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GREENING INDUSTRIAL STEAM

Low-carbon and clean air
roadmap for process boiler

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This report is a collective outcome of shared commitment to industrial transformation and green growth.



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List of Abbreviations

'000 tonnes	Thousand tonnes	PJ	Petajoule (10 ¹⁵ Joule)
ASI	Annual Survey of Industries	PM	Particulate Matter
BAU	Business-As-Usual	PNG	Piped Natural Gas
BEE	Bureau of Energy Efficiency	RTC	Round-the-clock
CAGR	Compound annual growth rate	SE	Annual energy demand as steam
CAPEX	Capital Expenditure	SG	Annual Steam Generation
CHP	Combined Heat and Power Boiler	SO ₂	Sulphur dioxide
CPCB	Central Pollution Control Board	NO _x	Nitrogen oxides
CRF	Capital Recovery Factor	Solar PV	Solar Photovoltaic
CV	Calorific Value	TPH	Tonnes per hour
E.C.	Installed capacity of boilers	UT	Union Territory
EJ	Exa-Joule	W.P	Rated working pressure of boiler
FE	Annual energy demand as fuel	WH	Working Hours of boiler
gCO ₂	grams of carbon dioxide	WHRB	Waste Heat Recovery Boiler
GCV	Gross Calorific Value		
GHG	Green House Gas		
IBR	Indian Boiler Regulation		
kcal	kilo calorie		
kt	kilo tonnes		
kWh	kilowatt-hour		
LCoS	Levelised Cost of Steam		
LF	Load factor of boilers		
mg/Nm ³	milligrams per normal cubic meter		
MJ	Mega-Joule		
MMT	Million Metric Tonnes		
MSME	Micro, Small & Medium Enterprises		
NIC	National Industrial Classification, 2008 of India		
OPEX	Operational Expenditure		

Foreword

The Government of India recognises the pivotal role that industrial boilers play in the nation's economic development. These systems are integral to various sectors, including petrochemicals, textiles, food processing, and heavy manufacturing, and are foundational to initiatives such as Make in India and Aatmanirbhar Bharat. However, the evolving industrial landscape necessitates a transition towards more sustainable and efficient practices.

In alignment with India's commitments under the Paris Agreement and the Mission LiFE initiative, the transformation of industrial boilers is essential. This report, "Greening Industrial Steam: Low-carbon and clean air roadmap for process boiler", is part of our research Memorandum of Understanding with iFOREST. It outlines a proposed approach to modernise boiler operations, emphasising the adoption of low-carbon technologies and enhanced air quality standards.

A significant step in this direction is the enactment of the Boilers Act, 2025, which supersedes the century-old Boilers Act, 1923. This new legislation introduces a more streamlined regulatory framework aimed at improving safety, efficiency, and environmental performance in boiler operations.

The implementation of the Boilers Act, 2025 is complemented by the Department for Promotion of Industry and Internal Trade's (DPIIT) broader strategy to position India as a hub for sustainable manufacturing. Aligned with the PM Gati Shakti Master Plan and the National Industrial Policy, DPIIT is driving integrated infrastructure and policy reforms that prioritise clean technologies, including efficient steam systems and process heating.

Public-private partnerships and collaborations with research institutions, such as iFOREST, are accelerating the development and deployment of advanced boiler technologies. Startups are also being incentivised to create innovative solutions such as retrofitting systems, intelligent monitoring tools and maintenance platforms.

Furthermore, the emphasis on skill development ensures that the workforce is equipped with the necessary expertise to operate and maintain modern, green boilers. Partnerships with agencies like the National Skill Development Corporation (NSDC) are facilitating the rollout of updated curricula and hands-on training modules.

International collaborations are also a cornerstone of this initiative, with engagements aimed at harmonising safety and efficiency standards, enabling technology transfer, and boosting investor confidence. The incorporation of international best practices into the Boilers Act, 2025 ensures that Indian industries remain competitive and compliant with global supply chain norms.

In conclusion, the Boilers Act, 2025 represents a significant advancement in India's regulatory framework, providing a robust foundation for the modernisation of industrial boiler operations. We hope this report serves as a guiding roadmap for stakeholders to navigate the transition towards low-carbon and clean-air boiler technologies, contributing to a sustainable and resilient industrial future for India.



Sandeep Sadanand Kumbhar

Technical Adviser and Secretary, Central Boilers Board
Department of Promotion of Industry and Internal Trade
Ministry of Commerce & Industry



Foreword

India's march toward becoming a developed nation by 2047 under the *Viksit Bharat* vision demands not only rapid industrial growth but also a resolute commitment to environmental sustainability. One of the lesser-discussed yet critically important sectors in this journey is industrial steam generation—a sector that underpins much of our manufacturing economy and accounts for a significant share of industrial energy consumption, greenhouse gas (GHG) emissions, and air pollution.

This report, “Greening Industrial Steam: Low-carbon and clean air roadmap for process boiler”, is the first comprehensive national study to shine a spotlight on process boilers—a ubiquitous yet often overlooked component of Indian industry. Through rigorous data collection, on-ground surveys, and techno-economic analyses, it presents a deep understanding of the current boiler landscape, the associated energy and emissions profile, and makes a compelling case for a green transition.

The findings are stark. With over 45,000 process boilers in operation—many aged and inefficient—this sector consumes nearly 38% of India's industrial energy and contributes to a quarter of its industrial carbon emissions. GHG emissions from process boilers are nearly equivalent to those from the transport sector. Even more critically, over 90% of existing boiler capacity poses air pollution risks, particularly from particulate matter and nitrogen oxides. In fact, particulate matter emissions from process boilers exceed those from the transport sector, which has traditionally been the main focus of air pollution abatement efforts.

Yet this challenge presents an extraordinary opportunity. With the right mix of targeted policies, technological shifts, and government-industry collaboration, India can green its industrial steam systems. This report outlines feasible pathways—including electrification, solar thermal integration, clean biomass, green hydrogen, and strengthened regulatory standards—that can drive emissions reductions while enhancing energy efficiency,

safety, and industrial competitiveness. Notably, greening process boilers offers an opportunity to launch a clean biomass revolution, one that could create rural employment and increase farmers' incomes.

We hope this report will serve as a foundation for a nationwide dialogue on industrial decarbonisation. It offers data-backed insights to inform policy, guide investment, and inspire innovation. Above all, it emphasises the importance of inclusive and just transition strategies—especially for MSMEs and smaller boilers—so that the path to green growth is not only rapid but also equitable.

We extend our appreciation to all partners, stakeholders, and contributors whose expertise and commitment made this study possible. This report would not have been possible without the support of the Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce and Industry, Government of India. We also thank the Boiler Directorates of 16 States and Union Territories for willingly sharing critical data. In particular, we acknowledge the proactive support of the Directorate of Boilers & Factories, Government of Uttar Pradesh, in enabling on-ground surveys and industry interactions. I especially thank my colleagues for their dedication in producing this important report.

Let this report be both a call to action and a roadmap for transformation.



Chandra Bhushan
CEO, iFOREST

Executive summary

Key Insights

- The first ever boiler inventory of India estimates forty-five thousand process boilers in the country with 8 States/UTs housing two-thirds of them. Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh and Uttar Pradesh are top 5 states.
- Cumulative installed capacity of industrial process steam is estimated to be 428 kilo tonnes per hour.
- Eighty five percent of the process boilers are up to 10 Tonnes per hour (TPH) and account for 37% of the installed capacity.
- Existing steam capacity in India is significantly aged (average age of 18 years), posing safety and efficiency challenges.
- About 48% of the capacity is based on biomass and 40% is fossil fuel driven. Biomass share is high in small boilers.
- In terms of industry sector, Food (NIC 10) has the highest (41%) cumulative installed capacity followed by Chemicals and Petroleum refinery.
- The operational capacity actively utilised in most States/UTs is half the total installed capacity. The excess capacity is either underutilised, caters to demand fluctuations or is used for non-process use such as power co-generation.
- Annual steam generation in India, determined by operational factors, is estimated to be 1.26 billion tonnes.
- On average at country-level, India produces 2.95 kilo tonnes steam annually per TPH of installed capacity.
- Distribution of steam generation across States/UTs largely mirrors the manufacturing output distribution.
- Energy consumption for process steam generation is estimated to account for 38% of total industrial energy consumption and is comparable to that of transport sector.
- CO₂ emissions from process steam in India are estimated to be 182 Million Metric Tonnes (MMT) with 50% emitted by just five States/UTs and 65% by three industry sectors.
- Emission intensity of India's industrial process steam ranges from 0.03–0.2 tonnes per tonne of steam across various States/UTs.
- Air pollution analysis reveals that process steam is responsible for more PM and NO_x emissions than the transport sector.
- Gujarat, Maharashtra, Tamil Nadu and Uttar Pradesh are the top polluters.
- Food and chemicals are most polluting industries. Food industry contributes to 44% of the total Particulate Matter emissions from industrial steam generation.
- Based on 'Viksit Bharat' growth scenario, the annual steam generation could grow four times by 2047, driven by high growth rates of steam intensive sectors. This results into corresponding growth in CO₂ emissions and air pollution.
- Cost analysis of process boilers shows that fuel cost makes up to 94% of the total cost of steam.
- Techno-economic feasibility analysis of fuel switch, as on 2025, shows that it is economically viable to switch gas-fired boilers to electricity. Biomass is already one of the cheapest fuel for industrial steam, but it needs stringent air pollution controls. Similarly, electricity and solar-thermal applications are viable for small boilers.
- After 2030, low-carbon fuel options become more attractive with RTC renewable electricity and green hydrogen emerging as most feasible for new installations.

Executive summary

Recommendations

- A National Green Boiler Mission with a multi-pronged approach to address India's rising steam requirements is the need of the hour.
- The mission should focus on retiring very old boilers, mandating energy efficiency norms for operational boilers and switching to cleaner fuels or emerging steam generation technologies as part of its larger goals. Encouraging retrofits and upgrades instead of complete equipment replacement can help, subject to meeting of safety regulations and standards.
- Clean fuel options, based on techno-economic feasibility assessment between now till 2050, indicates the potential for switching to solar thermal, RTC renewable electricity, biomass and green hydrogen for new installations.
- Switch to cleaner fuels will need to be enabled by integrating industrial boilers as a critical and priority end use in existing clean fuel missions including the National Biomass Mission and National Hydrogen Mission. Supporting steam intensive industries to tap into Green open access rules can serve to expand access to green electricity for process boilers.
- Given the significant air pollution concerns, especially Particulate Matter from biomass firing in boilers, developing stringent air pollution norms and enforcing those is necessary.
- Steam-as-a-Service (SaaS), preferably in PPP mode, can drive faster clean energy transition for small boilers in clustered settings.
- Targeted approach needs to be adopted for States/UTs with high concentration of boiler capacity and for context specific process-steam intensive industries.
- Strengthening the governance of boilers, which is predominantly safety-focused, requires the adoption of a more comprehensive regulatory framework, improved inter-departmental coordination, and the streamlining of the various agencies involved in boiler inspection and monitoring.



Introduction

As India advances its efforts to become a developed nation, industrial transformation will be the cornerstone of this ambitious journey. India's manufacturing sector, projected to increase its share of GDP to 25% over the next two decades, is poised to be the key engine driving the country's path to a \$30 trillion economy. Decoupling this growth from emissions—and industrialising sustainably while meeting climate goals—is the central challenge ahead.

At the heart of this transformation lies the greening of industrial steam—an often-overlooked but highly significant source of energy and carbon emissions.

Steam plays a vital role in numerous industrial operations, contributing to over half of global industrial heat demand. Key sectors such as food and beverages, textiles, chemicals, fertilisers, pulp and paper, sugar, and pharmaceuticals depend on steam for processes like heating, drying, pulping, evaporation, cleaning, and distillation. Central to steam generation are industrial boilers—equipment that burn fuels to produce heat, which is then used to convert water into steam. In India's manufacturing landscape, these boilers largely rely on coal, oil, and gas. While biomass-based systems are used as alternatives, their lower efficiency often leads to persistent air pollution challenges.

Globally, countries are accelerating efforts to transition steam systems toward cleaner alternatives—electric boilers powered by renewables, high-efficiency biomass boilers, solar thermal integration, and hybrid configurations. These technologies are already delivering measurable results in reducing emissions, lowering operational costs, and meeting stricter environmental regulations.

For India, where industrial energy demand is expected to more than double by 2047, decarbonising steam is not just a climate imperative—it is an economic and strategic necessity.

Modernising India's aging and inefficient boiler stock presents a high-leverage policy opportunity. Transitioning to low-emission steam systems will support multiple national goals: energy security by reducing fossil fuel dependence; industrial competitiveness through energy efficiency; and climate action via significant emissions reductions. Moreover, it directly aligns with key pillars of *Viksit Bharat*—sustainability, innovation, and green growth.

This report marks India's first-ever research on the critical industrial steam sector. It presents the boiler stock and the distribution of boiler systems across States/UTs and industries, the fuel mix used, and the associated GHG emissions and air pollution resulting from the projected increase in steam demand. It also provides policy recommendations and potential pathways to green and transition the country's steam systems.

Limitations of the Study

Lack of a Centralised Boiler Database

India currently lacks a comprehensive, centralised digital database of industrial boilers across States and Union Territories, making it challenging to obtain consistent and complete data for national-level analysis. The study was done through on-ground data collected from 16 States/UTs.

Inadequate Capture of Process-Relevant Parameters

Critical data such as fuel type, working pressure, thermal efficiency, and emissions are often not recorded during boiler inspections, as these metrics are not mandated under the current regulatory framework. However, few big states do collect these data. The study has used process parameter data from few major states to estimate for the rest of the country.

Limited Accessibility to State/UT-Level Records

Variability in data availability, formats, and digitisation levels across Boiler Directorates led to inconsistent data collection, particularly in smaller States and UTs.

Reliance on Industry Self-Reporting

Some data points were gathered through direct industry engagement, which may involve self-reported figures that lack independent verification.

Resource and Time Constraints

As with many large-scale studies, constraints on time, manpower, and access to site-level verification limited the scope for deeper field-level validation.



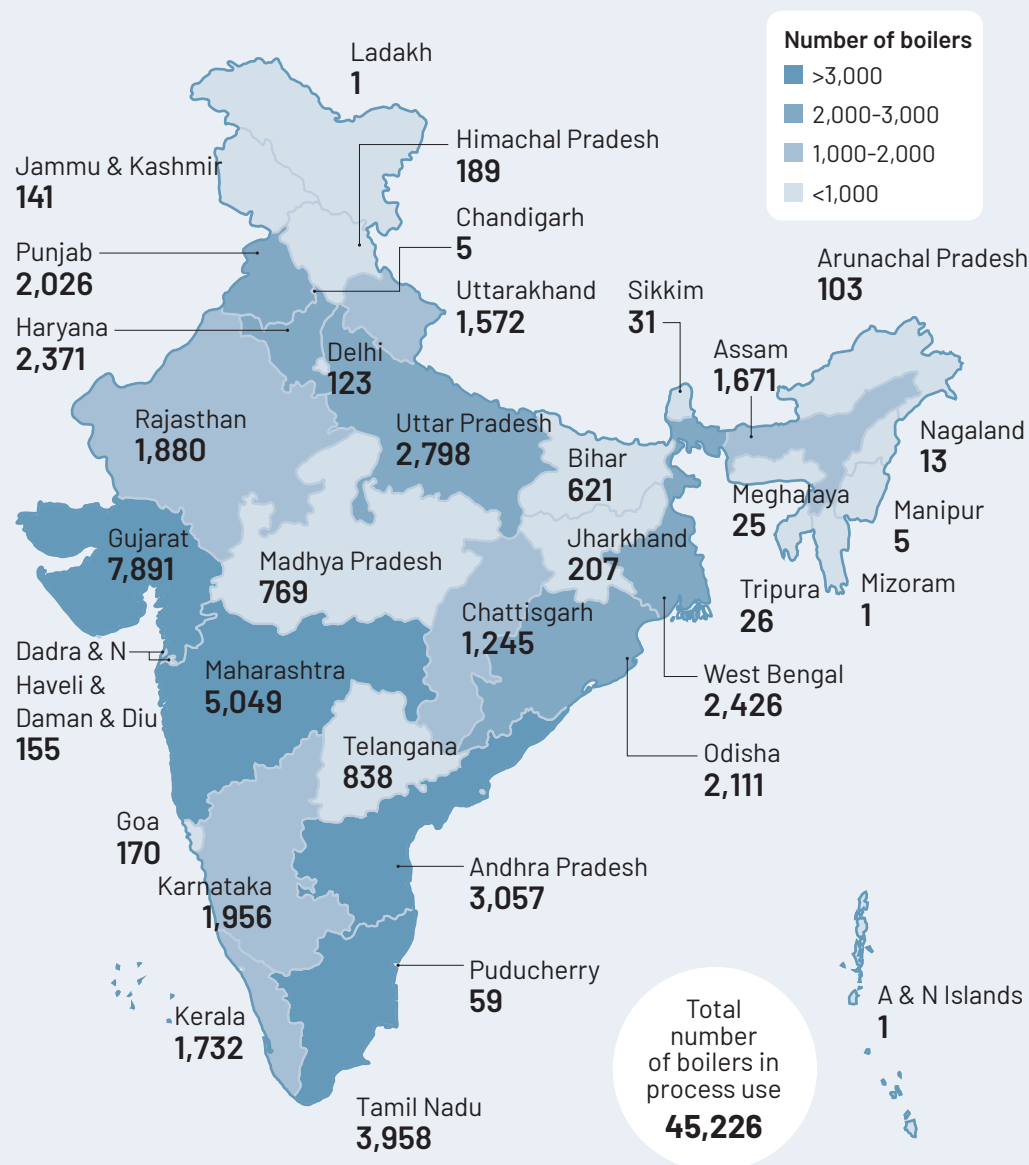
01 **Boiler Stock**



8 States/UTs house two-thirds of India's process boilers

- India has an extensive stock of boilers including process and co-generation (co-gen) or Combined Heat and Power (CHP) boilers. Process boilers are boilers utilised for generating and supplying steam to industrial processes. In the case of co-generation boilers, only a part of the steam is utilised in process while rest is used for electricity generation. This study focuses on boiler capacity utilised for industrial process use.
- Boilers in process use are estimated to be in the range of 40,000 to 62,000, with the best figure estimated to be 45,226 boilers. As there is currently no centralised and digitised database for boilers in the country these estimates are based on the on-ground data collected from 16 states and UTs.
- A significant geographic concentration exists: 8 states—Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Haryana, and Odisha—account for 65.5% of India's total stock.
- Gujarat leads with the highest number of process boilers. In contrast, eastern and central states like Jharkhand, Chhattisgarh, and Madhya Pradesh possess comparatively fewer number of large process boilers.

Map 1: Distribution of number of boilers by State/UT



1 Refer to Annexure A1 for detailed methodology

Eighty five percent of the process boilers are up to 10 TPH; account for 37% of the installed capacity

Figure 1: Size distribution of process boilers by count

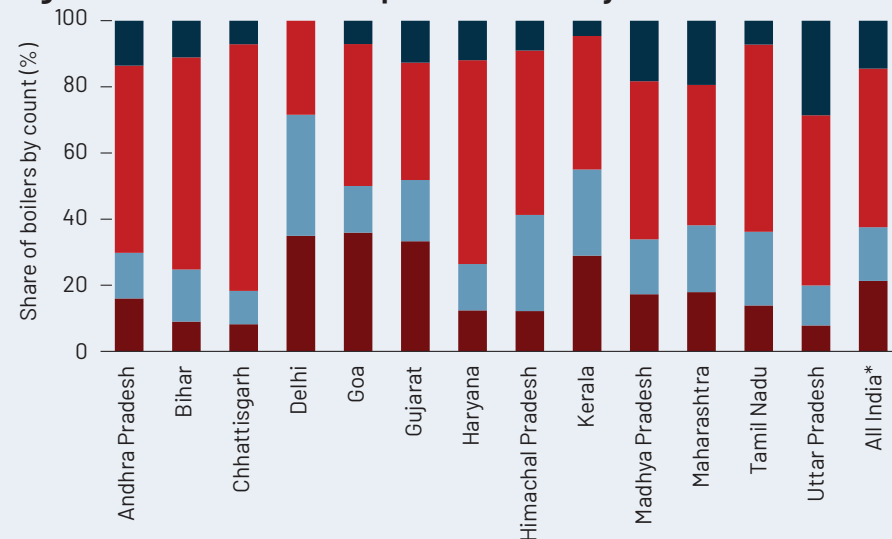
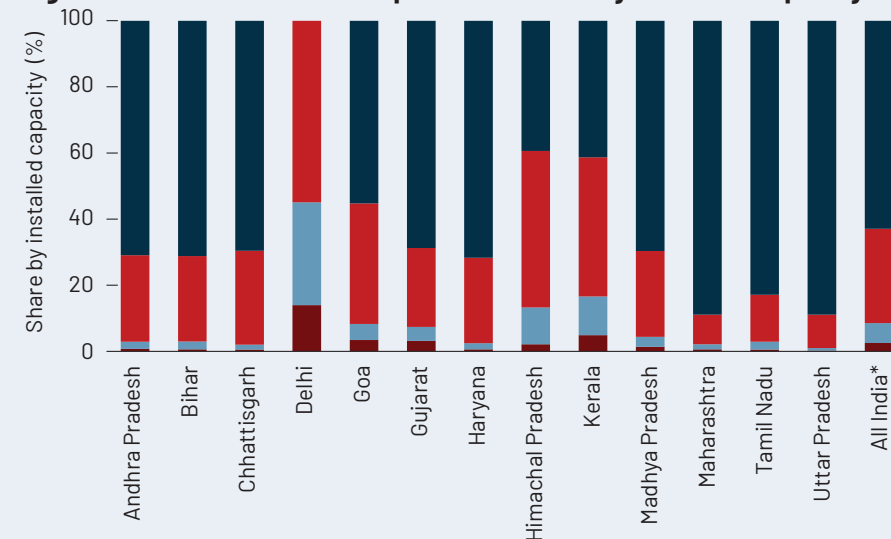


Figure 2: Size distribution of process boilers by installed capacity



*Size distribution in Other States/UTs is considered same as the all India distribution based on distribution in the 13 States/UTs with complete data collected.

The size of process boilers in India varies widely, but the vast majority can be categorised as small boilers.

- 37% of boilers are up to 2 Tonnes per hour (TPH).
- 85% of boilers have a capacity up to 10 TPH.
- Boilers under 10 TPH constitute 37% of the installed capacity
- Gujarat (6,889), Maharashtra (4,069), and Tamil Nadu (3,673) are the top three by number of small capacity boilers (<10 TPH).

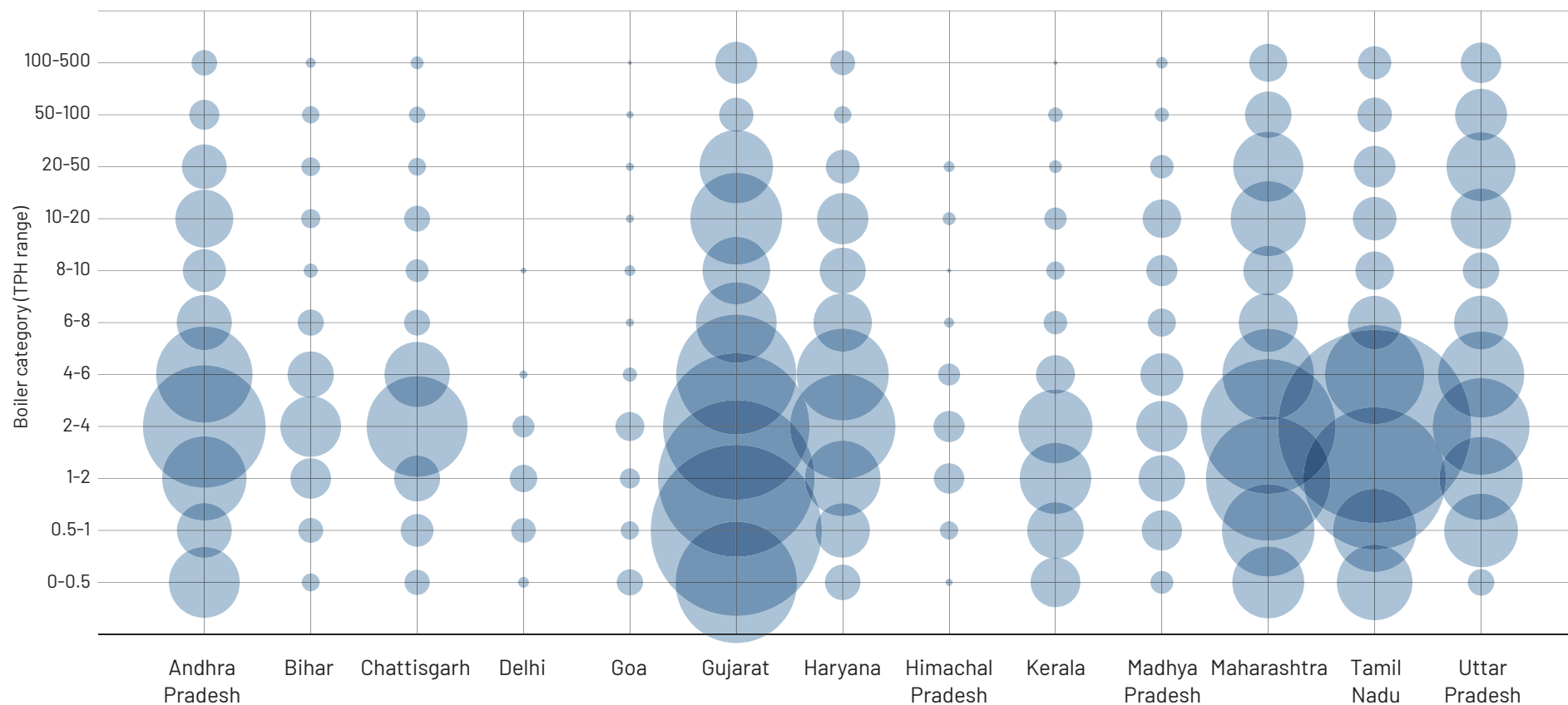
Large-capacity boilers (>10 TPH) make up 63% of the installed capacity.

- Two states with high share of large capacity boilers (>10 TPH) are Uttar Pradesh and Maharashtra.
- In Uttar Pradesh, 28.5 % boiler stock is large and in Maharashtra, it is 19.3%.
- On the other hand, smaller States/UTs like Delhi, Goa, and Himachal Pradesh, have few or no large boilers.

The large number of small process boilers poses challenges related to regulatory coverage, enforcement, and high transaction costs for any transition. Decarbonising them at scale may require intensive efforts. Steam-as-a-Service (SaaS) model can potentially be used to decarbonise steam in MSME sector.

Size category of process boilers that dominates in each State/UT varies

Figure 3: Boiler count as a function of State/UT and boiler category

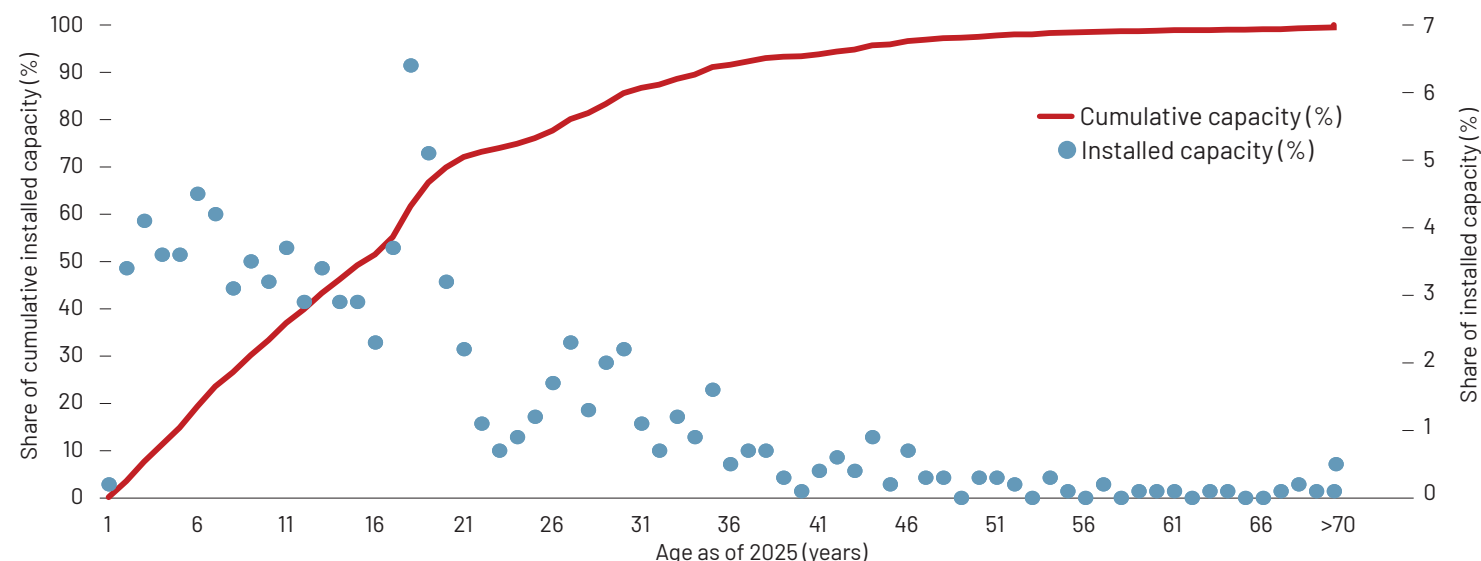


- Various States/UTs have different numbers of boilers across various size categories. Specifically, Gujarat exhibits a bottom-heavy distribution pattern, indicating a higher number of small-sized boilers, while Tamil Nadu shows a middle-heavy distribution, indicating a higher number of medium-sized boilers.

- States such as Uttar Pradesh and Maharashtra have two peaks - one below 4 TPH, and the other between 10-50 TPH.

Existing stock is significantly aged posing safety and efficiency challenges

Figure 4: Distribution of installed boiler capacity by age in 2025



Age analysis is based on data from six States/UTs. (96.1% of boilers in 6 States/UTs reported commissioning year; overall 44.9% boilers in 16 States/UTs reported commissioning year)

The boiler stock in India is significantly aged

- Average age of installed boiler capacity is 18 years.
- Nearly one-third (15,000 boilers) are over 15 years old, accounting for half the installed capacity.
- Around one-fifth (9,000 boilers) are over 20 years old, contributing to 30% of the capacity.

• The lifespan of boilers depends on various factors including maintenance, fuel type, operational load and design standards but is typically assumed to be 25 years.

• Age of boilers has implications for safety, efficiency, and emissions. Age leads to increased safety risks and declining fuel efficiency, potentially increasing GHG and air pollution.

• According to Indian Boiler Regulations (Section 391A), the operational pressure of boilers must be reduced after 25 years for safety considerations, but enforcement needs to be ensured.

Cumulative capacity of the process boilers is 428 kilo tonnes per hour

- The total installed steam generation capacity in India is estimated at 428 kilo tonnes per hour.

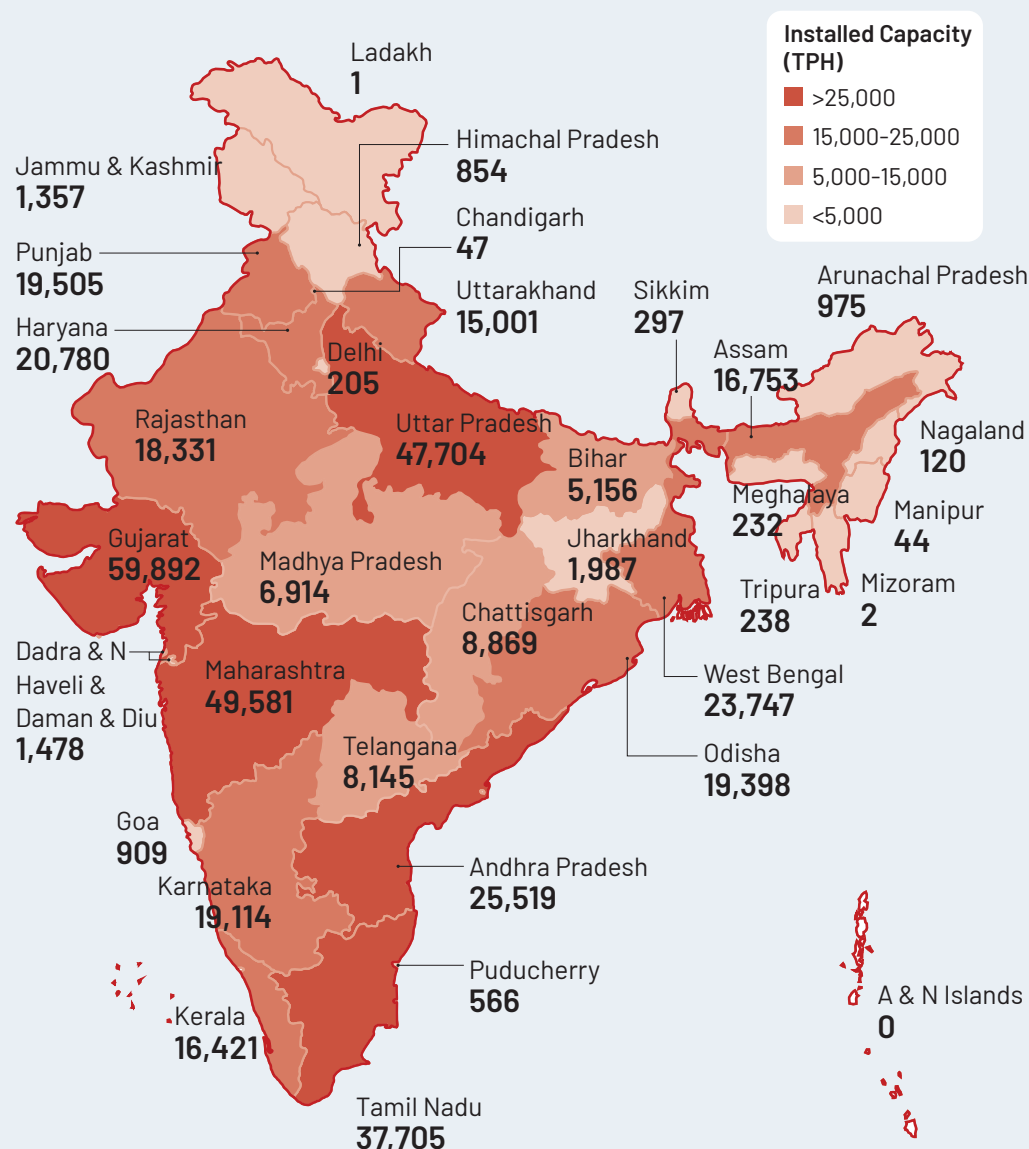
The distribution of installed capacity is similar to the distribution of boiler and is concentrated in a few States/UTs.

- Eight states (Gujarat, Maharashtra, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, West Bengal, Haryana, Punjab) together house about two-thirds of the total capacity.
- Notably, Gujarat and Maharashtra together contribute one-fourth of the national capacity.

Installed capacity doesn't always directly correlate with the number of boilers.

- Uttar Pradesh, despite having only 6.2% of the boilers, contributes 11.1% to the total capacity, indicating that the state has larger boilers on an average.
- On the other hand, Gujarat, while having 17.5% of boilers, contributes only 14% to capacity, reflecting concentration of small-capacity boilers.
- Punjab ranks eighth in terms of installed capacity of process boilers while Odisha ranks eighth in terms of number of boilers.

Map 2: Installed capacity of process steam by State/UT



About half of the installed capacity is based on biomass, while 40% is fossil-fuel fired

Figure 5: Distribution of installed capacity by size and fuel type

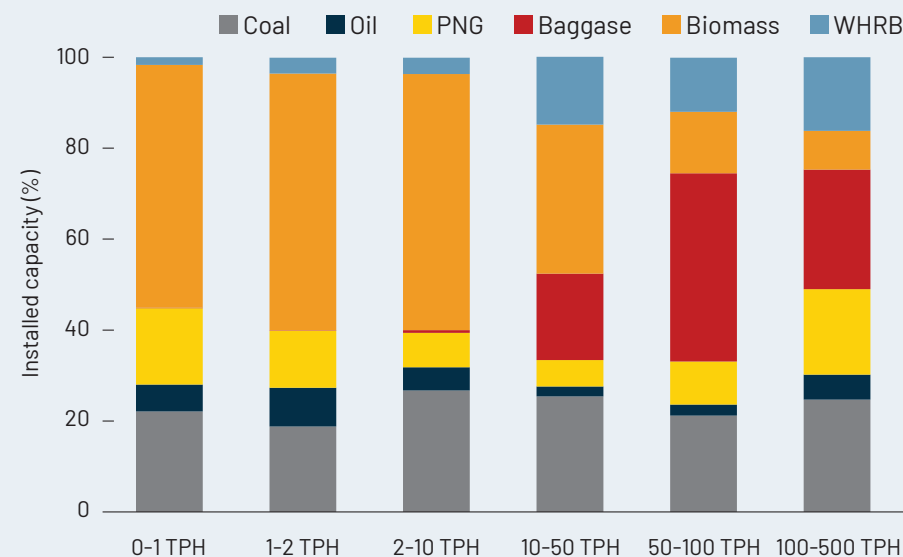
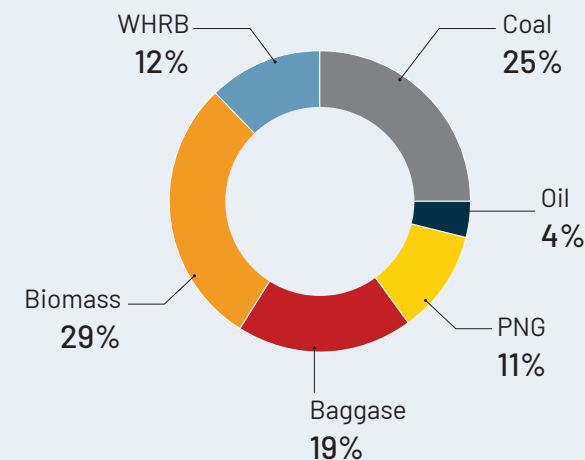


Figure 6: Fuel distribution of boilers by installed capacity



- 40% of the installed boiler capacity is powered by fossil fuels: coal, gas or oil. These units account for 36.9% of the total number of boilers.
- Biomass (including bagasse), although considered largely carbon neutral, powers nearly half of the installed steam capacity and poses air pollution challenge.
- A significant share of small boilers (0-2 TPH) are fossil fired - coal being the dominating fuel.
- Share of biomass as a fuel decreases after 10 TPH boiler size, while the share of coal as a fuel largely remains constant.
- Share of waste heat recovery remains fairly constant in the small boiler categories (0-10 TPH) and then increases with increasing boiler size.

Food industry (including sugar) accounts for 41% of total installed capacity

Figure 7: Distribution of installed capacity by size and industry type

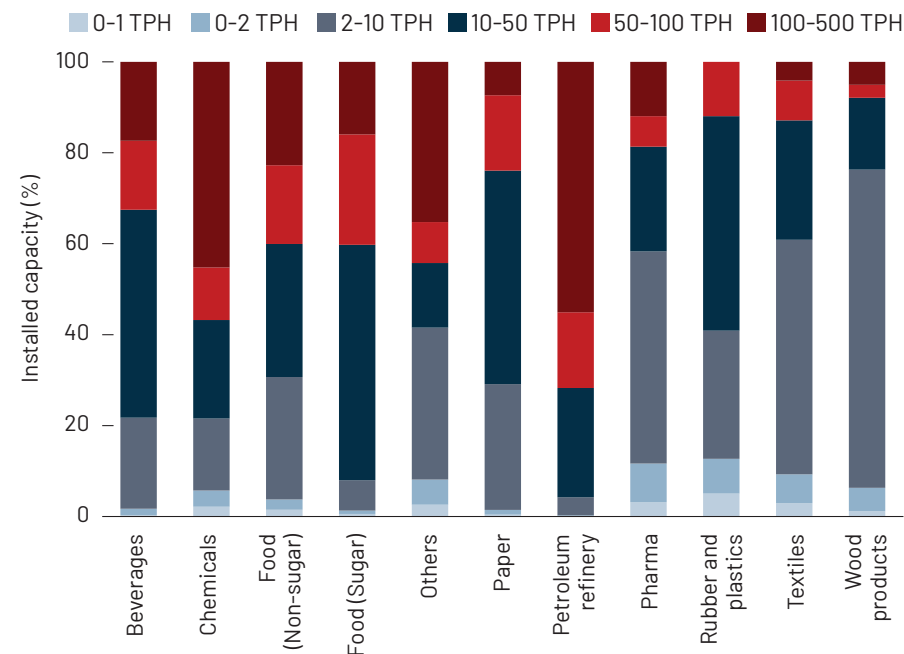
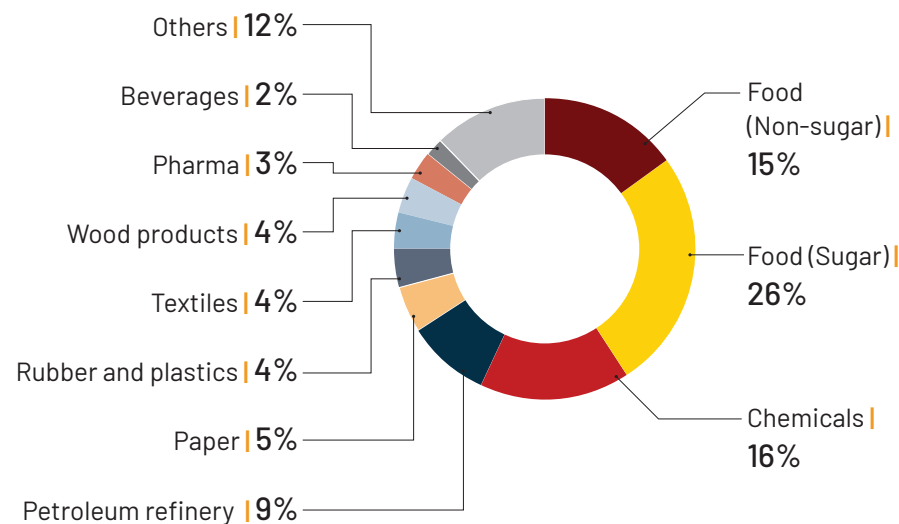


Figure 8: Installed capacity by industry



• Nine industries account for ~88% of the total installed capacity.

• Food, code 10 as per National Industrial Classification 2008 (NIC), holds the largest share of steam capacity at 41%. This is largely on account of Sugar industry, a highly steam intensive industry requiring 3-5 tonnes of steam per tonne of production.

• Average boiler size is highest in the Sugar industry - about 57.5 TPH, which is much larger than the industry average of 9.2 TPH.

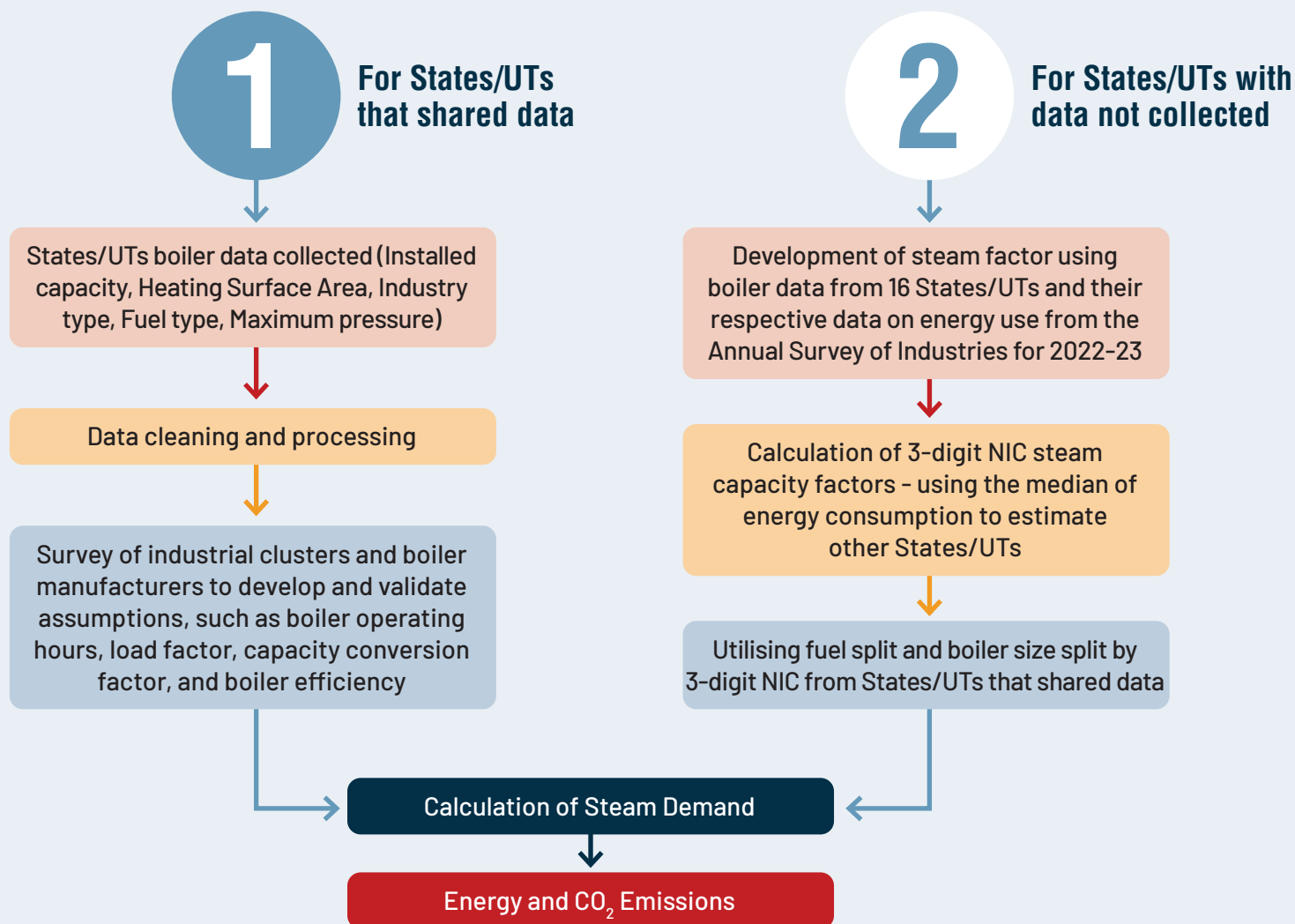
• The chemical sector is the second-largest in terms of installed capacity. This is driven mostly by the fertiliser industry, which accounts for 94% of steam demand within the chemical industry sector.

02

Steam Generation



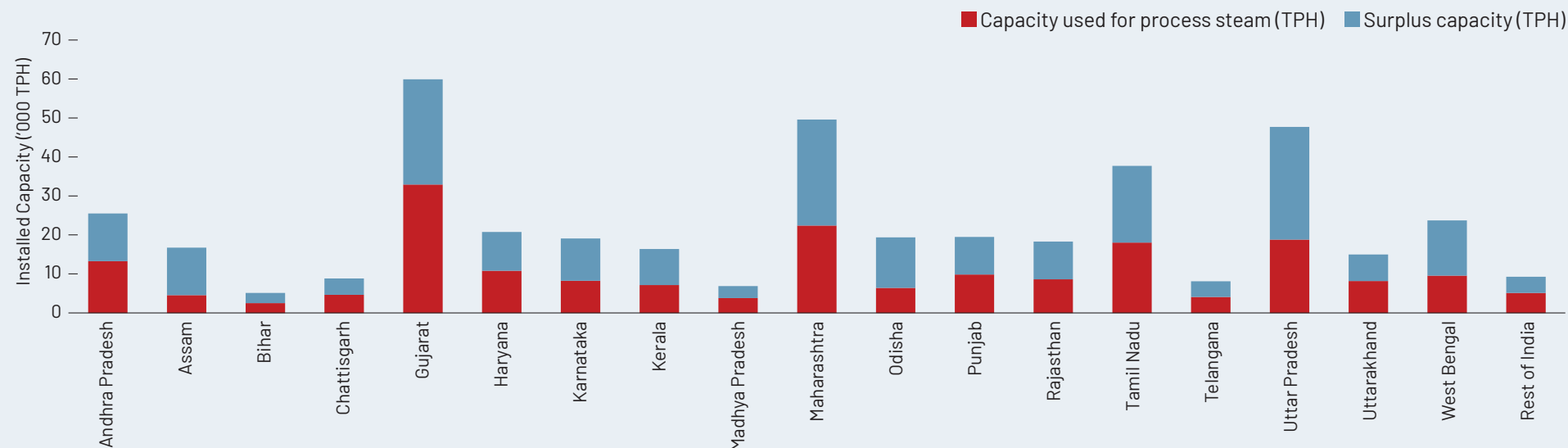
Methodology for Calculating Steam Generation



*NIC – National Industrial Classification, 2008 of India
Details of this methodology are provided in Annexure A1

Capacity in process use across all major States/UTs is about half the installed capacity

Figure 9: Installed capacity in process use and non-process use by State/UT



- Only about 50% of the installed capacity is actively used for process steam generation. The other half is either underutilised or used for other purposes such as power generation.

- Most industries install boilers of higher design capacity, than needed. This idling capacity is maintained to accommodate future industrial expansion or manage seasonal fluctuations in industrial production.

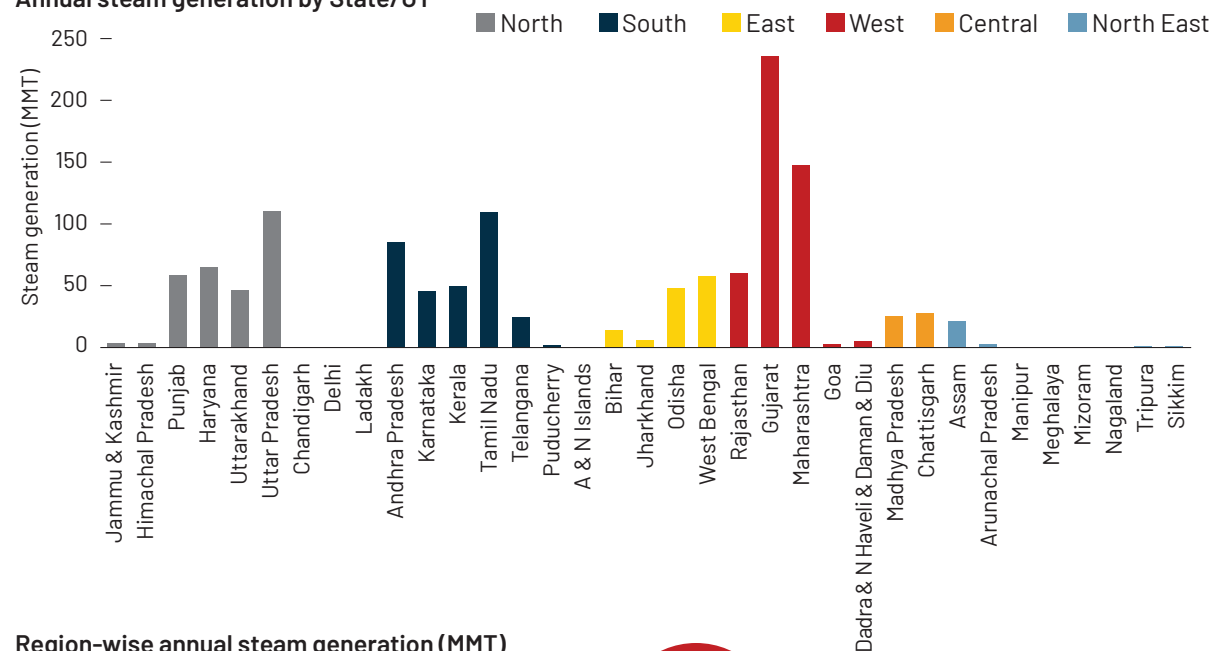
Uttar Pradesh and Maharashtra are two states with lowest share of capacity for process steam generation

- In Uttar Pradesh, over 50% (around 28,871 TPH out of 47,704 TPH) steam capacity is not used for process steam generation, In Maharashtra, it is around 40% (27,166 TPH out of 49,581 TPH) of the total installed capacity.
- Both Uttar Pradesh and Maharashtra have significant presence of sugar industry which houses co-generation boilers. Sugar industry is seasonal and requires about one fourth of the steam capacity for use in production process. The installed capacity is often higher to utilise the abundant fuel (bagasse) available as a byproduct for power generation.

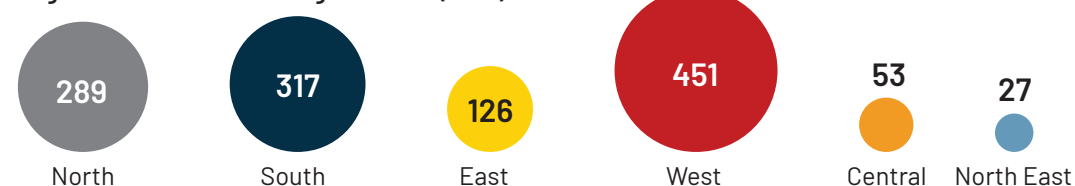
Annual steam generation in India, determined by operational factors, is estimated to be 1.26 billion tonnes

Figure 10: Comparison of region-wise annual steam generation and manufacturing output in India

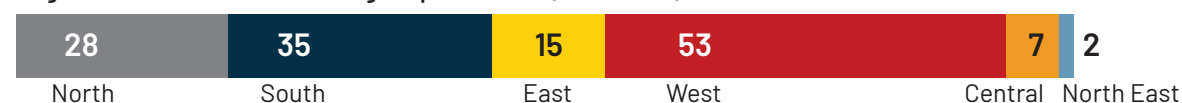
Annual steam generation by State/UT



Region-wise annual steam generation (MMT)



Regional share of manufacturing output of India (₹ in trillion)



Source: Annual Survey of Industries, 2022-23

- West and South India jointly account for over 60% of the country's total industrial steam generation, with 451 MMT and 317 MMT, respectively. This concentration correlates strongly with the regions' dominant share in India's overall manufacturing output. Western India accounts for 36% of process steam generation; it also contributes 38% of the national manufacturing output.

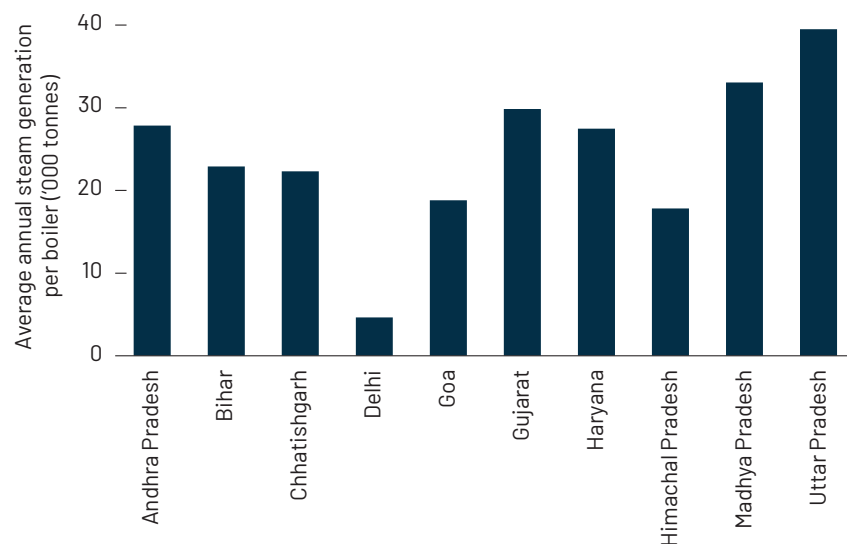
- Gujarat leads in industrial process steam generation, producing over 236 MMT annually. This dominance is driven by a large number of boilers operating at high capacity, supported by the state's concentration of steam-intensive industries.

- Tamil Nadu (110 MMT) and Maharashtra (147 MMT) also exhibit substantial steam demand, highlighting the strength of their industrial sectors.

- In contrast, the North-Eastern states together contribute less than 2% to the total national steam demand, with Assam alone responsible for nearly 85% of the region's generation.

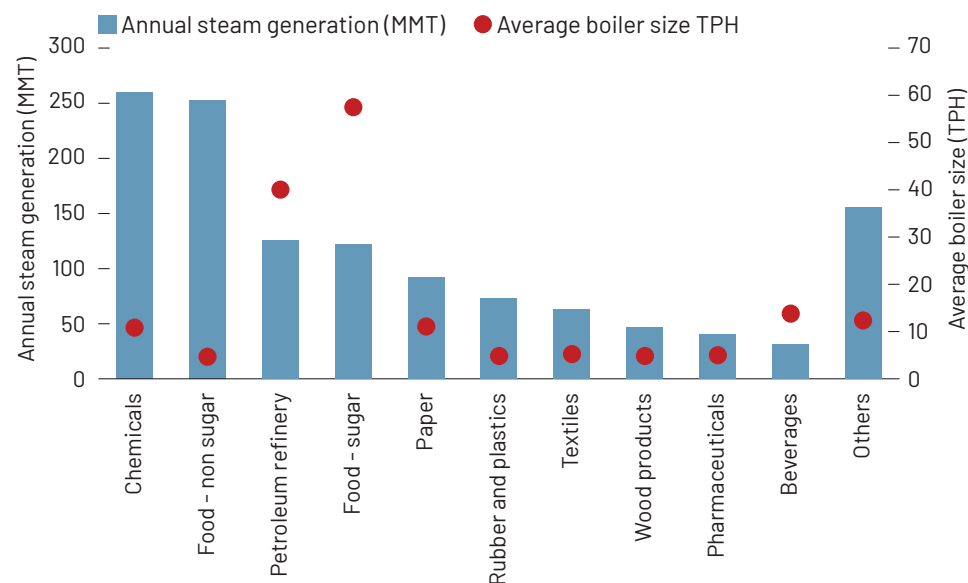
Annual generation of steam is linked to demand and nature of industrial process

Figure 11: Annual steam generation per boiler by State/UT



- A state-wise comparison of steam generation per boiler reveals notable differences—for instance, Delhi records a significantly lower output per boiler compared to Uttar Pradesh, which produces much higher annual steam. This variation primarily stems from the deployment of larger-capacity boilers in certain industrial sectors, prompting a more detailed examination of steam generation patterns by industry.

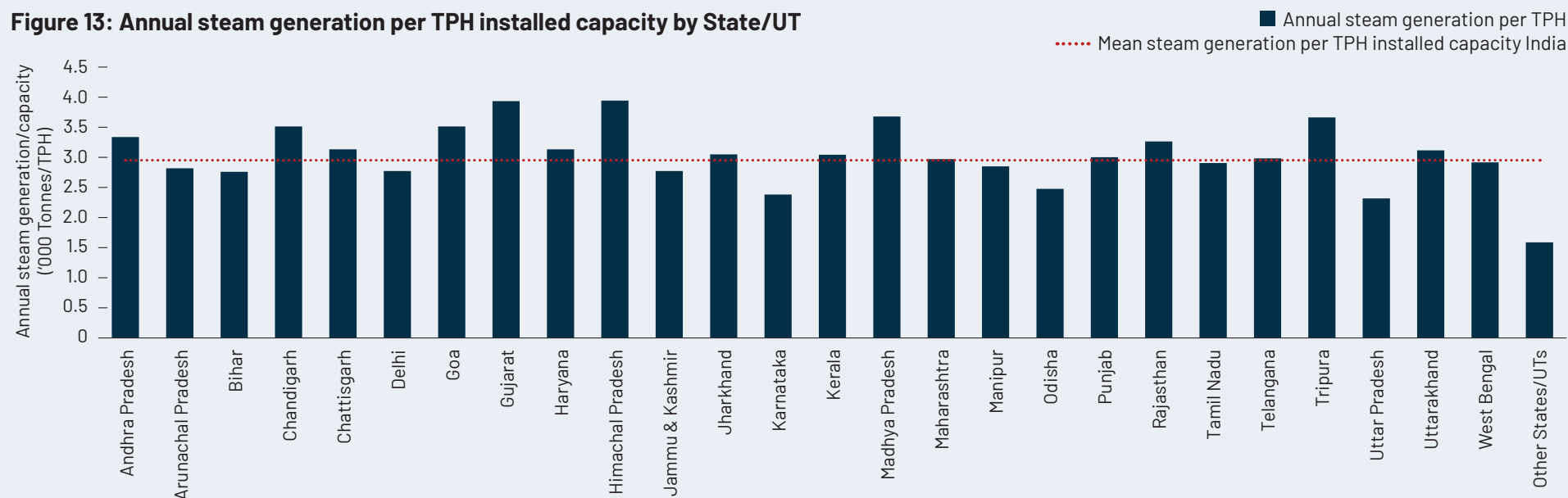
Figure 12: Annual steam generation and average boiler size by industry



- Among various industrial sector's food processing (including sugar) emerges as the largest contributor, accounting for roughly 30% of India's total industrial steam generation. This reflects industry's heavy dependence on process steam, largely due to the widespread presence of sugar mills, rice mills, dairy facilities, and edible oil refineries.
- Industrial steam demand is shaped by several factors, including production needs, the nature of industrial processes, and typical boiler sizes. Industrial sectors such as food, chemicals, petroleum, and paper tend to operate with larger boilers and generate substantial steam volumes. These sectors often run continuous-process operations where shutdowns are typically not feasible—examples include sugar production (food sector), fertiliser manufacturing (chemicals), and oil refining (petroleum).

On average at country level, India produces 2.95 kt steam annually per TPH of installed capacity

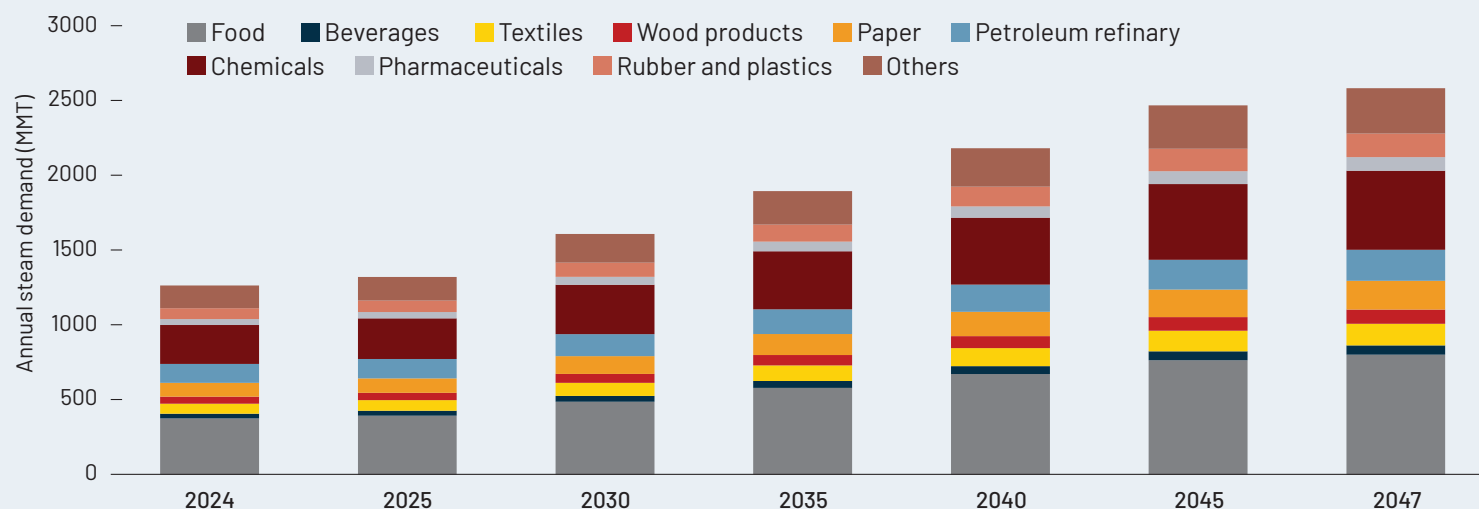
Figure 13: Annual steam generation per TPH installed capacity by State/UT



- Overall, around sixteen States/UTs generate steam per TPH of installed capacity at levels above the national average of 2.95 kilo tonnes per TPH, suggesting lower idle capacity and more consistent boiler utilisation.
- Gujarat stands out for its higher process steam generation relative to its installed boiler capacity. This efficiency is largely due to the concentration of steam-intensive industries such as chemicals, petrochemicals, pharmaceuticals, and textiles—sectors that typically operate year-round with consistently high thermal energy demand. As a result, boiler capacity in the State sees sustained usage.
- In contrast, Uttar Pradesh records one of the lowest steam generation per TPH of installed capacity, pointing to considerable underutilisation. This is primarily due to the prevalence of cogeneration boilers, which are mainly used for electricity generation with only a portion allocated to process steam. Additionally, the state's industrial landscape is heavily shaped by seasonal operations like sugar and rice milling, which do not run year-round. These two industries together account for approximately 53% of Uttar Pradesh's total installed boiler capacity, significantly influencing the state's overall utilisation rate.

India's industrial steam generation is set to double by 2047 based on historic growth rate of industries'

Figure 14: Annual steam demand (MMT) by industry in Historic Growth Rate scenario

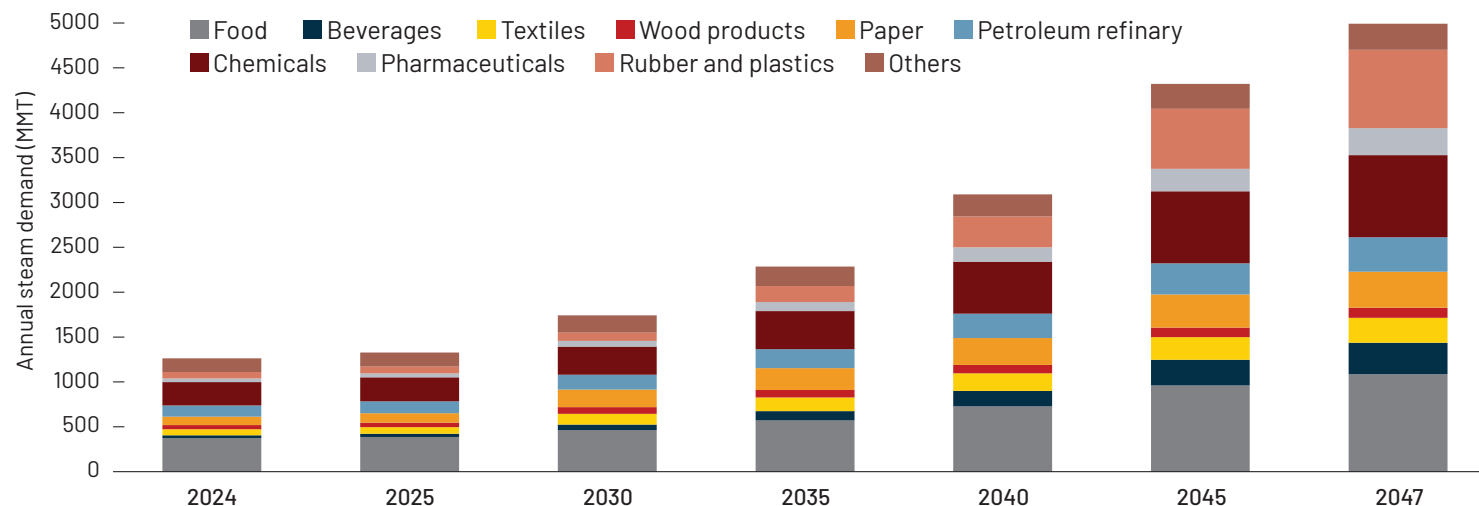


- In the historic growth rate (HGR) scenario¹ industrial steam demand is projected to grow from 1,263 MMT in 2024 to 2,581 MMT by 2047—a 104% increase. While the food and chemical sectors will remain the primary consumers, notable growth in pharmaceuticals, paper, and rubber & plastics indicates a diversification of steam-intensive industries.
- Importantly, nearly 60% of the total increase in steam demand will come from just three sectors—food, chemicals, and paper—making them key targets for policy and technological interventions aimed at improving efficiency and reducing emissions.
- The food sector will continue to be the largest consumer in absolute terms, with steam demand rising from 374 MMT in 2024 to 801 MMT by 2047. However, the pharmaceutical industry is expected to grow the fastest, with steam use expanding by 2.3 times, followed by strong growth in textiles and food.
- After the food sector, the chemical sector is projected to see one of the largest absolute increases in steam demand, adding approximately 269 MMT over the period. This underscores its central role in industrial thermal energy use and highlights the decarbonisation challenges it faces due to its heavy reliance on fossil fuels, particularly coal.

1. Historic growth rate (HGR) scenario is defined wherein 2 digit NIC Industry growth rate in future is assumed to be the same as last 10 year growth rate. For more details, refer Annexure A2.

India's industrial steam generation is set to grow by four times by 2047 in the *Viksit Bharat* scenario

Figure 15: Annual steam demand (MMT) by industry in *Viksit Bharat* scenario.



- In the *Viksit Bharat* scenario², industrial steam demand is projected to surge nearly fourfold—from 1,263 MMT in 2024 to 4,991 MMT in 2047. This dramatic rise emphasises the pivotal role of steam-intensive manufacturing in driving India's transformation into a \$30 trillion economy, where industry is expected to contribute roughly one-third of the GDP.
- The scale of growth in the *Viksit Bharat* scenario is double that in the HGR scenario (2,581 MMT by 2047), highlighting the urgent need for substantial expansion in steam infrastructure.
- The food sector alone is expected to reach 1,086 MMT in steam generation by 2047, up from 375 MMT in 2024—an increase by 190%. Similarly, the chemical sector, designated as a sunrise sector in the *Viksit Bharat* vision, is projected to increase its steam demand by 3.5 times. Combined, these two sectors will account for over 40% of total industrial steam demand in 2047.
- Industries like pharmaceuticals, rubber, plastics, and beverages are also expected to grow rapidly in the future.

² The *Viksit Bharat* Scenario (VBS) is defined as a scenario where the future growth rates of 2-digit NIC industries are aligned with the overall growth projections under the *Viksit Bharat* framework. For more details, refer to Annexure A2.

03 Energy Consumption



The fuel mix driving energy consumption varies across States/UTs and industries

Figure 16: Fuel mix of steam generation by industry

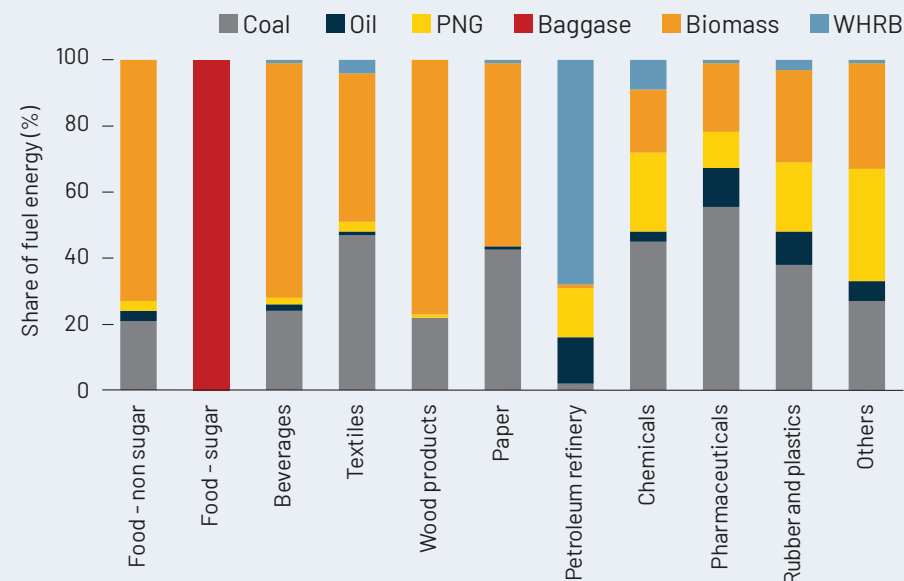
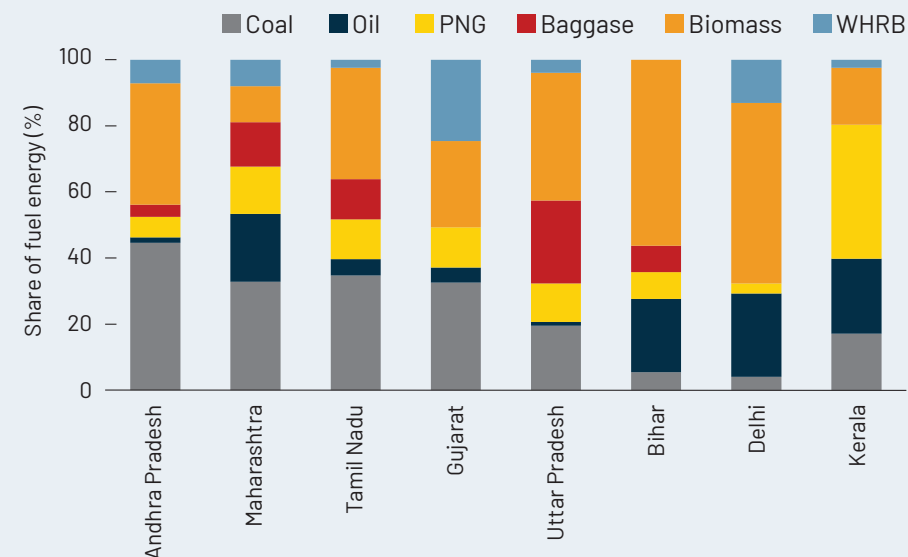


Figure 17: Fuel mix of steam generation by State/UT



- Biomass fuels dominate process steam generation in several sectors—accounting for 86% in food processing, 77% in wood products, and 71% in beverages. This high reliance is driven by the ready availability of biomass by-products such as bagasse in sugar mills, rice husk in rice mills, and wood waste in timber-based industries. This setup enables cost-effective, renewable steam generation and demonstrates a natural alignment between production processes and fuel sources.

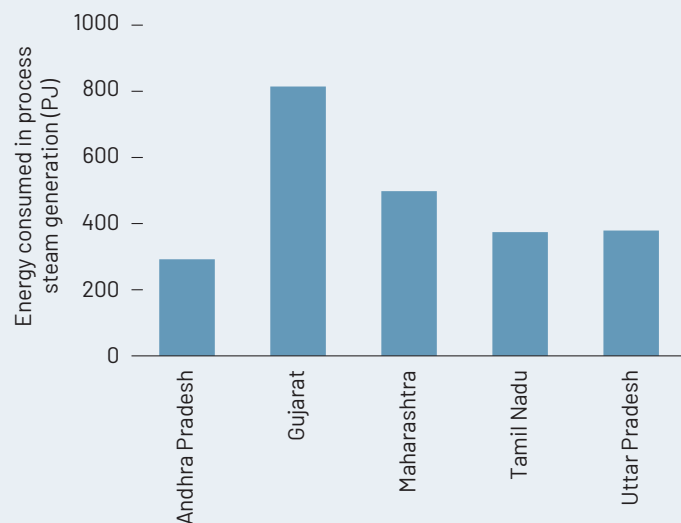
- In contrast, industries such as pharmaceuticals (56% coal), chemicals (45% coal, 24% PNG), and rubber (38% coal, 21% PNG) continue to depend heavily on fossil fuels for steam. These sectors represent key opportunities for initiating a shift toward low-carbon alternatives.

- While fuel oil has largely been phased out across industries, it remains relatively prominent in pharmaceuticals, rubber, and petroleum products. Regionally, states like Kerala, Himachal Pradesh, and Maharashtra report comparatively higher fuel oil usage.

- Gujarat stands out with about 25% of its steam generated through Waste Heat Recovery Boilers (WHRBs), along with a balanced fuel mix of coal, PNG, and biomass—indicating a mature and adaptable steam infrastructure capable of accommodating cleaner technologies. On the other hand, WHRBs are producing very little steam in states like Uttar Pradesh and Maharashtra.

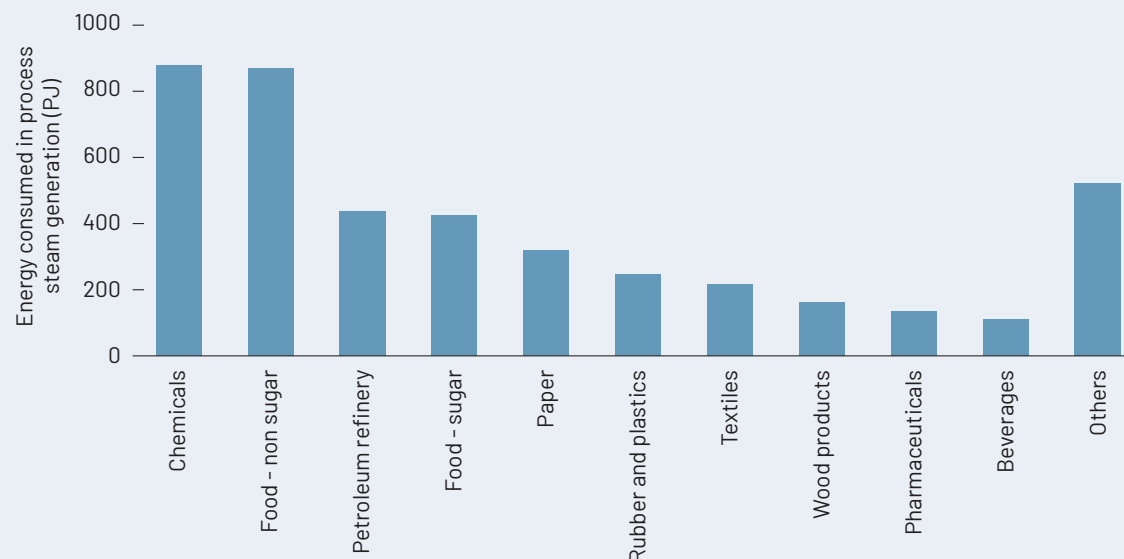
Three states account for 40% of total energy consumption, while two industrial sectors—food and chemicals—make up half

Figure 18: Process steam energy use by State/UT



- Together, Gujarat, Maharashtra, and Uttar Pradesh account for nearly 1,700 PJ of energy used for process steam generation, making up 40% of India's total steam energy consumption. The leading industries by energy use in each of these states are fertilisers and petroleum in Gujarat, fertilisers and sugar in both Maharashtra, and Uttar Pradesh.

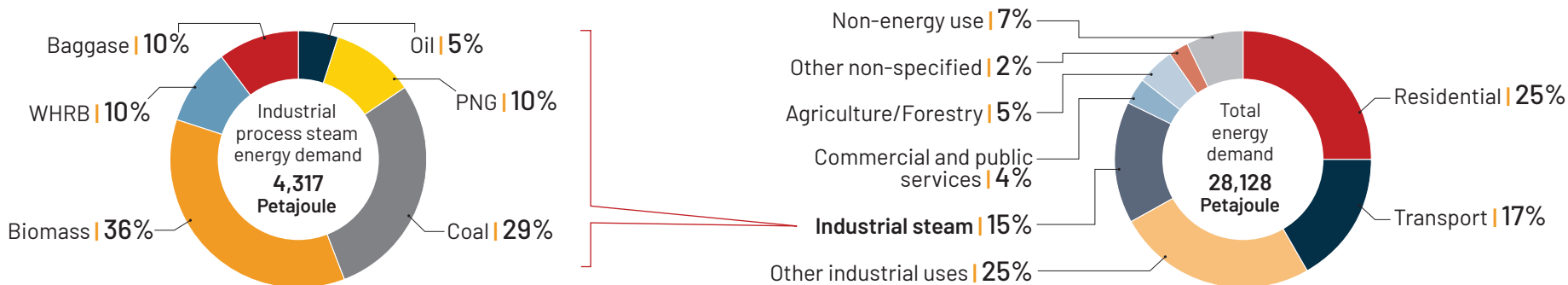
Figure 19: Process steam energy use by industry



- The food industry (including Sugar production), uses 1,293 PJ of energy, accounting for more than 30% of all industrial process steam energy. When combined with Chemical industry's usage of 879 PJ, these two sectors represent half of nation's total steam energy demand.
- Industries classified under "Others"—including sectors like tobacco, electronics, leather, machinery, and motor vehicles—account for 12% of the total energy used for process steam.

Energy consumption for process steam generation accounts for ~38% of total industrial energy consumption and 15% of total energy consumption in India

Figure 20: Energy use in India by: a) Fuel type in process steam in 2024 and b) Sectoral energy consumption in 2022¹



- Boiler-based process steam generation accounts for a significant 38% (4.3 EJ) of India’s total industrial energy consumption (11.4 EJ), representing nearly one-sixth of the country’s overall energy use and about two-fifths of all energy consumed by industry.
- Energy use for process steam generation (15%) is comparable with that of the transport sector (17%).
- Currently, biomass has become the dominant fuel for process steam in India, accounting for 46% of total steam-related energy use—surpassing coal and signaling a significant move toward low-carbon energy sources.
- WHRBs which help lower fuel consumption, now contribute 10% of total process steam energy use. Their growing deployment—mainly in the petroleum sector, followed by chemicals—reflects increasing adoption of energy-efficient technologies and a focus on circular energy use in industrial operations.

¹ International Energy Agency. (2025). India: Energy mix. International Energy Agency. Retrieved April 10, 2025, from <https://www.iea.org/countries/india/energy-mix>

04 Carbon Dioxide Emissions



Five states and three industries are responsible for over half of the total emissions

Figure 21: Annual CO₂ emission from process steam by State/UT in 2024

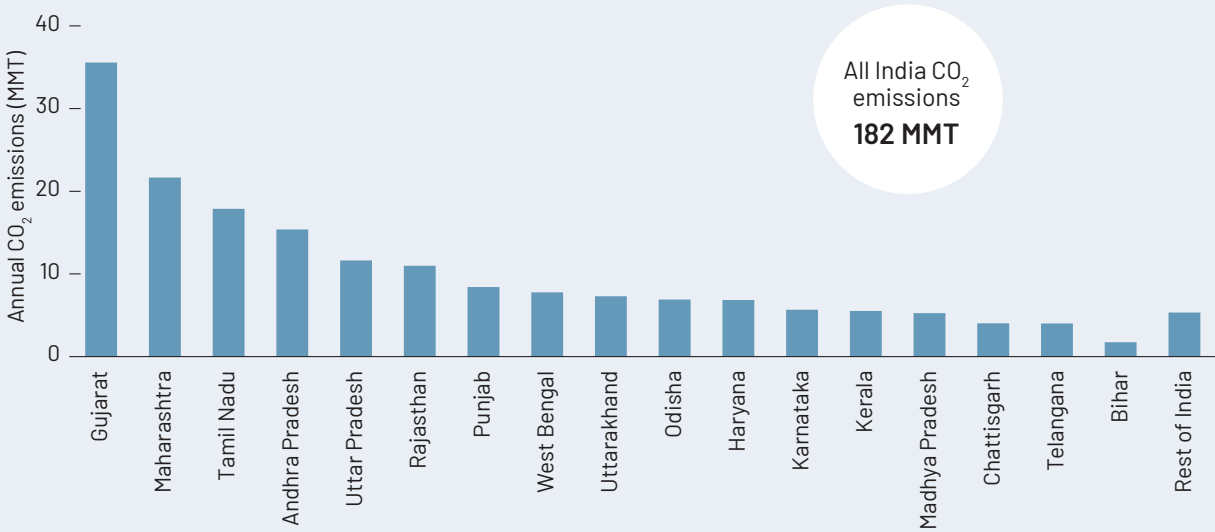
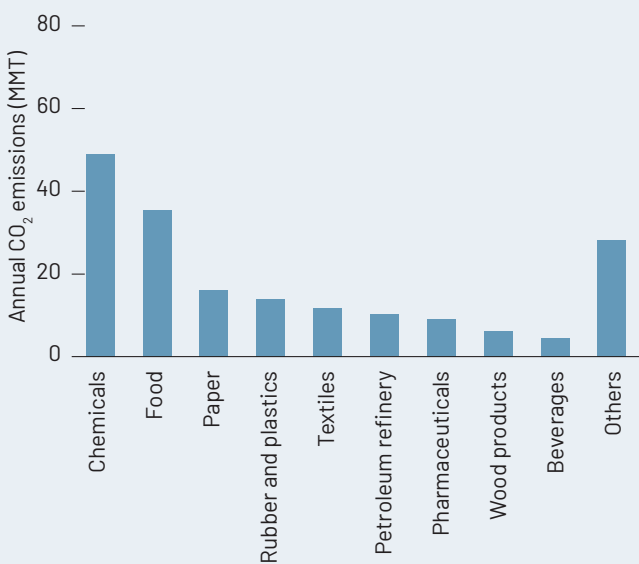


Figure 22: Annual CO₂ emission from process steam by Industry in 2024

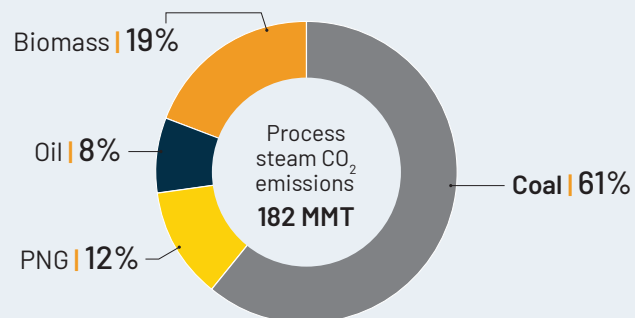


- Based on the current fuel mix, Gujarat has the highest steam-related emissions, followed by Maharashtra.
- State-wise emission patterns closely reflect their steam generation levels, largely due to the widespread use of biomass as the primary fuel across most States/UTs.
- While the food industry (including sugar) leads in steam generation, the chemical industry accounts for the highest emissions. This is primarily because the food sector is largely biomass-based, with sugar and rice milling industries relying almost entirely on in-house biomass residues. In contrast, the chemical industry has a significantly lower share of biomass in its fuel mix, leading to greater dependence on fossil fuels and, consequently, higher emissions.
- The paper, rubber & plastics, and textiles also produce substantial fossil fuel-based emissions due to their existing fuel profiles, making them key targets for decarbonisation efforts.

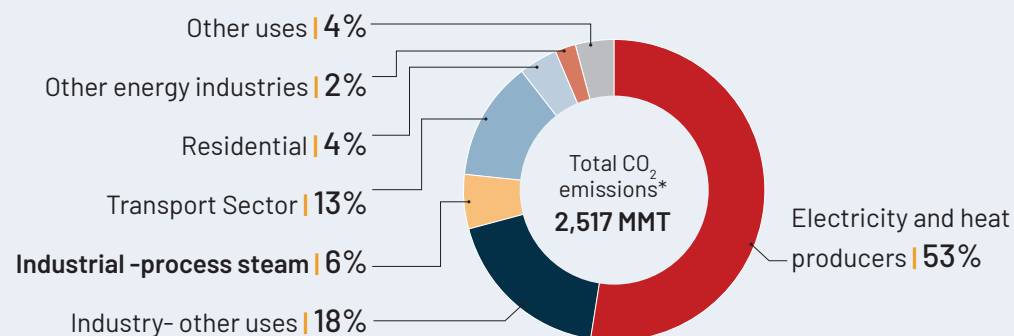
Process steam is responsible for one fourth of India's industrial carbon emissions

Figure 23: CO₂ emissions in India by a) fuel type from process steam in India in 2024 and b) segment in 2022

Emissions from process steam by fuel



India's total CO₂ emissions in 2022¹



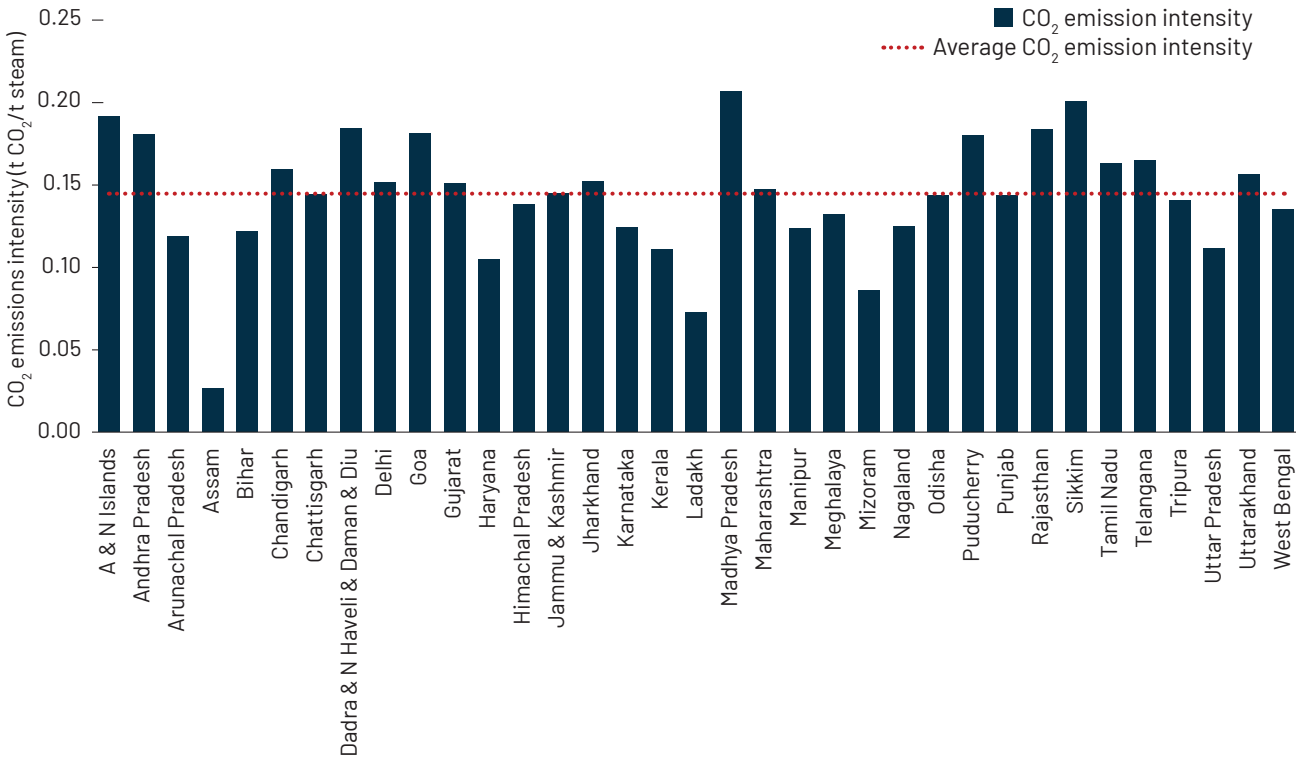
- India's industrial sector emits over 600 MMT CO₂ each year, accounting for 24% of the country's total emissions—making it the second-largest contributor after electricity and heat generation.
- Process steam generation is responsible for 25% of fossil fuel-based industrial emissions and 6% of India's overall fossil fuel emissions. However, when emissions from both fossil fuels and biomass are included, total CO₂ emissions from process steam generation are 23% higher.
- Altogether, the process steam sector emits 182 MMT of CO₂ annually—nearly 1.5 times the total emissions from the entire residential sector, which stands at 100 MMT.

¹ International Energy Agency. (2025). India: Emissions. International Energy Agency. Retrieved April 1, 2025, from <https://www.iea.org/countries/india/emissions>

* Only the CO₂ emissions from fossil fuel are considered. CO₂ emissions from biomass are not considered.

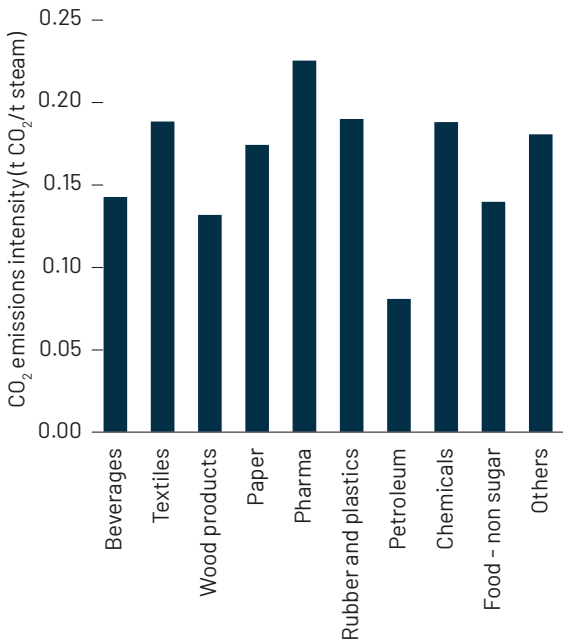
Emission intensity of industrial process steam in India across States/UTs is in 0.03-0.2 tonnes range

Figure 24: CO₂ emissions intensity of steam generation by State/UT



- Emissions intensity of steam generation stands at 0.14 tonnes of CO₂ per tonne of steam.
- State/UT like Andhra Pradesh, which rely heavily on coal, exhibit higher emissions per tonne of steam produced. In contrast, regions such as Uttar Pradesh, where biomass dominates the fuel mix, have a lower CO₂ emission intensity for steam generation.

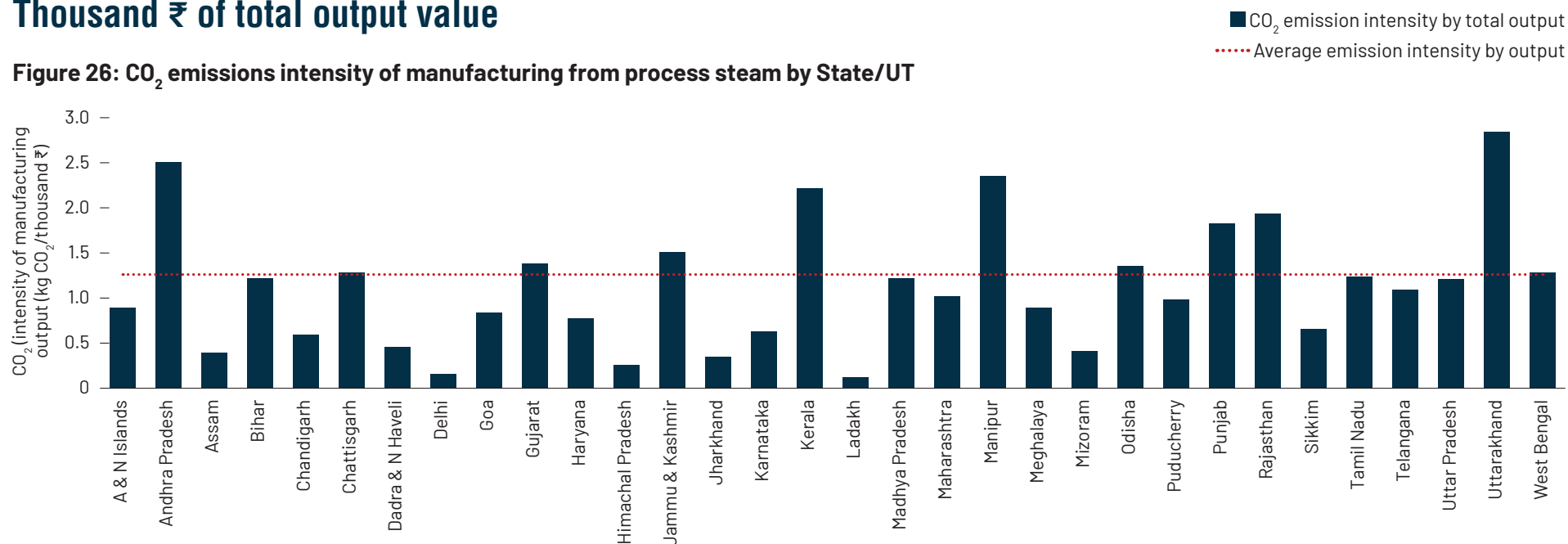
Figure 25: CO₂ emissions intensity of steam generation by industry



- Among industries, petroleum refining shows the lowest emission intensity at 0.08 tonnes CO₂ per tonne of steam. While this may appear to indicate greater efficiency, it is primarily due to the extensive use of waste heat recovery boilers (WHRBs) in the sector, which supply nearly half of its process steam needs without adding new emissions.

Steam emission intensity of manufacturing in India is 1.2 kg CO₂ per Thousand ₹ of total output value

Figure 26: CO₂ emissions intensity of manufacturing from process steam by State/UT



- Uttarakhand, Andhra Pradesh, Manipur, Kerala and Rajasthan have the highest emission intensity relative to their total industrial output, according to the Annual Survey of Industries. Notably, Andhra Pradesh and Rajasthan are major contributors to India's overall manufacturing output, and their high emission intensity points to a carbon-intensive fuel mix used in process boilers.
- In Andhra Pradesh, elevated emissions stem primarily from coal use in sectors such as chemicals, pharmaceuticals, and petroleum refining. In Kerala, the high emissions are largely due to the use of oil and natural gas.
- Although Gujarat and Maharashtra rank among the top emitters of CO₂ from process steam generation—driven by their large manufacturing sectors—their emissions intensity remains moderate, suggesting a cleaner fuel profile. Gujarat benefits from significant adoption of Waste Heat Recovery Boilers (WHRBs), while Maharashtra's lower intensity is largely due to its widespread use of natural gas, the cleanest among fossil fuel options.

Assuming the current fuel mix continues, emissions will increase based on the expected industrial growth rates

Figure 27: Projection of India's annual process steam related CO₂ emissions in Historic Growth Rate Scenario

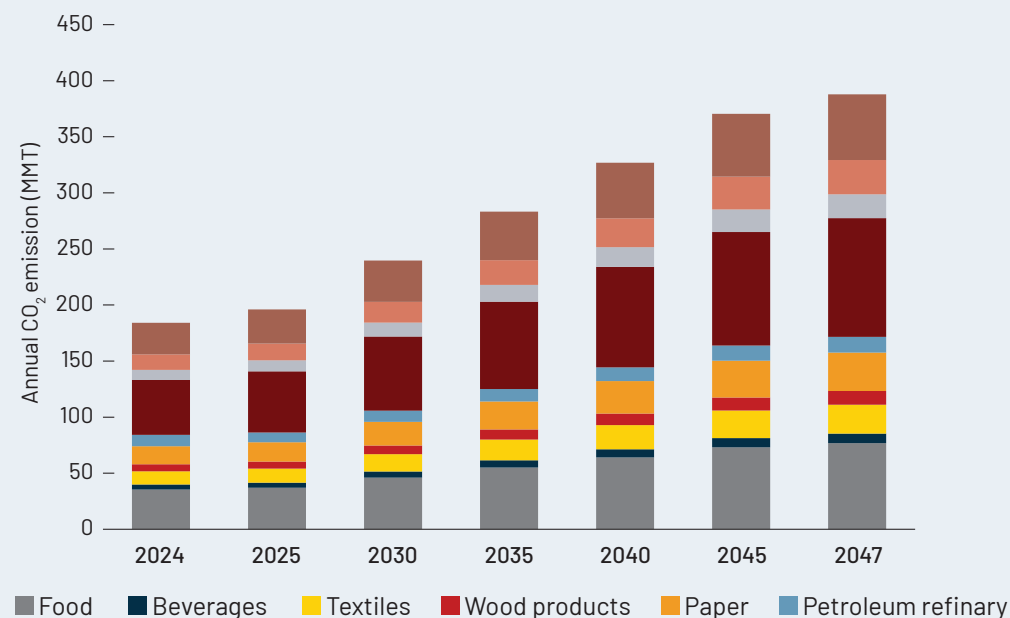
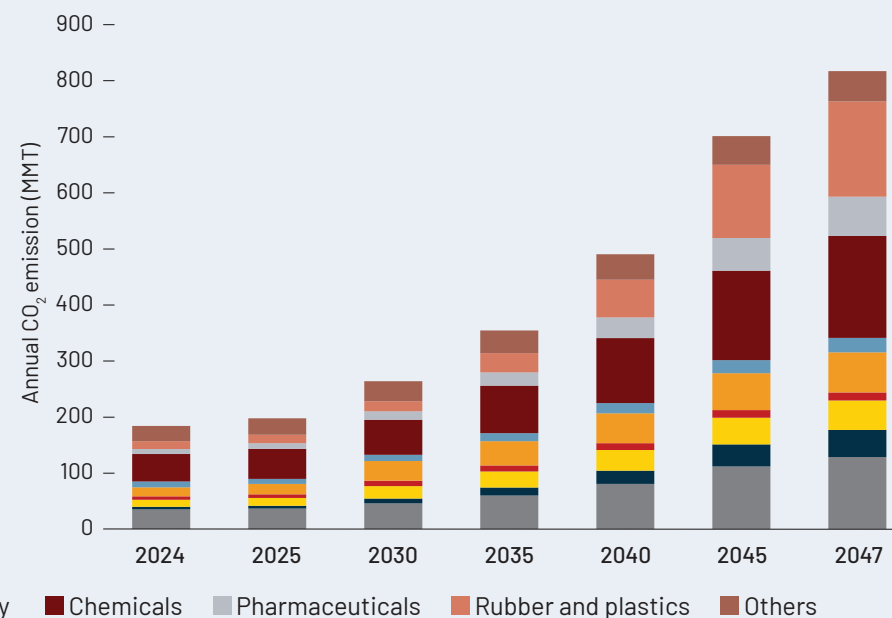


Figure 28: Projection of India's annual process steam related CO₂ emissions in Viksit Bharat Scenario



Based on historical industry growth rates (HGR scenario), overall emissions in 2047 are projected to be double those of 2024, with the chemical sector becoming the largest contributor.

In the *Viksit Bharat* scenario, CO₂ emissions steadily rise from 2024 through 2047, reflecting the assumption that the current 2024 fuel mix for steam generation remains unchanged, with no improvements in technology or operations.

By 2047, emissions are projected to increase nearly four times compared to 2024, underscoring the need to alter the existing energy mix.

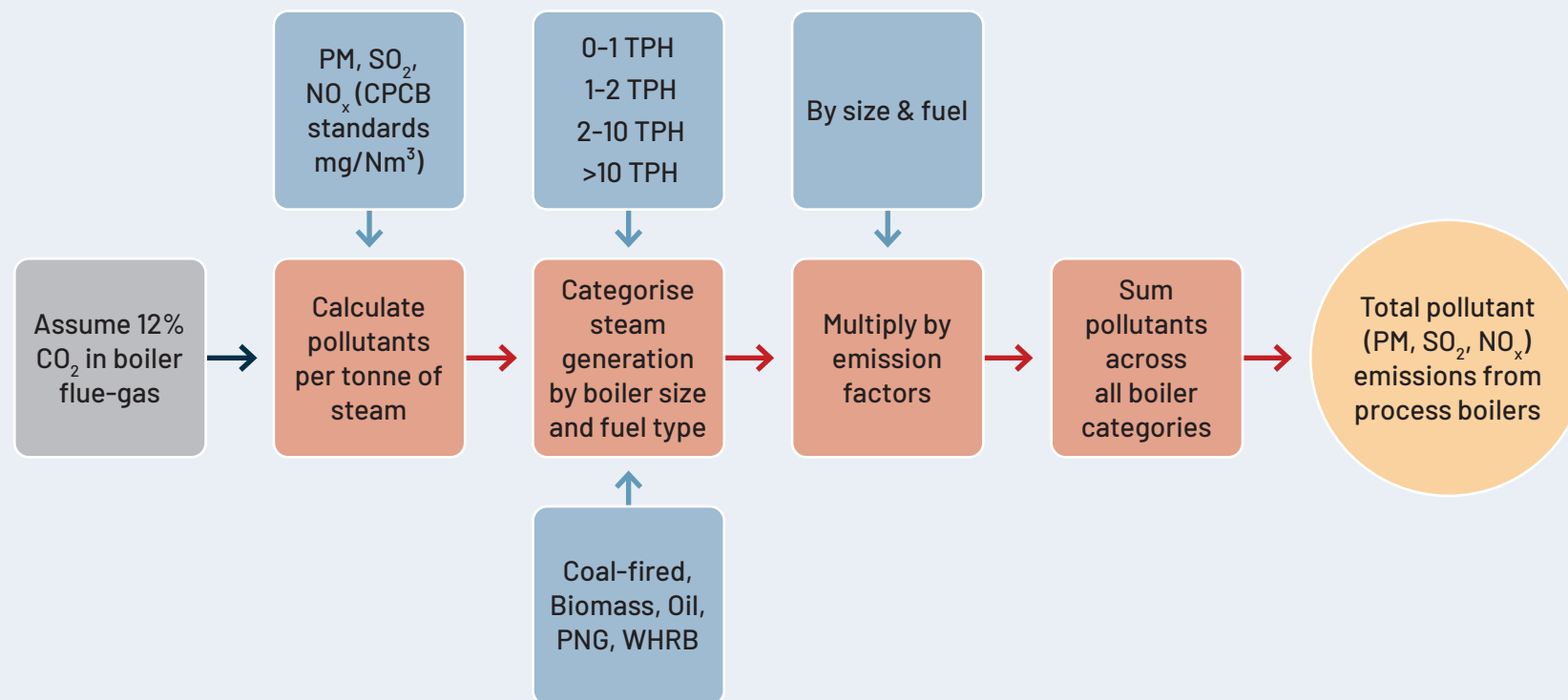
By 2047, the chemical industry is projected to be the largest emitter across all scenarios, with emissions increasing from 49 MMT in 2024 to 106 MMT under the HGR scenario and 182 MMT under the VBS scenario—representing the highest contribution to total industrial emissions.

05 Air Pollution



Methodology for estimation

Estimation of Air Pollution (PM, SO₂, NO_x) due to industrial process steam generation has been done based on fuel profile data of industrial process boilers combined with observed adoption of pollution control equipment. The entire estimation is carried out under two different scenarios: Compliance and BAU.

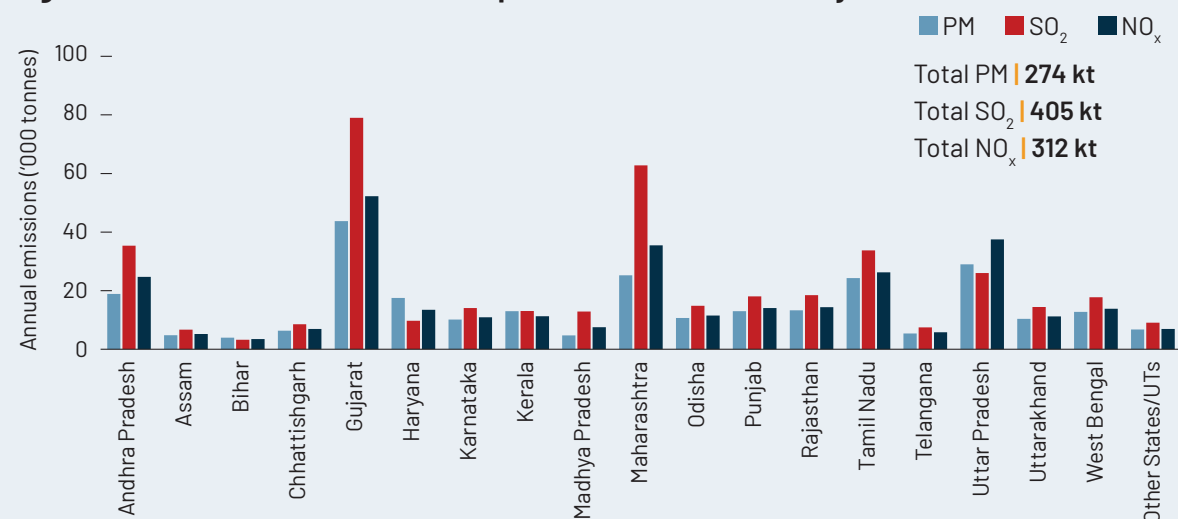


- Compliance scenario is defined as one in which all the industries comply with the pollutant emission norms set by Central Pollution Control Board (CPCB).
- The Business-as-Usual (BAU) scenario for air pollution is defined as one in which only a fraction of the industries comply with the current emission norms. Rest of the industries are either following old norms or are releasing unmitigated emissions.

Detailed methodology for estimating pollutant emissions is described in Annexure A4.

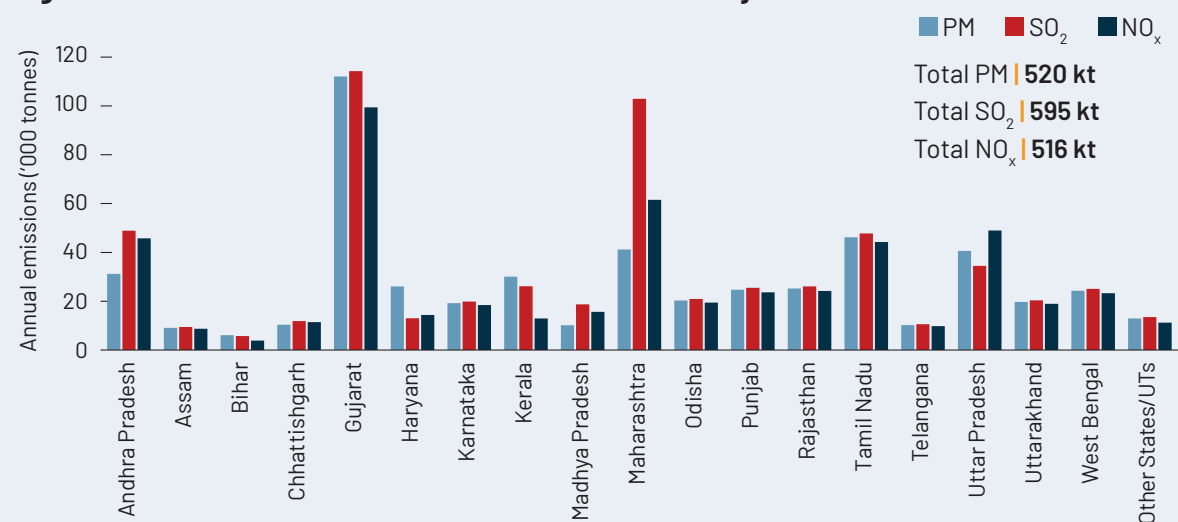
Gujarat and Maharashtra are the top polluters

Figure 29: Pollutant emissions in compliance scenario in 2024 by State/UT



- States such as Gujarat, Maharashtra, and Andhra Pradesh, which rely heavily on fossil fuels for steam generation, exhibit disproportionately high SO₂ emissions, driven by the sulfur content in these fuels.
- In contrast, Uttar Pradesh—despite its high steam output—shows lower SO₂ emissions due to the dominance of the sugar industry, which primarily uses bagasse. However, NO_x emissions are relatively high, owing to the significant presence of coal-powered chemical and fertiliser industries.

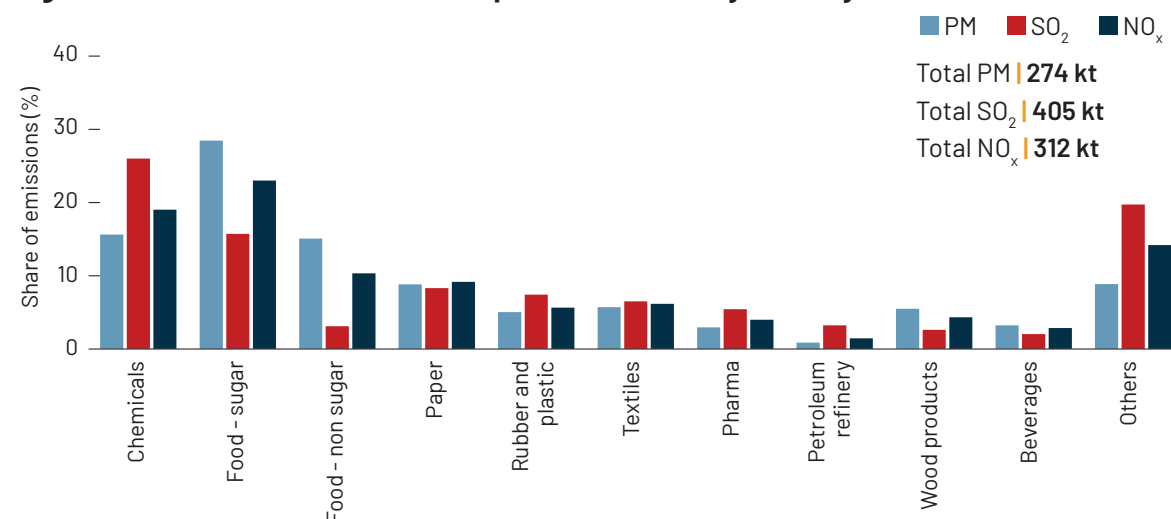
Figure 30: Pollutant emissions in BAU scenario in 2024 by State/UT



- Under the BAU scenario, PM emissions are 1.4 to 2.6 times higher compared to the compliance scenario, while SO₂ emissions can be up to twice as high, and NO_x emissions up to 2.1 times higher.
- The largest difference in the SO₂ emissions ratio between the Compliance and BAU scenarios is observed in Kerala, primarily due to the widespread use of oil-fired boilers. In contrast, Haryana shows the smallest differential, owing to its greater reliance on biomass.

Food Industry (including Sugar) accounts for 44 % of the PM emissions

Figure 31: Pollutant emissions in compliance scenario by industry

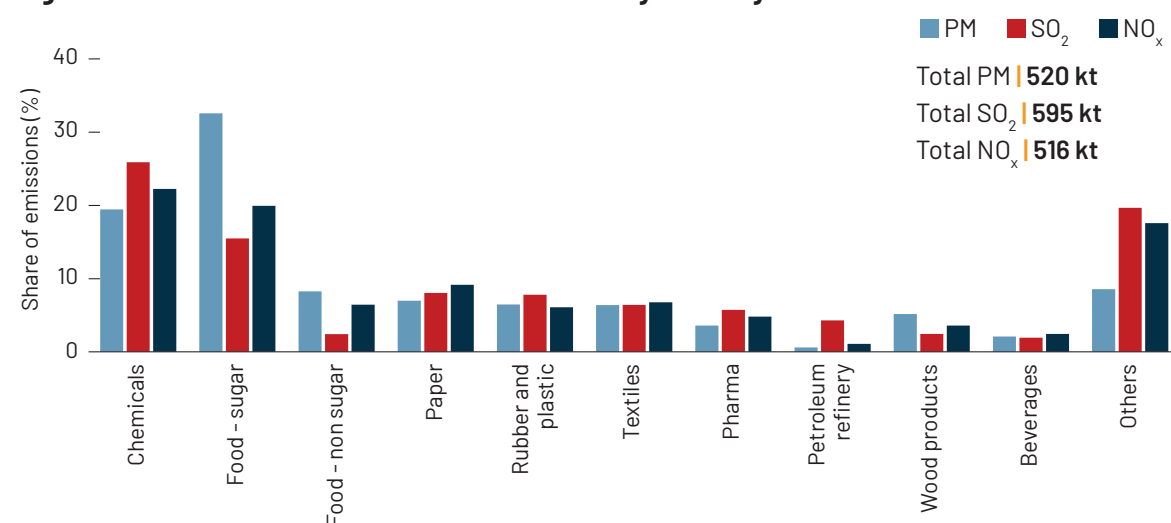


• The chemical and food industries together account for nearly 50% of total SO₂ and NO_x emissions.

• The chemical sector contributes a larger share of SO₂ emissions due to its heavy dependence on fossil fuels.

• In the paper industry, emissions of PM, SO₂, and NO_x are relatively balanced, reflecting a mixed fuel profile that includes both biomass and fossil fuels.

Figure 32: Pollutant emissions in BAU scenario by industry



• The food industry, with its strong dependence on biomass, is the leading source of PM emissions—contributing nearly half of all PM emissions from process steam generation in both the compliance and BAU scenarios. Its contribution to SO₂ emissions is comparatively lower, again due to the predominant use of biomass.

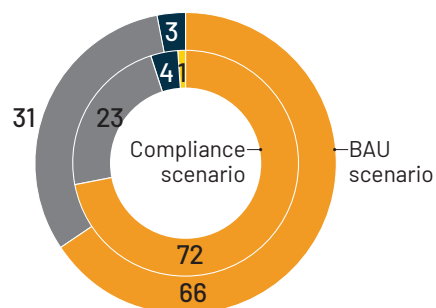
• Across both scenarios, the relative contribution of each industry to overall emissions remains largely consistent.

Pollutant emissions from process steam in BAU scenario are 1.5-2 times higher than the compliance scenario

Figure 33: Pollutant emissions from process boilers by fuel type under Compliance scenario and BAU scenario for: a) PM, b) SO₂, and c) NO_x

■ Biomass ■ Coal ■ Oil ■ PNG

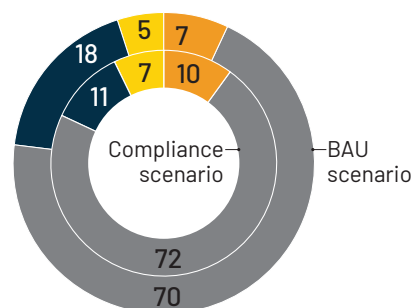
PM Emissions (%)



Total PM emissions (Compliance) | 274 kt

Total PM emissions (BAU) | 520 kt

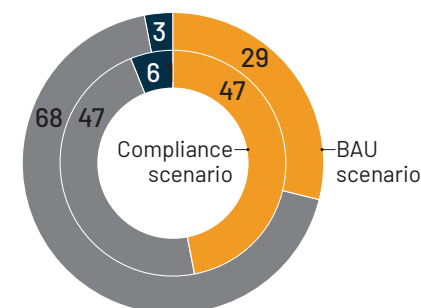
SO₂ Emissions (%)



Total SO₂ emissions (Compliance) | 405 kt

Total SO₂ emissions (BAU) | 595 kt

NO_x Emissions (%)



Total NO_x emissions (Compliance) | 312 kt

Total NO_x emissions (BAU) | 516 kt

In BAU scenario as compared to the Compliance scenario:

- The share of coal in PM emissions increases from 23% to 31% and NO_x emissions increases from 48% to 69%.
- The share of oil in SO₂ emissions increases from 11% to 18%.

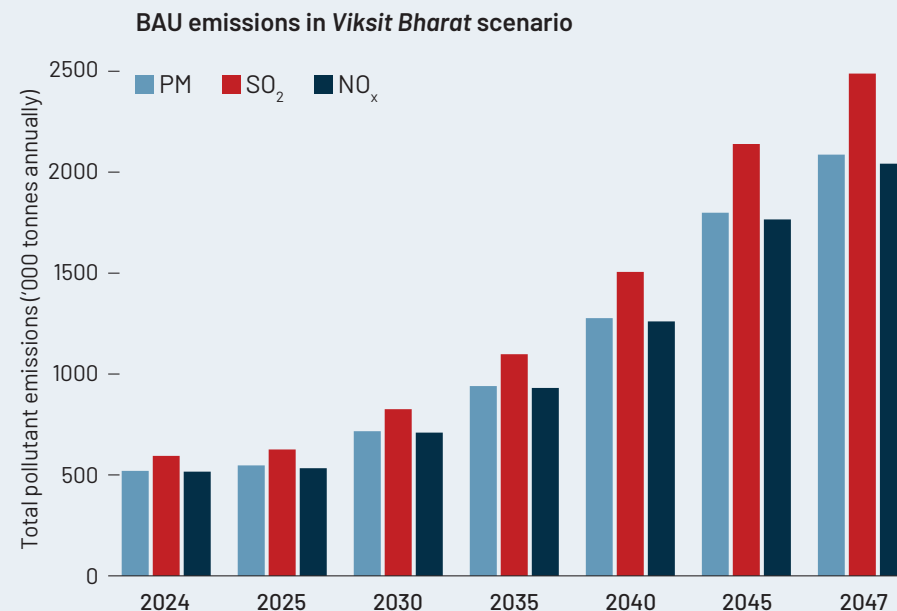
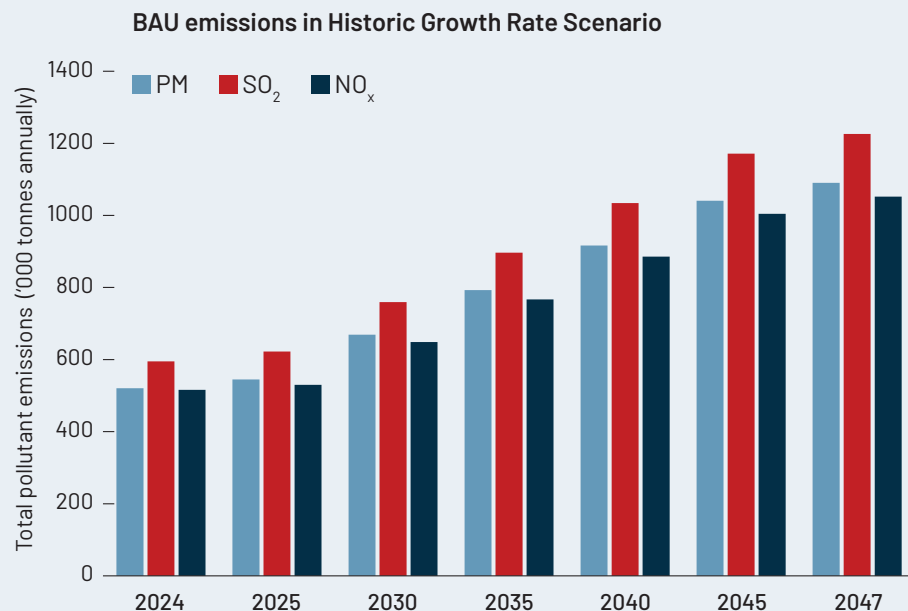
• Based on BAU emissions, process steam generation is responsible for 8% of the industrial NO_x emissions.

• These numbers are significantly higher than the PM and SO₂ emissions in the transport sector (estimated 181 kt for PM2.5, and 40 kt for SO₂)¹

¹ Velamuri, V., Nayak, D. K., Sharma, S., Parmar, P. D., Nagar, P. K., Singh, D., ... & Kota, S. H. (2024). India leads in emission intensity per GDP: Insights from the gridded emission inventory for residential, road transport, and energy sectors. Journal of Environmental Sciences.

Pollutant emissions are projected to increase in proportion to the expected rise in steam demand

Figure 34: Projection of India's pollutant emissions from process boilers in: (a) Historic Growth Rate Scenario, and b) *Viksit Bharat* Scenario



- Increase in pollutant emissions are driven by industrial steam demand which increase twice in Historic Growth Rate Scenario, and by four times in the *Viksit Bharat* Scenario.

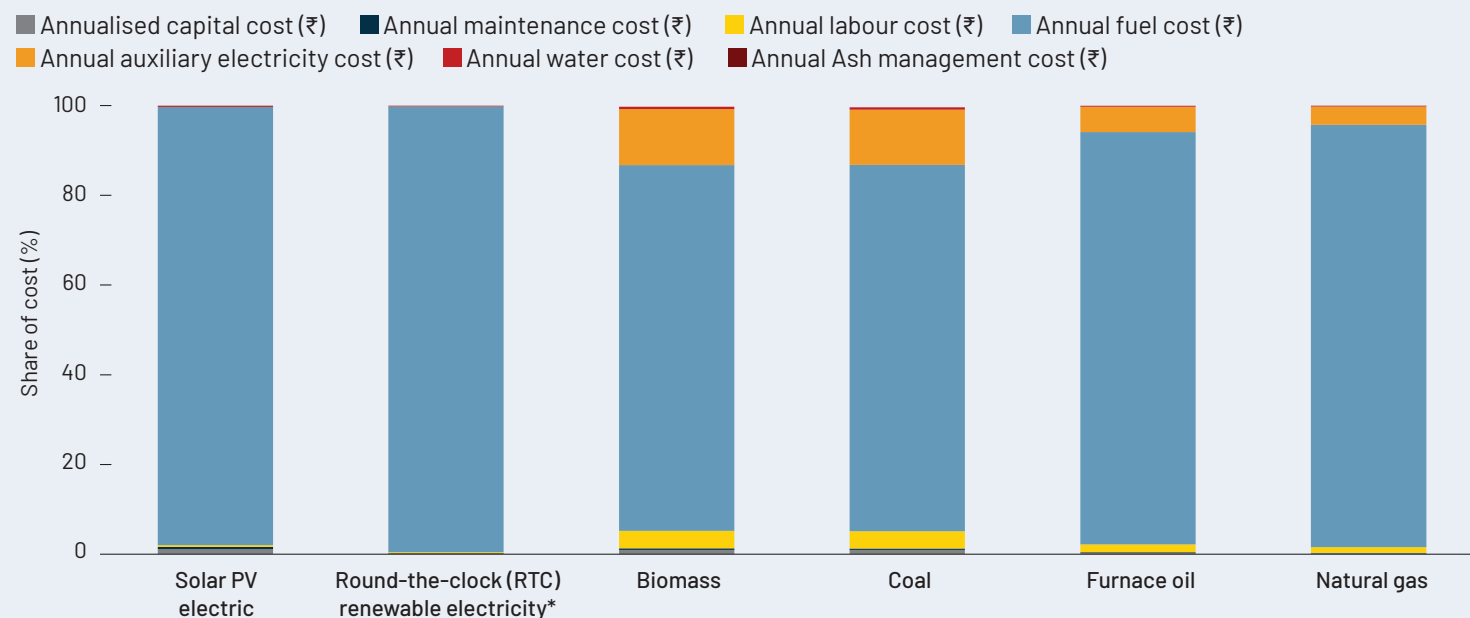
- Food and chemicals are likely to continue to be a significant pollutant emitter due to their consistent share in steam demand in the coming years.

06 **Techno-economic Feasibility**



Cost breakup: Fuel cost is the primary driver of steam cost

Figure 35: Cost structure of steam generation across various fuel types, showing contribution of cost components in annual steam generation cost for a 6 TPH boiler as of 2024

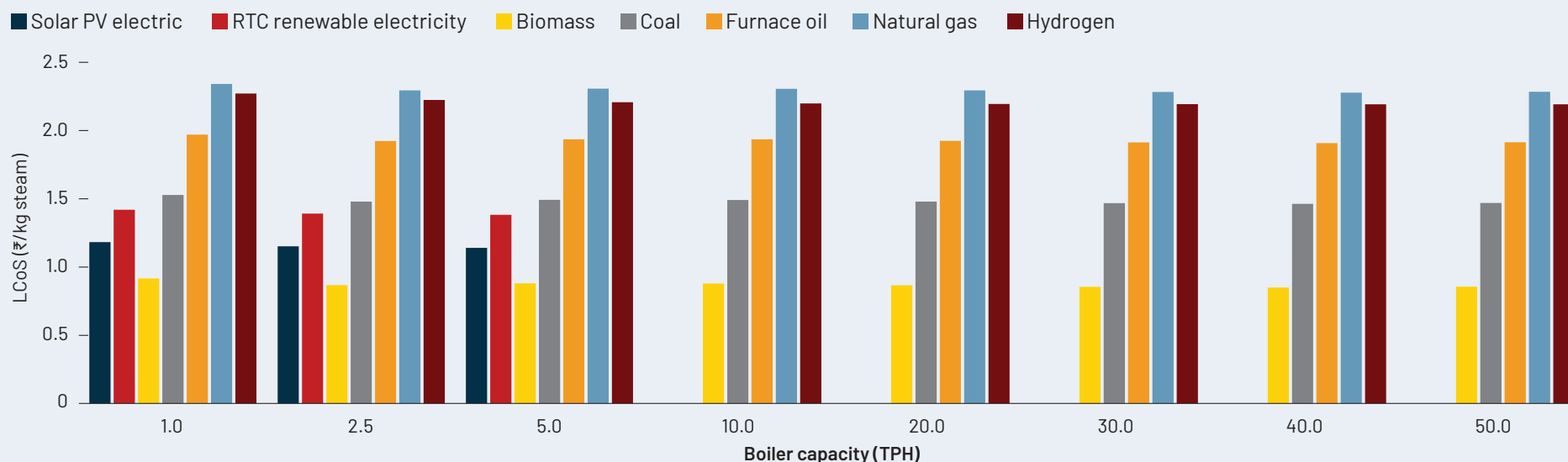


- For biomass- or coal-fired boilers, fuel costs account for about 82% of the total steam cost, rising to as much as 94% for gas-fired boilers.
- For technologies that use more expensive fuels, such as electricity, the share of fuel costs is even higher.
- In solid fuel (biomass, coal) boilers, approximately 12% of the total cost is attributed to auxiliary power. This electricity is used for tasks like feeding fuel into the furnace, circulating water, operating draft fans for efficient combustion, and powering pollution control systems.
- Labor costs for solid fuel-fired boilers account for about 4% of total costs, while in other types of boilers, labor costs are relatively low due to reduced labor requirements.
- Solar thermal boilers are currently feasible till 0.5 TPH capacity. In this case, fuel cost is absent but capital cost remains high.

*RTC renewable electricity is a form of continuous and reliable electricity supply primarily from renewable energy sources. Detailed methodology for techno-economic feasibility is described in Annexure A5.

LCoS Estimation in 2025: Commercial viability of fuel switch shows potential to transition gas-fired boilers to biomass and small boilers to electricity, preferably solar or RTC renewable electricity

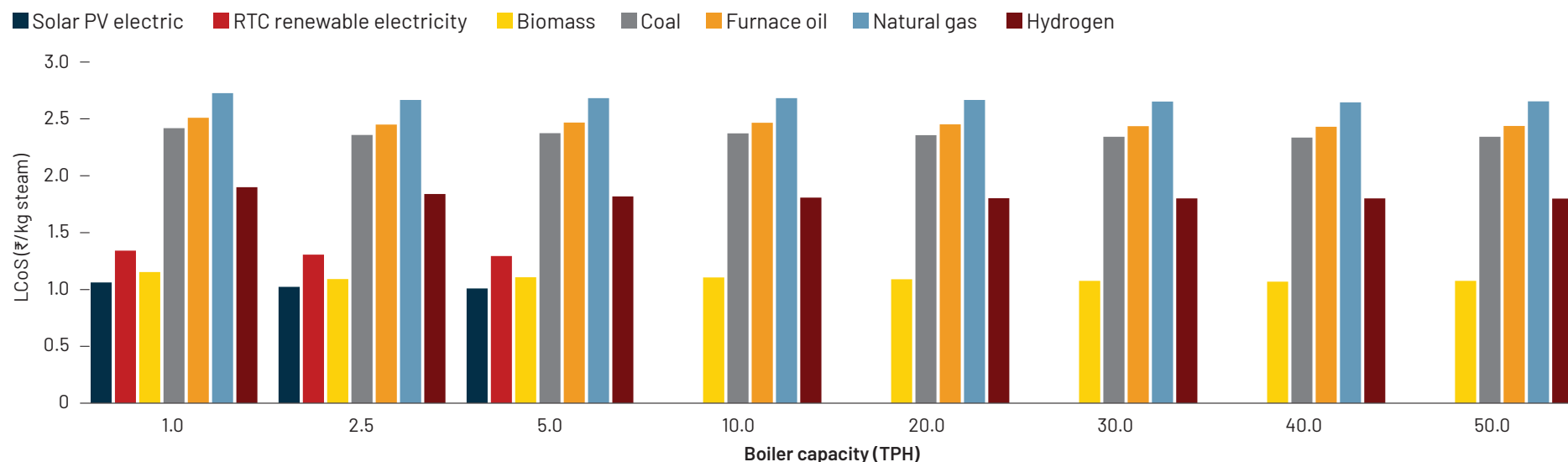
Figure 36: Comparison of Levelised Cost of Steam across various fuels and capacities in 2025



- Across all boiler sizes, natural gas is the most expensive option (2.34–2.28 ₹/kg steam) followed by green hydrogen (2.27–2.19 ₹/kg steam) and furnace oil (1.97–1.91 ₹/kg steam).
- Biomass has the least levelised cost of steam (0.92 – 0.86 ₹/kg steam) across all fuel types and boiler sizes. The cost of biomass-based steam generation dips to ₹0.86 per kg of steam at capacities of 50 TPH and above, due to economies of scale.
- Round the clock (RTC) renewable electricity sourced through green open access shows an LCoS of around 1.38–1.42 ₹/kg steam, which is lower than coal, challenging assumptions that RTC renewable power is too costly for industrial use. This positions RTC renewable electricity as a strong candidate for reliable, clean steam generation for small capacity boilers (< 10 TPH).
- Despite being widely used, coal is now costlier than biomass, solar PV, and RTC renewable electricity. Its LCoS remains around 1.47–1.53 ₹/kg steam across various boiler sizes. This is largely because of the carbon prices likely to be imposed on coal post 2030.
- LCoS remains fairly constant over varying boiler capacities, highlighting the significant role of operating cost in driving LCoS.

By 2030, the Levelized Cost of Solar (LCoS) for solar PV is projected to fall below that of biomass, making it the most appealing fuel choice for new installations—assuming carbon pricing is applied to fossil fuels

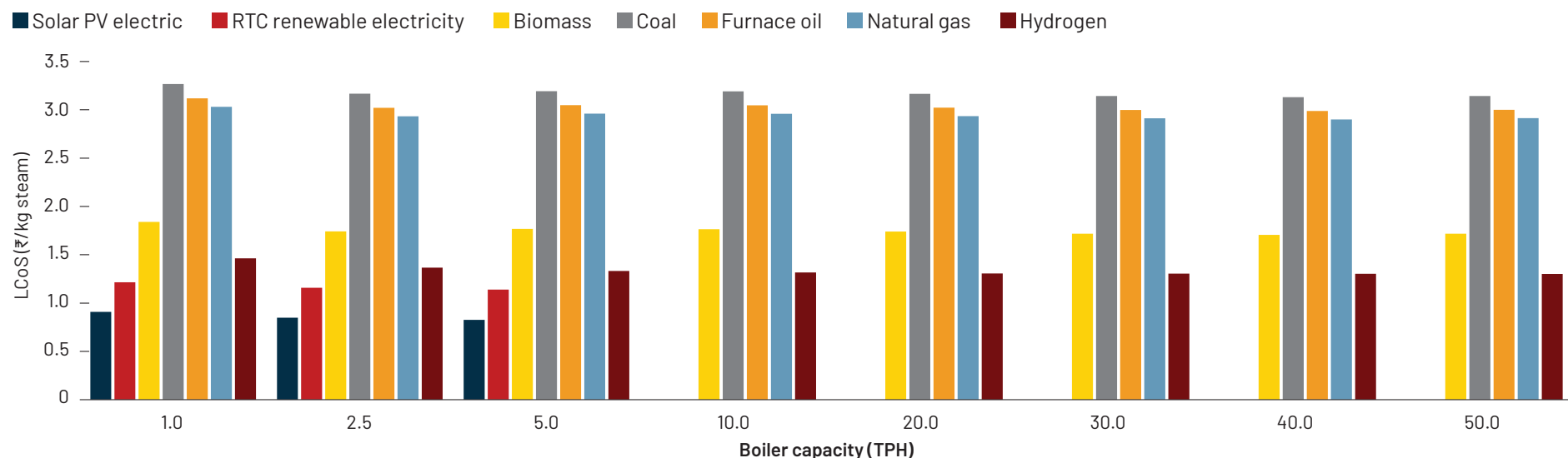
Figure 37: Comparison of Levelised Cost of Steam across various fuels and capacities in 2030



- Coal (₹2.34–2.42), furnace oil (₹2.43–2.51), and natural gas (₹2.65–2.73) show substantially higher LCoS in 2030 than low-carbon options.
- Solar PV based electric boilers, though only feasible for small size batch processes, offers the lowest LCoS across all boiler sizes (₹1.01–1.06/kg steam), making it the most cost-effective low-carbon solution followed by biomass (₹1.07–1.15/kg steam), which is only marginally costlier than solar PV.
- At ₹1.29–1.34/kg steam, RTC renewable electricity based boiler is cheaper than all fossil fuels.
- Hydrogen shows LCoS values of ₹1.80–1.90/kg steam – significantly higher than other low-carbon options, but still cheaper than coal, furnace oil, and natural gas. Its future role depends on cost reduction through scale and policy support, especially for hard-to-electrify industrial processes.
- With multiple low-carbon options now cheaper than fossil fuels, the primary transition bottlenecks are policy alignment, infrastructure, and end-user readiness. This calls for accelerated deployment strategies for solar PV, biomass, and RTC renewable power, supported by financing and regulatory incentives.

By 2040, low-carbon alternatives become increasingly viable, with hydrogen emerging as a more favorable option than biomass for large-scale boilers, particularly where electrification is difficult

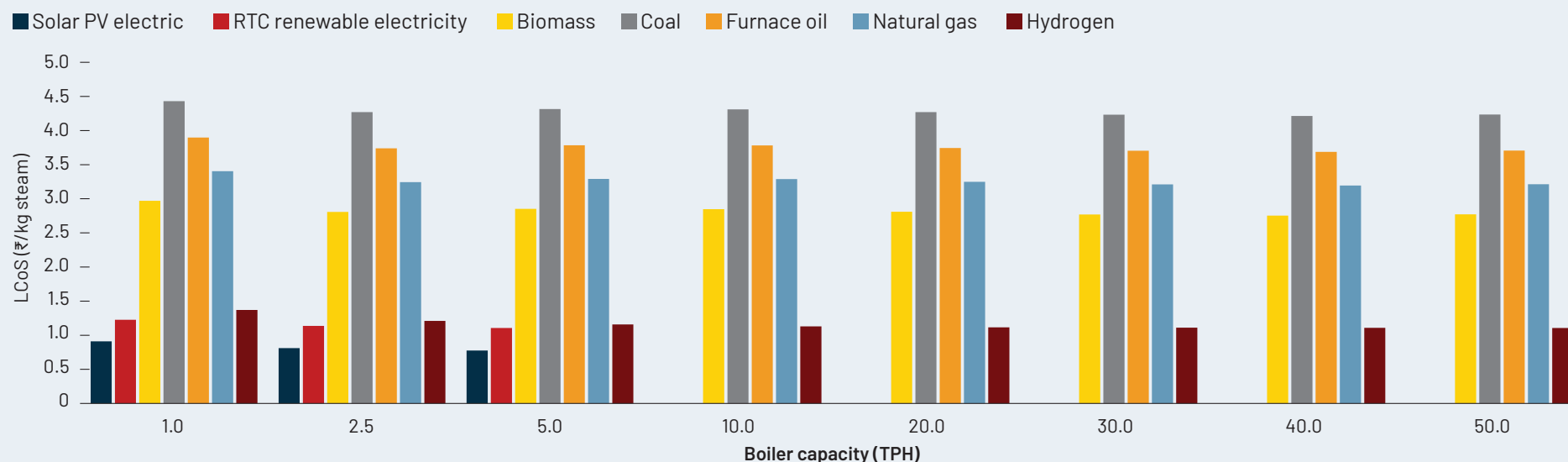
Figure 38: Comparison of Levelised Cost of Steam by fuel type and boiler capacity in 2040



- Coal (3.14–3.27 ₹/ kg steam), furnace oil (3.00–3.12 ₹/ kg steam), and natural gas (2.91–3.03 ₹/ kg steam) remain significantly costlier than all low-carbon technologies, making continued fossil use economically unfeasible.
- In 2040, solar PV electricity reaches 0.83–0.91 ₹/kg steam, making it the cheapest option across all technologies, including fossil fuels.
- RTC renewable electricity (₹1.14–1.21/kg steam) cost just 35% - 40% of fossil fuels (coal, gas and oil).
- Biomass ranges between 1.72–1.84 ₹/kg steam – costlier than solar and RTC renewable electricity but still well below fossil fuels.
- Hydrogen drops to ₹1.30–1.46/kg steam, cheaper than fossil fuels (coal, natural gas and furnace oil) and biomass. If infrastructure and supply chains mature, hydrogen could emerge as a key clean fuel, especially for large-sized boilers where electrification is challenging.

By 2050, boilers powered by hydrogen and those using RTC renewable electricity are expected to be the most viable choices for new installations

Figure 39: Comparison of Levelised Cost of Steam by fuel type and boiler capacity in 2050



- Fossil fuels are by far the costliest options (coal costing 4.23–4.43 ₹/kg steam; oil costing 3.71–3.90 ₹/kg steam; gas costing 3.40–3.21 ₹/kg steam).
- With costs at ₹0.78–0.91/kg steam, solar PV is the lowest-cost fuel option followed by RTC renewable electricity which costs 1.11–1.14 ₹/kg steam.
- For green hydrogen, LCoS falls to ₹1.11–1.13/kg steam, making it cheaper than biomass and all fossil fuels, and nearly at par with RTC renewable power. Given its dispatchability and zero emissions, hydrogen emerges as a core technology for deep decarbonisation, especially in large sized boilers where technological feasibility of electric technology remains uncertain.
- LCoS for biomass rises to ₹2.75–2.97/kg steam, making it 2–3 times more expensive than solar, hydrogen, or RTC renewable power. While being a low carbon option, its use may be limited to niche or agro-industrial clusters where feedstock is abundant.

07 Recommendations and Way Forward



Action Pathways

To achieve 65–80% reduction in GHG emissions, aligned to 2070 net zero goals, a multi-pronged approach will be required. A National Green Boiler Mission can be formulated.

Retire very old boilers

- Incentivise timely retirement of older boilers (> 25 years) as an effective lever for reducing GHG emissions, pollution as well as improving industrial safety.

Improve Energy efficiency

- Retrofitting old boilers with low thermal efficiency using suitable technologies, such as heat recovery systems, economisers and efficient combustion control can reduce fuel usage and corresponding emissions. As data shows, there are about nine to ten thousand boilers in the market which are more than 20 years old.
 - » Promoting energy efficiency market for new boilers in India is critical not only for emissions from process steam but also from captive power generation in industries.
 - » Institute mandatory boiler efficiency rating and labelling program for all boilers. Under this program all boilers must be mandated to meet minimum energy performance standards and those achieving higher standards should be incentivised.
- Increasing awareness among MSMEs, which constitute the largest market for process boilers, alongside offering subsidies and carbon market incentives for labelled boilers, is essential to drive demand.
- The Bureau of Energy Efficiency (BEE), India Star Labelling program launched in 2024 is presently limited to packaged boilers and is voluntary in nature to provide the initial impetus to the market. Packaged boilers are those available majorly in small size categories. The program has not yet seen much uptake due to several regulatory, market and technical barriers which need to be addressed on priority.

Fuel Switching

An aggressive penetration of cleaner fuel options to power boilers needs to be enabled. A potential approach could be based on boiler sizes and technological feasibility.

- Discourage the use of fossil fuels through carbon pricing mechanisms that reduce their cost advantage.
- For very small boilers up to 0.5 TPH, particularly those operating in single-shift (daytime) schedules, switching to solar thermal steam systems is currently feasible and should be actively promoted. It can also drive transition of a huge number of unregulated steam generators not covered under the Indian Boiler Regulations Act.
- Fuel source for other smaller boilers – up to 8 TPH – running on natural gas can be shifted viably to cleaner options such as electricity or RTC renewable electricity from green open access.
- Fuel switching for medium size boilers running on natural gas to green hydrogen, biofuel or hybrid should be enabled through R&D and technology adoption.
- Fuel switching for boilers greater than 30 TPH, often also linked to captive power plants and running on fossil fuels, could be done by co-firing fuels such as biomass and in the long term with green hydrogen.

Promote Emerging technologies

Expand research & development (R&D) efforts on emerging technologies such as high energy efficiency super-critical boilers, electric boilers, Hydrogen boilers, Electric Heat Pumps for medium temperature applications in food, pharmaceuticals and textile industries etc.

Steam as Service

Expand suitable delivery models such as Steam-as-a-Service (SaaS) and community boilers, preferably in Public Private

Partnership (PPP) mode, particularly for faster transition of small dispersed boilers in clustered approaches.

Stringent Air Pollution norms

The dominance of biomass fired boilers poses air pollution challenges and will require added steps. Pollution control norms are currently relaxed for biomass-based fuels resulting in higher emissions. This necessitates:

- Better pollution norms for all boilers: PM be limited to 30 mg/Nm³ for new boilers irrespective of fuel and size.
- Stringent pollution norms for biomass boilers, especially in NCR are necessary. Further, data shows that pollution levels are equally hazardous in Tier-2 and Tier-3 cities as well. PM emission norms for all existing industrial boilers need to be revised as under.
 - » Boilers above 10 TPH: 30 mg/Nm³
 - » Boilers between 2-10 TPH: 50 mg/Nm³
 - » Boilers below 2 TPH: 75 mg/Nm³
- Mandate all existing boilers to comply with these revised standards by 2030.

Strengthen Boiler Governance

- Reform boiler act: Indian Boiler Regulations are safety led and do not govern energy efficiency or emissions which are governed by separate energy conservation and pollution norms.
- Streamline monitoring: Boiler inspection is spread across multiple agencies (Labor department, Pollution Control boards, energy utilities) with lack of sufficient coordination and alignment.
- Increase data availability, benchmarks and transparency: Real time boiler registry for emissions and pollution data from industrial boilers can drive increased focus on energy consumption and efficiency.



Need for Targeted Interventions by State/UT and by Industry

- Capacity concentration in certain States/UTs and specific industries highlights opportunities for targeted interventions.
- States, with large number of process boilers across size categories such as Gujarat and Andhra Pradesh and with diverse industry spread can benefit from blanket policy measures while states such as Uttar Pradesh with large biomass fired boilers require policies targeting pollution control. Additionally, existing infrastructure—such as Gujarat’s extensive gas grid—can make certain fuel-switching options more feasible and attractive in some regions.
- Industries such as food processing, chemicals, and textiles, which rely on fossil fuel-fired boilers and are predominantly MSME-driven, should be prioritized for green transition initiatives.

Optimise and streamline clean fuel supply for boilers integrating with existing missions

- **Revive Solar Thermal technology deployment:** The National Solar Mission has had limited success in solar thermal technology and the focus on solar thermal needs to be revived and incentivised to support industrial decarbonisation objectives. Solar boilers will further require capability development for in-depth boiler load assessment, site suitability, choosing suitable thermal technology based on the type of industrial process and steam temperature needs. Operator trainings, thermal storage infrastructure and advanced control systems need to be enabled to facilitate this.
- **Enable use of Green open access rules for powering process boilers:** RTC renewable electricity requirement for industrial process steam can leverage existing green open access rules. This requires increased awareness, capacity building and enhanced infrastructure support, for steam-intensive MSMEs on priority.

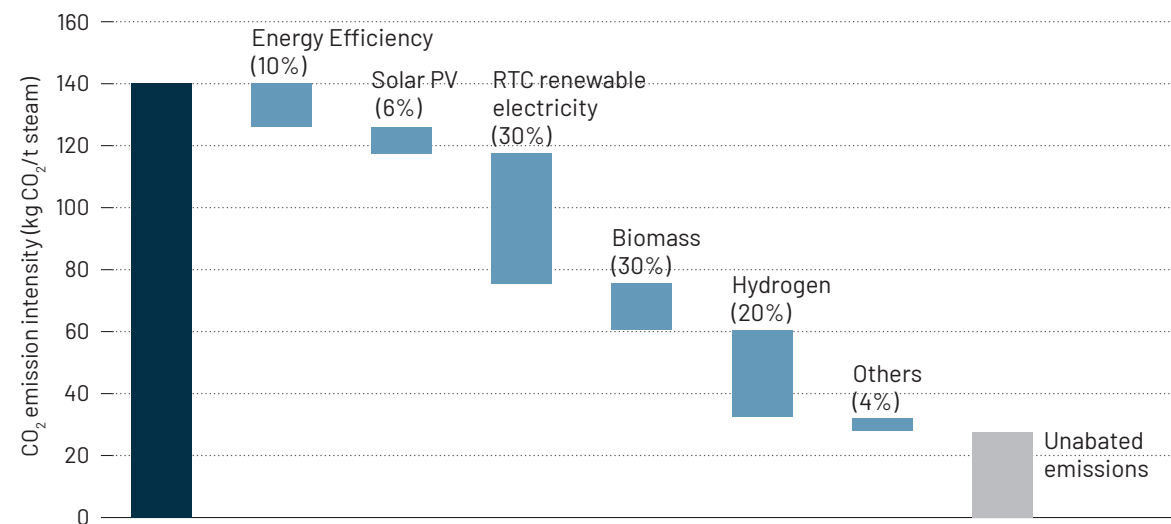
- **Target boilers in National Green Hydrogen Mission:** Boilers need to be prioritised as a critical end use under National Hydrogen Mission and enabling support infrastructure including on-site electrolyzers or distribution grids for piped supply needs to be enabled.
- **Expand coverage of National Biomass Mission (SAMARTH) for boilers:** Biomass is a major fuel for process boilers. Anywhere between, 200-300 millions of biomass will be required by process boilers by 2030. The National Biomass mission for thermal power plants should also cover providing necessary support for biomass firing in industrial process boilers and for other industrial consumers. If done well, it will revitalise the rural economy – creating jobs and increasing farmers income. Enforcement of BIS standards on solid biofuels, securing local agri-residue through long-term contracts and other measures can facilitate efficient biomass firing or co-firing in boilers.

Roadmap to a National Green Boiler Mission

Boiler Size	Short-Term (2025–2030)	Medium-Term (2030–2035)	Long-Term (2035–2050)
<10 TPH	• Develop energy efficiency benchmarks for small boilers. • Raise awareness of MSMEs and leverage existing incentives. • Retrofit existing old boilers with economisers, auto-feed, and insulation systems for enhancing efficiency. • Promote electric boilers to replace gas-fired boilers in urban clusters with robust grid. • Update air pollution norms.	• Mandate boiler-level energy rating and energy efficiency upgrades. • Provide specific MSME incentives for boiler equipment. • Integrate solar thermal, especially for preheating to reduce fuel requirement. • Encourage transition to biomass or electricity where feasible. • Incentivise Steam-as-a-Service (SaaS) models.	• Phase out fossil fuels and integrate biofuels or Green electricity. • Implement hydrogen-ready small boilers. • Establish community-level clean steam services in PPP mode.
10–30 TPH	• Update pollution norms and enforce Continuous Emission Monitoring System (CEMS). • Mandate boiler-level energy rating and reporting. • Incentivise hybrid, biomass or hydrogen systems.	• Scale technologies for electricity and hydrogen. • Incentivise green hydrogen, electricity and biofuels for new installations. • Implement waste heat recovery and cogeneration systems for circular economy. • Develop regional clean boiler clusters with piped distribution network.	• Transition to green hydrogen electricity and biogas compatible systems. • Integrate with circular industrial zones with waste heat co-use and re-use. • Explore and encourage district heating systems.
>30 TPH	• Mandate boiler-level energy rating and reporting. • Implement advanced digital combustion controls. • Enforce stringent emission norms with CEMS. • Standardise energy performance benchmarks across boiler types. • Encourage waste heat recovery systems.	• Co-fire biofuel for existing fossil boilers. • Incentivise electricity and green hydrogen for new boilers. • Pilot district heating systems.	• Transition to green hydrogen, electricity and biomass. • Integrate with circular industrial zones with waste heat co-use and re-use.

Based on proposed interventions, 80% reduction in emission intensity of process steam is possible by 2050

Figure 40: Emission reduction potential of various decarbonisation methods for industrial steam generation in 2050



- Electric boilers running on Solar PV can contribute up to 6% share of process steam production by 2050. But they will be largely used for batch processes and during day-time.

- Other low-carbon interventions, comprising 4% of the generation mix, will be from niche technologies like solar thermal and other emerging technologies.

- Despite full deployment of all modelled decarbonisation options, 20% of the emissions will be unabated, indicating the need for complementary measures such as carbon capture, offsetting, or further innovation.

- Baseline emission intensity from steam generation presently stands at 140 kg CO₂ per tonne of steam.

- Suggested interventions can enable significant emission reductions, bringing down the average emission intensity to approximately 28 kg CO₂/t steam, which translates to 80% reduction from baseline levels.

- Round-the-Clock (RTC) renewable electricity emerges as the single largest contributor to emission reductions, accounting for 30% of total steam generation in 2050.

- Green hydrogen contributes an additional 20% share in 2050 steam generation, highlighting its growing role as a dispatchable, low-carbon alternative.

- Energy efficiency improvements can reduce emission intensity by 10%, underscoring the importance of demand-side interventions alongside supply decarbonisation.

Annexures

Annexure A1: Methodology for boiler stock and estimating steam generation

Boiler stock

The all-India boiler stock estimation for process steam generation was undertaken by first consolidating and cleaning the dataset shared by various States/UTs. The initial dataset comprised 34,634 boiler entries.

Out of these, 1,912 entries were excluded as they were not related to process steam applications, primarily belonging to sectors such as power generation, cement, and iron & steel. An additional 881 entries were removed due to data inconsistencies, including unrealistic values for boiler capacity, pressure, or heating surface area (HSA).

After filtering, 31,841 boiler entries remained. However, a portion of this dataset originated from States/UTs that had shared only partial or incomplete information. Therefore, only the complete datasets from select States/UTs were used as the foundation for further analysis and extrapolation.

To estimate boiler stock for the remaining States/UTs, supplementary data from the Annual Survey of Industries (ASI)—published by the Ministry of Statistics and Programme Implementation (MoSPI)—was utilised. The methodology involved the following steps:

Validation of Proportional Relationship: In the States with complete datasets, it was validated at the 3-digit National Industrial Classification (NIC) level that steam demand varied proportionally with manufacturing output.

Assumption of Capacity Distribution: It was assumed that the boiler capacity distribution in the remaining States/UTs would follow a similar pattern to that observed in the States/UTs with complete data.

Estimation Procedure: Using ASI's detailed manufacturing output data, industry-wise boiler stock in the remaining States/UTs was estimated.

This approach enabled the preparation of a comprehensive and nationally representative estimate of boiler stock used for industrial process steam generation across India.

Methodology for Steam Generation

To assess the scale of process steam generation, a bottom-up approach was adopted. The estimation is based on two key parameters:

1. Installed capacity of boilers used for process steam generation
2. Annual operating hours of each boiler unit

The working hours of industrial boilers vary significantly depending on industrial demand and the nature of the production process—whether batch-based or continuous, seasonal or year-round—as well as the operational schedule (single-shift or multi-shift operations). These operational characteristics influence the run-time of factories and, by extension, the run-time of their boilers.

Taking these factors into account, the following formula was used to estimate annual steam generation:

$$SG_s = \sum_{i=1}^n (EC_{s,i} * LF_{s,i} * WH_{s,i}) \quad (1)$$

Where;

$EC_{s,i}$ = Installed capacity of boiler 'i' in a sector 's'

$LF_{s,i}$ = Load factor of boiler 'i' in a sector 's'

$WH_{s,i}$ = Working hours of boiler 'i' in a sector 's'

n = number of boilers in the particular sector 's'

The load factor defines the effective capacity utilisation of a boiler as a fraction of its rated installed capacity being used to produce process steam. The annual working hours reflect the specific operating patterns of the industry in which the boiler is installed.

Assumptions related to load factors and working hours were derived from a field survey of 84 industrial process boilers conducted by iFOREST in the Ghaziabad and Kanpur districts of Uttar Pradesh. These assumptions were further validated through consultations with industry experts, industrial associations, and boiler manufacturers to ensure realistic, sector-specific operational parameters.

Annexure A2: Projections for Future Steam Generation

Methodology for Steam Demand Projection till 2047 – Historic Growth Rate Scenario

The projection of steam demand for the manufacturing sector in India is based on the correlation between steam consumption and manufacturing output. This approach is grounded in the assumption that steam demand is directly proportional to industrial manufacturing output across steam-intensive sectors. However, the specific factor by which steam demand correlates with manufacturing output is industry-specific.

Base Parameter Selection: The primary base parameter used for the projection is the manufacturing output of India. This output was collected for each state and Union Territory (UT), disaggregated by individual manufacturing sectors where steam usage is prominent.

Industry-Wise Projections under HGR Scenario: For the Historic Growth Rate (HGR) scenario, industry-wise linear projections of manufacturing output were carried out for each State/UT. These were then aggregated to enhance the robustness and reliability of the national-level steam demand estimation.

Historical Manufacturing Output Data: The historical data for manufacturing output was taken from the year 2008 onwards, as this marks the implementation of the revised National Industrial Classification (NIC) system. A 15-year trend (2008–2023) was used as the basis for projecting manufacturing output up to 2047 under the HGR scenario.

Steam Demand Estimation Using ASI Data: In parallel, State/UT-wise industrial fuel consumption data for the manufacturing sector were extracted from the Annual Survey of Industries (ASI) reports. This data was used to estimate historical steam demand up to the year 2008.

Industry-Specific Steam-to-Output Ratio Calculation: For each steam-intensive industry, a unique steam-to-output factor was calculated based on historical trends from the past 15 years. These industry-specific factors were then applied to the projected manufacturing output to estimate future steam demand across sectors and States/UTs.

Projection Methodology for Steam Demand – *Viksit Bharat* Scenario (2024 –2047)

Projection Basis – GDP-Driven Industrial Transformation: The projection of steam demand under the *Viksit Bharat* scenario is anchored to India's aspirational economic growth trajectory, targeting a US \$30 trillion economy by 2047¹. This approach assumes that steam demand continues to be directly proportional to manufacturing output across steam-intensive industries.

Base Parameter Selection: The primary base parameter used for this scenario is the projected manufacturing output of India aligned with the *Viksit Bharat* vision. To achieve the ambitious target of becoming a US \$ 30 trillion economy by 2047, different industries are expected to grow at different rates based on their contribution to national economic goals. Therefore, sector-specific growth

projections were developed to align with the expected economic structure in 2047.

Industry-Wise Projections under *Viksit Bharat* Scenario: Based on the projected manufacturing output for each industry under the *Viksit Bharat* scenario, steam demand was estimated using the same steam to output relationship that is established in the Historic Growth Rate (HGR) scenario based on past 15 years of data. This ensured methodological consistency while capturing the accelerated growth anticipated across sectors. By maintaining the historical steam-output proportionality, the future steam demand was projected till 2047 in alignment with the *Viksit Bharat* industrial output growth trajectory.

¹ Department of Administrative Reforms & Public Grievances. (2025, February). *Viksit Bharat @ 2047 – Governance Transformed*. Ministry of Personnel, Public Grievances and Pensions, Government of India. Retrieved June 5, 2025, from https://darpg.gov.in/sites/default/files/Viksit_Bharat_2047_Governance_Transformed.pdf

Annexure A3:Energy and CO₂ emission estimation methodology

Assumptions:

Fuel based efficiency of Boilers as per table

Fuel	Emission Factor (gCO ₂ /kCal)	Boiler efficiency – GCV basis (%)
Coal Fired	0.379	81
Oil	0.295	89
PNG	0.207	86
WHRB	0	-
Biomass	0.402	80

To calculate the total non-renewable emissions from process boilers, it is assumed that in India biomass is 23.2% non-renewable and bagasse is completely renewable/carbon neutral as far as emissions is concerned.¹

As all the boilers use saturated steam in their industrial process application, steam enthalpy is calculated using the operating pressure of the boiler. Hence the annual energy demand as steam (SE) and annual energy demand as fuel (FE) for each sector

is calculated by the following equation by multiplying the annual steam generation with the enthalpy of steam and summing over all boilers in the sector followed by dividing by the efficiency of the boiler respectively:

$$SE_s = \sum_{i=1}^n (SG_{s,i} * H_{s,i}) \quad (2)$$

$$FE_s = \sum_{i=1}^n (SE_{s,i} / \eta_{s,i}) \quad (3)$$

Where:

$H_{s,i}$ = Enthalpy of steam associated with boiler 'i' in the sector 's'

$\eta_{s,i}$ = efficiency of boiler 'i' in the sector 's'

Utilising the emission factors, the annual CO₂ emissions (E) are calculated as follows:

$$E_s = \sum_{i=1}^n (FE_{s,i} * \alpha_{s,i}) \quad (4)$$

Where, $\alpha_{s,i}$ = emission factor of the fuel, used in boiler 'i' in the sector 's'

Methodology: Emission Projection till 2047

The projection of CO₂ emissions for the manufacturing sector is directly linked to the steam demand projections described earlier. Emission projections are based on the assumption that the steam generation process remains consistent in terms of technology, fuel mix, and boiler efficiency, as projected under the Historic growth rate (HGR) scenario.

Industry-Wise Steam Demand Projections: Yearly steam demand for each industry was projected based on the HGR and *Viksit Bharat* Scenario, as detailed in the previous section. This projection assumes that steam demand will continue to increase in line with the projected growth in manufacturing output. The projected steam demand for each industry is calculated under both the scenarios on an annual basis up to 2047.

Assumptions for Boiler Share and Fuel Mix: It is assumed that the share of steam generation by different boiler sizes in 2024 will remain constant throughout the

projection period. The distribution of boiler sizes, along with the associated fuel consumption, is maintained at the 2024 levels to estimate future emissions.

Constant Fuel Mix and Emission Factors: It is assumed that the fuel mix used for steam generation across industries will remain the same as in 2024. The boiler efficiency and the emission factors corresponding to each industry type are kept constant as it is in 2024.

CO₂ Emission Calculations: Using the projected steam demand and maintaining the fuel mix and boiler efficiency as they were in 2024, the CO₂ emissions are calculated for each industry on an annual basis for both the scenarios.

¹ Kar, A., Wathore, R., Ghosh, A., Sharma, S., Floess, E., Grieshop, A., Bailis, R., & Labhasetwar, N. (2023, July). Promoting the use of LPG for household cooking in developing countries (T20 Policy Brief). ThinkTwenty (T20) India. Retrieved May 5, 2025, from https://t20ind.org/wp-content/uploads/2023/07/T20_PolicyBrief_TF4_PromotingLPGInTheGlobalSouth_New.pdf

Annexure A4: Methodology for Air Pollution

- To calculate the pollutant emissions per tonne of steam three different metrics are used – emissions based on latest CPCB norms, emissions based on old CPCB norms, and the uncontrolled pollutant emissions based on emission factor of fuels.
- CPCB norms are available for various categories of fuels for particulate matter (PM), SO_x and NO_x. These norms are based on capacity of boilers as tabulated in Tables 1 and 2. Old PM emission norms for boilers are listed in Table 3.

Table 1: Revised PM emission standards for boilers¹

Revised PM Standards (mg/Nm ³)		
Boiler capacity	Agrobased fuels	Other fuels
Less than 2	500	500
2 to less than 10	250	150
10 and above	250	100

Table 2: SO₂ and NO_x emission standards for boilers²

Standards (mg/Nm ³)		
Boiler capacity	SO ₂	NO _x
Agro based fuels	-	-
Natural gas	-	-
Other fuels	600	300

Table 4: Uncontrolled emission factors for various fuels

Fuel	Efficiency	CV of fuel	Fuel required	Emission factor/t fuel ^{4, 5, 6}			Emission factor/t steam		
				PM	SO ₂	NO _x	PM	SO ₂	NO _x
	%	MJ/kg	kg/t steam	kg/t fuel	kg/t fuel	kg/t fuel	kg/t steam	kg/t steam	kg/t steam
Bagasse	80%	16	216	28.9	0.21	2.6	6.24	0.05	0.56
Rice husk	80%	14.6	236	36.9	0.8	1.5	8.7	0.19	0.35
Wood	80%	16	216	17.3	0.18	1.54	3.73	0.04	0.33
Other biomass	80%	12	288	29.7	0.2	0.7	8.54	0.06	0.2
Coal	81%	17.4	196	70.6	9.5	11	13.83	1.86	2.16
Oil	90%	43.1	71	9.1	44	3.3	0.65	3.13	0.23
Natural gas	86%	55.6	58	0.34	3.92	0.013	0.02	0.22	0

Table 3: Old PM emission standards for boilers³

Old PM Standards (mg/Nm ³)		
Boiler capacity	Agrobased fuels	Other fuels
Less than 2	1200	1200
2 to less than 10	800	800
10 and above	250	100

- The amount of fuel required for generating one tonne of steam is calculated by dividing the calorific value of fuel with the enthalpy of steam. The amount of fuel required per tonne of steam is multiplied with the corresponding fuel emission factor to get the emission factor per tonne of steam as mentioned in Table 4.
- Table 4 provides uncontrolled emission factors for various fuels used in boilers. The carbon content of the fuel is then used to calculate the amount of CO₂ formed per tonne of steam. The amount of flue gas from the boiler equipment is calculated based on 12% CO₂ in the flue gas. The amount of flue gas is multiplied with the emission norms to arrive at the compliance emissions per tonne of steam.
- To estimate the pollution due to steam generation, two different scenarios are created – Compliance scenario and the business as usual (BAU) scenario. In the Compliance scenario, it is assumed that all the industries comply with the set norms. If norms are not there in place, as in the case of SO₂ emissions for biomass, uncontrolled emissions are considered as a metric. The BAU Scenario was based on the actual status of compliance derived from baseline survey and expert opinion.

1 Ministry of Environment, Forest and Climate Change. (2023, June 14). Environment (Protection) Amendment Rules, 2023 – Corrigendum. Retrieved April 1, 2025, from <https://cpcb.nic.in/displaypdf.php?id=SW5kdXN0cnktU3BIY2lmaWMTU3RhbmRhcmRzL0VmZmxlZW50LzQ1OS0xLnBkZg==>

2 Ministry of Environment, Forest and Climate Change. (2018, January 29). Environment (Protection) Amendment Rules, 2018 – Notification. Retrieved April 1, 2025, from https://cpcb.nic.in/uploads/Industry-Specific-Standards/Effluent/106-industrial_boiler.pdf

3 Verma, S. (2022, July 6). Tightening emission standards for ‘baby’ boilers: A much awaited step. Down to Earth. Retrieved April 1, 2025, from <https://www.downtoearth.org.in/pollution/tightening-emission-standards-for-baby-boilers-a-much-awaited-step-83565>

4 CSTEP. (2024). Emission Inventory and Pollution Reduction Strategy: Thirteen Non-attainment Cities in Uttar Pradesh. (CSTEP-RR-2024-05P).

5 Karuppiah, I., and S. Sumathi. “Emissions of particulate matter (PM), PM10, and PM2.5 from boilers using husk as fuel—a report.” Pollut Res 40 (2021): S140-4.

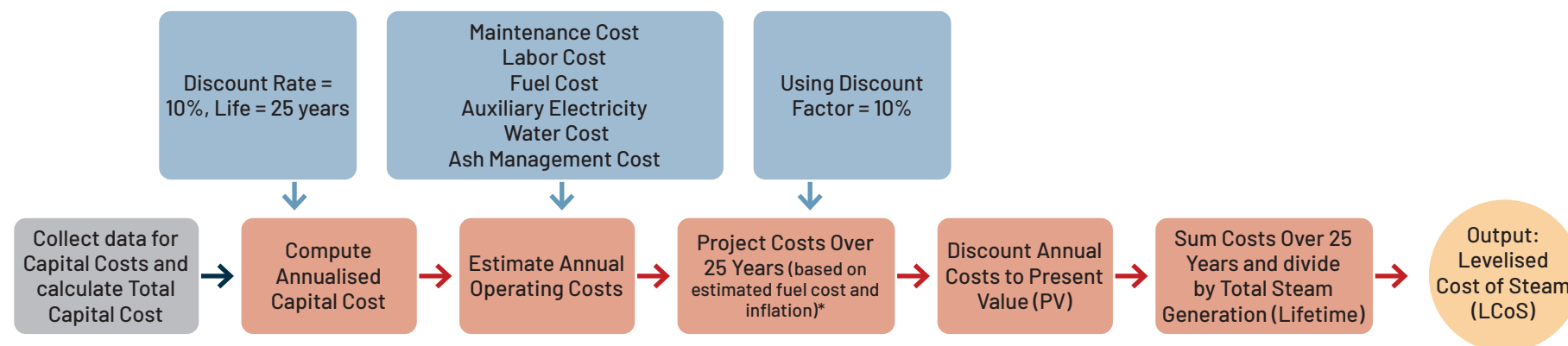
6 Karuppiah, I., & Sumathi, S. Emission profile of Pm, Pm10 and Pm 2.5 of Stationery sources from boilers using various Fuels—An investigation.

Annexure A5: Methodology for techno-economic feasibility

Calculation of Levelised Cost of Steam generation

Commercial feasibility analysis through an estimation of Levelised Cost of Steam has been undertaken based on capital expenditure (Capex) and Operational expenditure (Opex) data collected from industry discussions and prevailing market

conditions. Capital expenditure has been annualised and fuel cost has been considered to be constant in coming years.



Levelised Cost of Steam

- The Levelised Cost of Steam (LCoS) is computed through a discounted cash flow analysis spanning 25 years, incorporating capital operational, and fuel costs while accounting for inflation, and rise in fuel costs. Capital costs are derived from market surveys covering conventional (coal, biomass, oil/gas), electric, and solar thermal boilers. Installation cost and annual maintenance cost is based on the survey conducted in the Kanpur and Ghaziabad regions as discussed in operating cost heads in the assumption sheet. Annual operating expenses is comprised of fuel costs (future prices for fossil fuels are based on historical price CAGR, for biomass-based fuels, the future prices are based on the CAGR of MSP weighted to production of various crops), labor (linked to minimum wages act, and the future cost increase based on inflation), maintenance (scaled per boiler capacity), auxiliary power requirement (24.9 kWh/TPH for fuel fired boilers and 0.1 kWh/TPH for electric boilers), water usage, and ash disposal.
- A salvage value of 5% of the initial investment is applied at the end of the project life. Costs are annualised using a 10% discount rate. Steam output is normalised per tonne across boiler sizes (0.5–8 TPH), with technology-specific constraints (e.g., solar thermal limited to 0.5 TPH). Sensitivity analyses is done on electricity tariffs (₹2.98–7.90/kWh) and size of boilers (0.5–8 TPH).

$$LCoS \left(\frac{\text{₹}}{\text{kg}} \text{ of steam} \right) = \frac{\sum_{t=1}^{25} \frac{\text{Annualized capital cost}_t + \text{Operating cost}_t}{(1+d)^t}}{\text{Lifetime steam output (tonnes)}}$$

Where:

- Annualized capital cost = Total capital cost * Capital Recovery Factor
- Capital Recovery Factor (CRF) = $\frac{d(1+d)^n}{(1+d)^n - 1}$
- d is the discount rate, n is the useful life of the equipment
- Operating cost = fuel cost + maintenance cost + labor cost + auxiliary power cost + water cost + ash disposal cost + carbon cost*

Feasibility Analysis: Methodology – Assumptions

1. Capital Costs

Boiler Type	Capacity	Cost (lakhs)	Efficiency (%)
Coal fired	1 TPH	13	81
Biomass fired	1 TPH	13	80
Oil fired	1 TPH	7	89
Gas fired	1 TPH	7	86
Electric	1 TPH	10	99
Solar thermal	0.5 TPH	236	--

2. Lifetimes and Replacement

Boiler type	Life (years)	Periodic capital cost
Conventional	25	
Electric	25	40% after 10 years for heating element

3. Operating costs

- Maintenance cost: 0.41 lakh/TPH/year
- Ash disposal: ₹80/tonne (5% CAGR)
- Coal: 39% ash content | Biomass: 20% | Oil/Gas: 0%
- Water Cost: ₹8.25–14.25/tonne (scaled by usage)
- Inflation Rate: 6%
- Labor cost: As per minimum wages act

4. Labour requirement

Capacity Range (TPH)	Skilled	Unskilled
0–4	1	1
4–10	2	4
10–20	4	8
20–50	6	12
50–100	11	19
Solar/Electric	1	0

5. Fuel cost

Fuel	Current Cost (₹/MJ)	CAGR (%)
Coal	0.38	3.00%
Biomass	0.37	5.00%
Natural Gas	1.63	0.90%
Furnace Oil	1.03	2.00%
RTC Renewable Electricity	1.35	-1.40%
Solar Electricity	1.19	-2.70%

6. Energy & Auxiliary Costs

- Auxiliary Power: 8.3% of total energy | 24.9 kWh/TPH
- Grid Electricity: ₹7.99/kWh
- Pumping Power: 0.10 kWh/tonne (30m height, 80% efficiency)

* Carbon cost for fossil fuels are considered from 2030 onwards at a price of 150 \$/t CO₂ 1

1 Christoph Bertram, Ottmar Edenhofer, and Gunnar Luderer, 2021, A path to Zero Finance& Development Magazine, International Monetary Fund.

7. Financial Parameters

- Discount Rate: 10%
- Salvage Value: 5% of total capital cost
- Project Lifetime: 25 years

8. Coal

To calculate the LCoS from coal fired boilers, cost of coal is calculated in a manner similar to the grid power based on the data available in Annual Survey of Industries 2022-23². The production of coal by various coal grades is mentioned in the Indian Minerals Yearbook³. Based on this data the all India average value of GCV of coal is calculated. The cost of coal in terms of ₹/MJ is arrived by dividing the cost by GCV of coal. The future cost of coal is assumed to grow at a CAGR of 3%.⁴

9. Solar PV

The cost of solar PV varies under various scenarios – LCoE (based on electricity generation cost), competitive pricing (pricing through contracts and bidding), and regulated pricing (price ceiling set by government norms to encourage solar PV)

conditions. To evaluate the LCoS of electric boilers powered by solar PV, all these three conditions are considered.

- LCoE price⁵ is considered to be 4.3 ₹/kWh.
- The price of solar PV is assumed to reduce by 50% by 2050.⁶

10. RTC renewable electricity

Present price of RTC renewable electricity is assumed to be 0.0575 \$/kWh in 2025 and the price decrease by 1.4% annually till 2050.⁷

11. Other fuels

- Biomass prices are based on the survey conducted at Ghaziabad and Kanpur clusters.
- Natural gas prices are based on communication to gas distribution companies. Price growth rate is assumed as 0.9%⁸.
- Furnace oil prices are based on market research. And the future cost is assumed to increase at a rate of 2.1%.⁸

2 Ministry of Statistics and Programme Implementation. (2024, October). Annual Survey of Industries 2022-23: Volume I. National Statistics Office, Enterprise Survey Division, Kolkata. Retrieved January 10, 2025, from <https://mospi.gov.in/asi-summary-results/asi-2022-23-volume-i>

3 Indian Bureau of Mines. (2023). Indian Minerals Yearbook 2021 (Part III: Mineral Reviews) – Coal and Lignite. Retrieved December 4, 2024, from https://ibm.gov.in/writereaddata/files/16821574626443af961de58CoalLignite_2021.pdf

4 Chandra Bhushan, Srestha Banerjee, Chinmayi Shalya and Deeksha Pande (2022). Angul: Planning a just energy transition and a new green economy. International Forum for Environment, Sustainability and Technology (iFOREST). New Delhi, India. Page 109-110

5 Kothamasu, T. (2024, December 23). Rising PPA tariffs adding to landed costs of solar open access installations. Mercom India. <https://www.mercomindia.com/rising-ppa-tariffs-adding-to-landed-costs-of-solar-open-access-installations>

6 Rhatwal, B. (2024, November 20). Solar energy generation cost to drop by 60 per cent by 2050, will create 27 mn green jobs: ISA. BioEnergy Times. <https://bioenergytimes.com/solar-energy-generation-cost-to-drop-by-60-per-cent-by-2050-will-create-27-mn-green-jobs-isa/>

7 Chandra Bhushan, Kunal Singhal, Nikhil Pawar and Ahan Bezbaroa (2024). Green Urea: Economic and Environmental Benefits of a Low Carbon Future. International Forum for Environment, Sustainability and Technology (iFOREST). New Delhi, India.

8 U.S. Energy Information Administration. (2017). Annual Energy Outlook 2017: Table 3. Energy Prices by Sector and Source, United States, Reference Case. https://www.eia.gov/outlooks/aeo/excel/aeotab_3.xlsx

