Stakeholder interactions with MSME-focused lenders indicate that access to affordable financing remains a major constraint for technology upgrades in textile clusters. While dedicated green finance portfolios for MSMEs are emerging, financing is often provided through unsecured or semi-secured lending products that carry relatively high interest rates due to perceived credit risks and operational costs associated with lending to small enterprises.

Some financial institutions⁵³ have begun developing dedicated green MSME lending portfolios to support investments in clean energy technologies such as solar rooftop systems, solar-powered equipment, and other distributed energy applications. However, these financing products are currently focused largely on technologies that are already commercially mature,

standardized, and widely deployed. In contrast, emerging industrial decarbonisation technologies such as electrified heating systems often fall outside MSME lending frameworks due to higher capital costs, limited track record, and greater perceived technology risks.

Moreover, existing MSME financing products often have relatively small ticket sizes and shorter repayment tenures, typically ranging from three to five years. While suitable for smaller energy investments such as rooftop solar installations, these financing structures are less compatible with capital-intensive industrial electrified heating systems, which may require longer repayment periods to ensure viable project economics.

Financial institutions indicated that availability of baseline operational and energy consumption data for industrial clusters can significantly improve credit assessment and reduce financing risks. Reliable cluster-level data on energy consumption, process heat demand, and technology performance could enable lenders to better evaluate projects and potentially reduce borrowing costs for MSMEs adopting clean technologies.

Technology transition in MSME clusters is often constrained not only by technical feasibility but also by behavioural and financial factors, particularly where enterprises rely on first-generation production technologies and operate with limited working capital. Even technologies demonstrating short payback periods may face slow adoption due to risk aversion and operational uncertainty among MSMEs.

For emerging clean technologies like electrified heating systems for industry, standardized performance testing, certification, and verification by credible institutions can help reduce perceived risks and accelerate technology adoption.

Pilot deployments and demonstration projects in industrial facilities are emerging as important mechanisms for building industry confidence, validating technology performance, and reducing perceived risks among potential adopters.



9

Action Agenda for Scaling Electrification of Industrial Heat across Textile Clusters

1

Grid Readiness as a Core Enabler for Industrial Electrification	
a.	Complete electrification of industrial heat would require substantial upgrades to transmission and distribution infrastructure, potentially doubling electricity flows in some systems. Hence, grid capacity and feeder-level readiness would strengthen the case for electrification
b.	Evidence from recent industrial electrification programs ⁵⁴ shows that grid readiness is a decisive factor for successful deployment, often more critical than technology availability itself. Electrification of industrial heat increases both energy consumption and peak demand, making early coordination with utilities essential to avoid delays, cost overruns, and operational disruptions. Projects frequently stall due to insufficient transformer capacity, long lead times for service upgrades, and uncertainty around network connection costs
c.	Integrating electrification planning into utility load forecasts and infrastructure investment cycles is therefore a prerequisite for scaling industrial electrification, rather than treating grid upgrades as an afterthought ⁵⁵
d.	Industrial electrification can improve electricity system efficiency increasing baseload demand and enabling better utilisation of grid assets ^{35,56} . Electrified heating systems operate for long hours with relatively predictable demand profiles thereby raising load factors without proportionate network expansion. This creates a structural opportunity for electricity utilities and regulators to align electrification incentives with grid stability objectives, particularly in systems experiencing mid-day renewable oversupply or underutilised transmission capacity.

2

Early-Stage Technical Assistance and Diagnostics

a.	One of the strongest predictors of successful industrial electrification projects is early-stage technical assistance
b.	Multiple programs ⁵⁷ demonstrate that subsidised feasibility studies such as pinch analysis, waste-heat mapping, and process-level audits are critical to identifying viable electrification opportunities and building confidence among decision-makers
c.	Without this preparatory work, firms tend to overestimate technical risk and underestimate achievable efficiency gains, leading to underinvestment in electrified solutions
d.	The technical feasibility of electrified industrial heat is less constrained by achievable temperature levels than by the availability and quantity of suitable heat sources. Assessments show that most industrial processes generate recoverable waste heat at temperatures sufficient to act as input for electrified heating systems such as heat pumps. As a result, electrification potential is best evaluated at the process level rather than through sector-wide averages. This underscores the need for detailed process heat mapping and waste-heat audits as a pre-requisite for effective industrial electrification strategies ⁵⁸
e.	Installing steam flow meters, both at the process level and machine level (especially in processes where steam valve operate automatically, such as dyeing machines), can significantly improve understanding of process-wise steam demand patterns and help identify opportunities for efficiency improvements
f.	In dyeing operations, which typically follow a batch process, multiple machines may draw steam simultaneously even though the total daily steam consumption may appear moderate. Capturing this steam demand profile is therefore critical for process integration, techno-economic assessment, and appropriate sizing of electrified heating systems, improving their viability and economics

3

Optimizing Demand before Electrification

a.	Reducing heat demand ⁵⁶ through process optimisation, efficiency improvements, heat recovery and structural de-steaming is identified as a critical precursor to cost-effective and scalable electrification of industrial heat
b.	These measures lower required electrical capacity, reduce capital costs, and ease grid stress, improving both project-level economics and system-level feasibility
c.	While demand reduction measures are important, it is important to recognise that thermal energy remains integral to textile processing units. Certain pre- and post-processing and finishing activities may allow opportunities for partial de-steaming, but core operations continue to require steam or other forms of process heat
d.	Therefore, process houses need to prioritize optimisation of existing heat consumption through process improvements, identification of waste heat recovery opportunities, and operational efficiency measures while assessing the feasibility of electrified heating systems. Such an approach can ensure that electrification is applied to a right-sized thermal load, improving both technical viability and economic performance

4

Design Electrification around Load Profiles and Hybrid System Architectures

a.	The feasibility of industrial heat electrification depends not only on temperature requirements but also on the temporal characteristics of heat demand
b.	Industrial heat pumps are most effective when deployed to meet stable base-load heat demand while electric boilers are better suited for variable and peak loads
c.	Hybrid configurations that combine heat pumps, electric boilers, and thermal storage can therefore improve system performance, flexibility, and resilience
d.	A key but often overlooked benefit of industrial electrification is the ability to simultaneously deliver heating and cooling within the same system. Electrified heating systems can couple cooling demands such as refrigeration, spot cooling, process cooling and condensation with heat requirements, converting what would otherwise be rejected heat into useful thermal input
e.	For existing industrial facilities, electrification through industrial heat pumps becomes economically attractive when both heating and cooling demands can be addressed simultaneously or where waste heat streams can be captured and upgraded for process heating

5

Process-Integrated Electrification and Thermal System Reconfiguration

a.	Electrification of industrial heat enables a structural transition away from centralized steam networks toward decentralized, modular heat supply tailored to individual processes. Electrified heating systems such as heat pumps can be installed close to the point of demand, reducing distribution losses, improving controllability, and enabling phased retrofits of existing facilities
b.	Evidence from industrial heat pump deployments ⁶¹ shows that electrification delivers the highest efficiency and economic performance when it is intrinsically integrated into industrial processes, rather than implemented as a direct replacement for centralized fossil fuel-based heating systems. Intrinsic integration can achieve exceptionally high coefficients of performance by minimizing temperature lifts and recovering heat internally. In contrast, centralized electrified heat supply designed to meet multiple process requirements tends to operate at higher temperatures and lower efficiencies. This highlights the importance of re-engineering industrial processes alongside electrification, rather than treating electrified heat as a one-to-one substitute
c.	Evidence from industrial steam integration studies ⁵⁹ shows that the structure of existing steam systems including condensate return rates, pressure cascading, flash steam losses, and oversized distribution networks frequently limits electrification potential more than the capabilities of electrified heating technologies themselves. Without addressing these system inefficiencies, electrified steam generation can be technically viable but economically sub-optimal. This underscores that steam electrification strategies must prioritise system reconfiguration and pressure rationalisation, not just boiler replacement
d.	While industrial processes are highly diverse, detailed integration studies show that electrification opportunities cluster around a limited set of recurring unit operations such as drying, evaporation, low-pressure steam generation, etc. ⁶⁰ This creates a scope for standardised electrified heating solutions that can be replicated across sectors, reducing engineering costs and deployment time.

6

Differentiated and Phased Implementation Strategies

a.	A differentiated implementation strategy based on project typology (greenfield and brownfield projects) can significantly improve the feasibility and adoption of electrified heating solutions i. For new industrial facilities, electrified heating systems should be considered as the primary design option during the planning stage, even in applications where cooling benefits are limited or absent ii. For existing industrial facilities, electrification through industrial heat pumps becomes economically attractive when both heating and cooling demands can be addressed simultaneously (or) waste heat streams can be captured and upgraded for process heating
b.	Phased implementation strategies such as parallel operation of legacy and electrified systems, retention of backup capacity, and gradual load transfer are often critical for building confidence among industrial users
c.	Explicitly planning for redundancy and transition-period resilience can therefore be as important as technology selection itself, particularly in energy-intensive clusters where production disruptions carry significant economic consequences
d.	Modular and phased deployment of electrified heat systems reduces upfront capital exposure, allowing learning-by-doing, and flexible capital planning⁶¹

7

Electricity Pricing, Renewable Electricity Access and Market Design Reform

a.	The operational competitiveness of electrified industrial heat is strongly influenced by the relative prices of electricity and fossil fuels
b.	Broad tariff reductions lower electricity prices for all users, including those who do not invest in cleaner technologies, and can place significant financial strain on utilities
c.	Targeted electricity cost relief can instead be selectively provided to industrial users adopting electrified heat
d.	In contrast, targeted electricity cost relief can be selectively provided to industrial users that adopt electrified process heat in the form of reduced levies, exemptions, or time-bound tariff support linked to investments
e.	The operational cost competitiveness of electrified industrial heat is strongly influenced by the relative prices of electricity and fossil fuels, which are often shaped by policy choices rather than market fundamentals⁶². Addressing these distortions through tariff reform and fiscal restructuring is a critical lever for improving the business case for industrial electrification and shifting investment decisions
f.	Evidence from European industrial markets³³ shows that improving electricity-to-fuel price ratios through tax reforms, levy rebalancing, and predictable grid access is essential to unlock large scale deployment of electrified heating systems
g.	Electrification may be most viable in locations where adequate electrical capacity and renewable electricity are available
h.	Our analysis indicate that heat pumps are broadly at par with coal-based steam generation at an electricity tariff of approximately INR 6.0 per kWh or lower
i.	Access to lower-cost renewable electricity through open access, captive solar or hybrid renewable sourcing could significantly reduce operating costs
j.	For textile MSMEs, access to renewable electricity can be significantly improved through demand aggregation mechanisms such as group captive arrangements, which provide lower procurement costs, long-term price certainty and risk sharing

3

Align Electrification with Investment Cycles and Boiler Replacement Decisions

a.	Delaying electrification of long-lived heat infrastructure risks locking in fossil fuel assets, increasing future transition costs and the likelihood of stranded industrial equipment ⁶³
b.	Without targeted interventions, industries are likely to reinvest in fossil fuel-based technologies due to familiarity and lower perceived risk
c.	This highlights the importance of aligning electrification policies with equipment replacement cycles, electricity market evolution, and policy incentives and prioritizing electrified options at moments of re-investment, rather than relying solely on incremental efficiency improvements ⁶⁴
d.	Prioritization of electrification initiatives should focus on industrial units where the existing boiler fleet is approaching the end of its operational life and is likely to require replacement within the next two to three years
e.	Such prioritization is particularly relevant in textile processing units relying on coal or firewood, which are subject to supply uncertainties, seasonal quality variations and price volatility

9

Electrification as an Efficiency, Risk Management and Competitiveness Strategy

a.	Electrification is a form of energy efficiency, not just decarbonisation. Establishing electrification as a distinct industrial transformation pathway is critical to accelerating uptake and ensuring consistency across policy domains
b.	Conventional cost comparisons between electrified and fossil-fuel based heating systems often underestimate the benefits of electrification by focusing narrowly on fuel costs
c.	When system-wide energy savings, reduced maintenance needs, and avoided fuel infrastructure costs are accounted for, electrified heating systems can be competitive even in contexts where electricity prices remain higher than fossil fuels. Further, they lower insurance risks due to absence of on-site fuel combustion. ⁶⁵
d.	Evidence from electrification programs ⁵⁹ indicate that industrial firms with internal carbon pricing mechanisms or formal emissions reduction targets are more likely to pursue electrification projects. These firms are better positioned to value avoided emissions alongside energy savings, improving the perceived business case for electrified heat. As supply-chain disclosure requirements and product-level carbon accounting emerge, electrification increasingly serves as a risk management and market access strategy, rather than a purely compliance-driven instrument.

10

Appropriate Sizing and Cost Assessment of Electrified Heating System

a.	Unlike conventional boilers, electrified heating systems are often more sensitive to system sizing
b.	In solid-fuel boilers, much of the capital cost is associated with common infrastructure components. Consequently, the difference in capital cost between a 3 TPH and a 5 TPH boiler is often relatively modest
c.	In contrast, heat pumps scale more directly with installed capacity, since the compressor must be sized according to the required heating capacity and temperature lift
d.	Parameters such as heating capacity, hot water flow rate and output temperature significantly influence compressor and heat exchanger sizing and thereby directly affect overall capital cost
e.	The perceived cost advantage of conventional boilers often arises because several associated costs are either amortized over time or not fully accounted for in day-to-day operational assessments

11

Cluster-Level Aggregation and New Business Models

a.	Cluster-level demand aggregation can significantly improve the economics of electrified heating systems, as larger and aggregated heat demand enables better utilization of equipment, smoothens peak demand variation and lowers transaction costs per unit of thermal output
b.	Steam generation is not a core production activity but rather a supporting utility and can potentially be treated as a commodity service and externalized
c.	Service-based models such as heat-as-a-service, ESCO-led deployment and technology leasing can reduce upfront investment burdens and align payments with usage

12

Supply Chains, Industrial Capability and Regulatory Alignment

a.	Large-scale adoption of electrified heating technologies is expected to place a significant pressure on manufacturing capacity for key components such as compressors, power electronics, and control systems, while shortages of skilled engineers and technicians may slow project execution and commissioning
b.	Industrial electrification accelerates the diffusion of advanced manufacturing technologies by simplifying energy system design and reducing process complexity. Electrified heating systems eliminate fuel handling, combustion control, and exhaust temperature requirements, lowering operational risk and reducing maintenance intensity. This enables faster adoption of automation, digital control systems, and precision manufacturing techniques particularly in small and medium-scale facilities ⁶⁶
c.	Market analysis ⁶² highlight that electrified heating relies heavily on inverters, variable-speed drives, advanced sensors, and software-based control to optimise efficiency and responsiveness. This would require industrial capabilities centred on automation, predictive maintenance, and energy management.
d.	Policy analysis in the United States ⁶⁷ indicates that regulatory frameworks across the globe are increasingly shifting from fuel-based standards to performance-based clean heat obligations. Electrified heating systems align more naturally with these frameworks because compliance can be demonstrated through electricity sourcing, efficiency metrics, or emissions intensity of supplied intensity of supplied power, rather than through continuous emissions monitoring and fuel-specific controls.
e.	Industrial electrification is increasingly shaping where and how clean technologies are manufactured, with heat pumps, power electronics, compressors, and thermal storage emerging as strategic industrial value chains. Global assessments ⁶⁸ show that manufacturing capacity for electrified heating systems like heat pumps are currently insufficient relative to net-zero deployment needs. Countries that align industrial electrification demand with domestic manufacturing strategies are better positioned to capture economic value, reduce import dependence, and de-risk supply chains

13 Strengthening Supplier-Buyer Alignment and Value Chain Coordination

a.	Greater alignment between MSME suppliers and retail buyers is essential to enable transition to cleaner heating technologies
b.	Suppliers and buyers may need to recognise and share transition costs associated with technology adoption and fuel switching
c.	Stronger supply-chain coordination and procurement commitments can help ensure that MSMEs are not solely burdened with the costs of decarbonisation
d.	For domestic retailers, the transition can begin by encouraging suppliers to procure renewable electricity and create a favourable environment for broader decarbonisation measures.

Endnotes

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