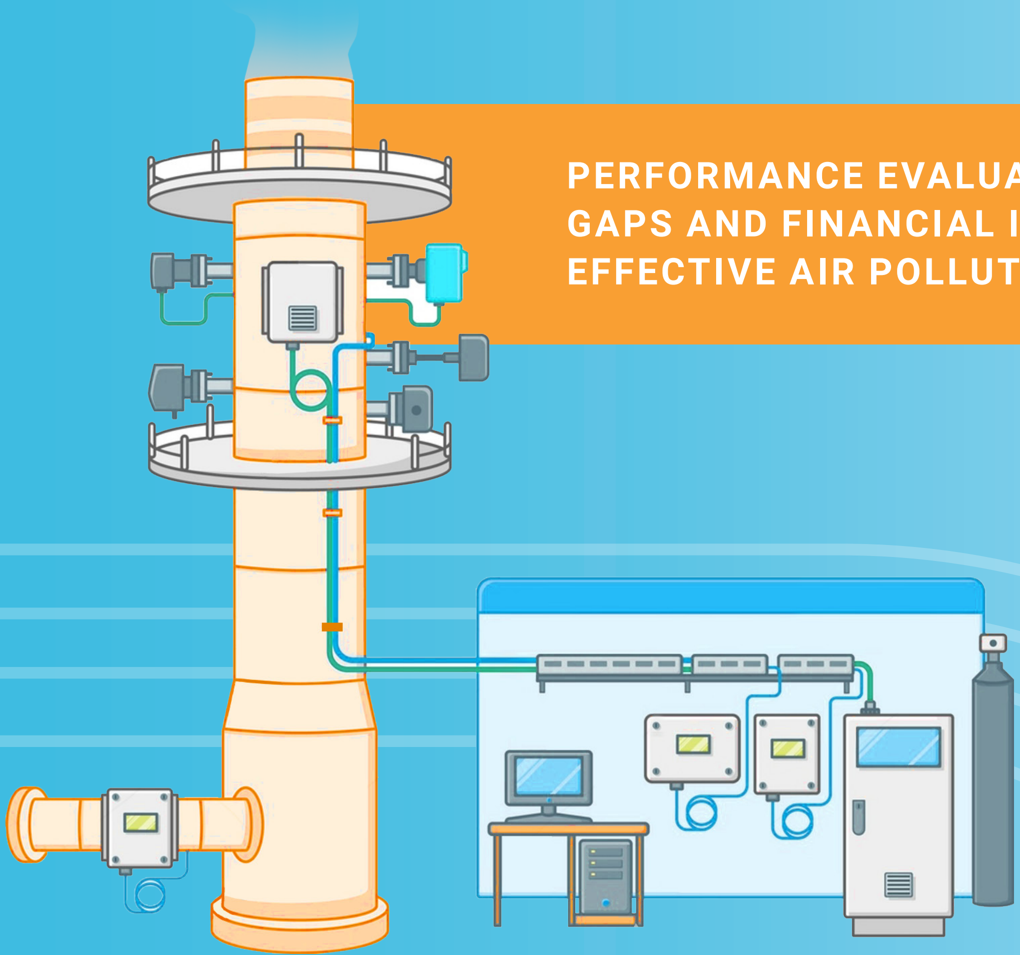
A REPORT ON

CONTINUOUS EMISSION MONITORING SYSTEMS (CEMS) IN INDIA

PERFORMANCE EVALUATION, POLICY GAPS AND FINANCIAL IMPLICATIONS FOR EFFECTIVE AIR POLLUTION CONTROL



Uttar Pradesh Climate Change Authority

Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

A REPORT ON

Continuous Emission Monitoring Systems (CEMS) in India

Performance Evaluation, Policy Gaps and Financial Implications for Effective Air Pollution Control

Dr. Ravi Prakash Srivastava, Mr. Sahil Kumar and Mr. Ashish Tiwari

Report
February 2024

Uttar Pradesh Climate Change Authority
Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

Research Direction: Secretary, Ashish Tiwari, DoEF&CC, GoUP

Authors:

1. Dr. Ravi Prakash Srivastava (Research Associate, Directorate of Environment, Gomti Nagar, Lucknow)
2. Mr. Sahil Kumar (Research Associate, Directorate of Environment, Gomti Nagar, Lucknow)
3. Mr. Ashish Tiwari (Secretary, DoEF&CC and Director, Directorate of Environment, UP)

Reviewers:

1. Prof. Mukesh Sharma (Department of Civil Engineering, IIT Kanpur)
2. Nivit Kumar Yadav (Programme Director - Industrial Pollution Unit at Centre for Science and Environment, New Delhi)
3. Dr. Anju Goel (Associate Director, Air Quality Research, The Energy and Resources Institute, New Delhi)

Acknowledgements

We are grateful to Mr. Maneesh Mittal (CF Banda and Member, WG, UPCAMP), Mr. Pranav Jain (DFO Ambedkar Nagar and Member, WG, UPCAMP), Mohd. Rahib (Assistant Director, Directorate of Environment and Member, WG, UPCAMP), the Officials of UPPCB, Mr. Jostein Nygard (World Bank), Ms. Karin Shephard (World Bank), Ms. Farah Zahir (World Bank), Ms. Ishaa Srivastava (World Bank), Mr. Sayantan Sarkar (World Bank), Ms. Neha Sharma (World Bank), Dr. Namita Gupta (Research Associate), Ms. Vidhu Kapoor (TERI), Mr. Nimish Singh (TERI), Ms. Shashi Tiwari (TERI) and Mr. Kunal Soni (HORIBA) for sharing their valuable insights and support through course of the study.

We would also like to appreciate the assistance of industries and stakeholders in developing this report.

Supported by

This work was supported by the Uttar Pradesh Climate Change Authority and the Department of Science and Technology. The Directorate of Environment acknowledges their support.

Citation: Ravi Prakash Srivastava, Sahil Kumar and Ashish Tiwari (2024). Continuous Emission Monitoring Systems (CEMS) in India: Performance Evaluation, Policy Gaps and Financial Implications for Effective Air Pollution Control. Directorate of Environment, Gomti Nagar, Lucknow, Uttar Pradesh, India.

Published by

Uttar Pradesh Climate Change Authority
Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

For more information

Directorate of Environment, Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010,
Phones: 0522-2300541 | E-mail: doeuplko@yahoo.com | Website: http://upenv.upsdc.gov.in/

Table of Contents

List of Figures

List of Tables

Abbreviations

ABB: ASEA Brown Boveri
ANPI: Australia's National Pollutant Inventory
AST: Annual Surveillance Test
BIS: Bureau of Indian Standards
CAA: Clean Air Asia
CAGR: Compound Annual Growth Rate
CEN: The European Committee for Standardization
CEQM: Continuous Effluent Quality Monitoring System
CETPs: Common Effluent Treatment Plants
CF: Conservator of Forests
CFPs: Coal Fire Power Plants
CFR: Code of Federal Regulations
CGA: Cylinder Gas Audits
CIED: Chinese Industrial Emissions Database
CO: Carbon Monoxide
CO_2: Carbon Dioxide
CPCB: Central Pollution Control Board
CRS: Compulsory Registration Scheme
CSCM: Centrally Sponsored Centrally Managed
CSE: Centre for Science and Environment
CSIR-NPL: Council of Scientific and Industrial Research-National Physical Laboratory
CSSM: Centrally Sponsored State Managed
CTO: Consent to Operate
DAHS: Data Acquisition and Handling System
DAMS: Data Acquisition and Management System
DAS: Data Acquisition System
DFO: District Forest Officer
DoE: Directorate of Environment
DoEF&CC: Department of Environment, Forest & Climate Change
DPR: Detailed Project Report
DTE: Down to Earth
EC: European Commission
ED: Economic Discussion
EEA: European Environment Agency
ERT: Electronic Reporting Tool
ESCI: Engineering Staff College of India
ETS: Emission Trading Scheme
ETU: Environmental Training Unit
EU: European Union
FE: Fuji Electric
GCP: Green Credit Program
GHG: Green House Gas
GOI: Government of India
GoUP: Government of Uttar Pradesh
GPCB: Gujarat Pollution Control Board
HCGA: Harvard Centre for Geographic Analysis

ICFRE: Indian Council of Forestry Research and Education
ICSC: International Centre for Sustainable Carbon
IED: Industrial Emissions Directive
IITK: Indian Institute Technology, Kanpur
IoT's: Internet of Things
ISO: International Organization for Standardization
IT: Information Technology
ITI: Industrial Training Institute
JSW: Jindal South West
MCERTS: Monitoring Certification Scheme
MoEF&CC: Ministry of Environment, Forest and Climate Change
MSDE: Ministry of Skill Development and Entrepreneurship
MSME's: Ministry of Micro, Small and Medium Enterprises
NABCB: National Accreditation Board for Certification Bodies
NABL: National Accreditation Board for Testing and Calibration Laboratories
NCAP: National Clean Air Program
NH3: Ammonia
NO_x: Nitrous Oxides
NPI: National Pollutant Inventory
NSDC: National Skill Development Corporation
NSQF: National Skill Qualification Framework
O&M: Operation and Maintenance
O_2: Oxygen
OCEMS: Online Continuous Emissions Monitoring Systems
OECD: Organization for Economic Cooperation and Development
PCCs: Pollution Control Committees
PEA: Philippines Environmental Agency
PIBR: Press Information Bureau Report
PLI: Production-Linked Incentive
PM: Particulate Matter
PMA: Project Management Agency
PMKVY: Pradhan Mantri Kaushal Vikas Yojana
PPP: Public Private Partnership
PS: Performance Specifications
PTZ: Pan-Tilt-Zoom
QA&QC: Quality Assurance & Quality Control
QAL: Quality Assurance Level
QAP: Quality Assurance Procedures
QSTI: Qualified Source Testing Individual
QSTO: Qualified Source Testing Observer
R&D: Research and Development
RAA: Relative Accuracy Audit
RATA: Relative Accuracy Test Audit
RTDMS: Real Time Data Monitoring System
SEPA: Swedish Environmental Protection Agency
SMART: Skill Management and Accreditation of Training Centre
SME's: Small and Medium Enterprises
SO_2: Sulphur Dioxide
SOP's: Standard Operating Procedures
SPCB: State Pollution Control Boards
SPECS: Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors
SRM: Standard Reference Method
SSC: Sector Skill Council
SSDM: State Skill Development Mission
STT: Short-Term Training
TERI: The Energy and Resources Institute
ToT's: Training of Trainers
TP: Training Provider
TUV: Technischer Uberwachungs-Verein
UBA: Umweltbundesamt
UFP's: Ultrafine Particles
UK: United Kingdom
UKEA: United Kingdom Environment Agency
UKSTA: United Kingdom Source Testing Association
UNEP: United Nations Environment Program
UP: Uttar Pradesh
UPCAMP: Uttar Pradesh Clean Air Management Project
UPIIEPP: Uttar Pradesh Industrial Investment and Employment Promotion Policy
UPPCB: Uttar Pradesh Pollution Control Board
US EPA: United States Environment Protection Act
US GPO: United States Government Publishing Office
USA: United States of America
USD: United States Dollar
USSES: United States Source Evaluation Society
VLEP: Vietnam's Law on Environmental Protection
VOCs: Volatile Organic Compounds
WG: Working Group
WHO: World Health Organization
YAL: Your Article Library

Executive Summary

Industrial emissions are one of the main causes of air pollution in India, which affects the environment and health of the people and releases various pollutants like carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) into the atmosphere. Air pollution causes over 6.5 million deaths annually worldwide and can lead to chronic diseases, impaired brain function, reduced visibility, acid rain and climate change (WHO, 2023).

The air quality needs to be monitored more effectively to prevent the damage caused by air pollution to human health and the environment. The sources of pollution are complex and dynamic and traditional methods are not sufficient to assess them. Therefore, the role of a possible solution comes with Continuous Emission Monitoring Systems (CEMS) that can measure pollution levels in real-time. CEMS offers real-time, automated and highly accurate monitoring of industrial emissions, providing not only timely detection of irregularities and deviations from regulatory standards but also precise identification of pollution sources. It plays a crucial role in quantifying pollutant concentrations, particularly sources like fossil fuel combustion and industrial operations which significantly contribute to climate change. Several countries including the United States of America (USA), the European Union (EU), Germany, United Kingdom (UK), China and India are increasing use of CEMS to combat air pollution and ensure regulatory environmental compliance.

The adoption of CEMS has evolved globally due to the pressing need for effective emissions monitoring. Developed countries like the USA and EU were early adopters of CEMS to enforce emission standards. China, being one of the largest greenhouse gas (GHG) emitters, has recently taken significant steps to promote CEMS adoption to control its industrial emissions. Consequently, the global CEMS market is experiencing substantial growth, reflecting the rising demand for emissions monitoring systems. This growth is propelled by stricter environmental regulations, increased awareness of environmental protection and the expansion of industries like power generation, oil, gas and chemicals. The highlights of Global CEMS Adoption, Historical Evolution, Industry-Specific Mandates and Market Growth Projections are shown in Table 1.

Table 1: Snapshot of Global CEMS adoption

Key Points	Details
Global Adoption of CEMS	As globalization and industrialization expand, monitoring numerous and diverse industrial emissions becomes challenging. CEMS, through real-time measurement, address this challenge, enabling effective environmental regulation and management worldwide. Adoption of CEMS varies by country, influenced by economic, social and environmental factors.
Historical Evolution of CEMS	The United States (US) pioneered CEMS implementation in the 1970s, initially for criteria pollutants. The European Union (EU), Japan, Canada and Australia followed suit in the 1980s and 1990s, driven by international agreements. China, a major emitter, started adopting CEMS in the late 1990s, with more recent emphasis on air pollution control.
Industry-Specific Mandates	Industries like power generation, oil and gas and chemicals are mandated to install CEMS for emissions monitoring and reporting.
Market Growth Projections	CEMS market growth is forecasted with substantial Compound Annual Growth Rate (CAGR) projections from various sources. The market's value is expected to increase, reflecting the expanding adoption of emission monitoring systems. Factors driving growth include environmental regulations, safety concerns and the usage of oil, gas and petrochemicals.

In India, the adoption of CEMS is on the rise as well, with the government and regulatory bodies taking proactive measures to combat air pollution. Initiatives like the National Clean Air Programme (NCAP) are driving the demand for CEMS in the country. Currently, over 30,000 CEMS are installed in Indian industries, with a focus on pollutants such as dust, SO_2, NO_x and others. This trend indicates a growing commitment to meeting emissions standards and reducing environmental pollution. However, challenges persist in ensuring that all industries share their real-time emissions data, emphasizing the need for broader compliance.

One region of particular interest is Uttar Pradesh (UP), where CEMS implementation, primarily in thermal power plants, has been a priority. These systems have been installed on each unit, underlining the state's commitment to pollution monitoring. Calibrated data is essential to ensure accurate measurements and the Uttar Pradesh Pollution Control Board (UPPCB) conducts regular inspections to enforce compliance. The presence of CEMS in thermal power plants and the strict regulation of pollution monitoring further underscore the potential demand for CEMS systems in the state.

A concise summary of the current status of CEMS adoption in India and the specific scenario in Uttar Pradesh, highlighting aspects such as adoption trends, regulatory compliance, government initiatives and real-time data sharing are shown in Table 2.

Table 2: Summary of CEMS Adoption in India and Uttar Pradesh

Key Points	Details	Current Scenario in Uttar Pradesh
Adoption of CEMS	Experiencing significant growth due to pollution monitoring regulations. Key players include ABB Ltd., AMETEK, Inc., Emerson Electric Company, Thermo Fisher Scientific Inc., and Horiba Ltd. Government initiatives like the National Clean Air Programme (NCAP) aim to decrease air pollution levels by 20%-30% by 2024. Estimated market value: US$800-900 million, focused on monitoring dust, SO_2, NO_x, and other pollutants. Industries classified as "red category" are required to establish CEMS.	Mainly observed in thermal power plants. CEMS systems are installed on each unit, but data calibration is required for accuracy. The Uttar Pradesh Pollution Control Board (UPPCB) enforces compliance with emission limits. 452 industries in Uttar Pradesh have installed CEMS, but only 279 share real-time data with CPCB. Challenges in acquiring real-time data from all industries.
Regulatory Compliance	Enforcement of pollution monitoring regulations and certification processes driving adoption	Strict rules and regulations in place for pollution monitoring in industries, driving CEMS demand
Government Initiatives	National Clean Air Programme (NCAP) aims to reduce air pollution	N/A
Real-time Data Sharing	There are 4,433 highly polluting industries under the CPCB guidelines for 17 categories of industries in India. Out of which 3430 industries installed CEMS and transferred their data to CPCB as per complying environmental standards	279 out of 452 industries in Uttar Pradesh share real-time data with CPCB. Challenge in acquiring real-time data from all industries
Certification and Quality Assurance	CSIR-NPL appointed as a certification body for CEMS, but the certification system is still in the developing phase.	Certification system requires well-framed quality assurance systems, guidelines and protocols.
Industry Types Covered	Various industries across India are covered under 17 categories of industries as per CPCB guidelines, particularly in highly polluting sectors.	Predominantly observed in thermal power plants and pulp and paper industries in Uttar Pradesh

This report probes into the challenges faced during CEMS implementation about issues like costs, technical limitations, calibration, certification systems, data management and maintenance. It also assesses existing policy frameworks, identifying gaps that need attention for successful CEMS adoption in India. The research is based on an extensive literature review, data from scholarly sources, questionnaires and consultations with experts and stakeholders. The study concludes with means of valuable insights for policymakers, regulatory bodies, industries and researchers involved in India's air pollution control efforts. The findings aim to inform the development of well-informed policies, improved CEMS implementation strategies and overall enhancement of environmental management in the country. The implementation challenges of CEMS are shown in Figure 1.

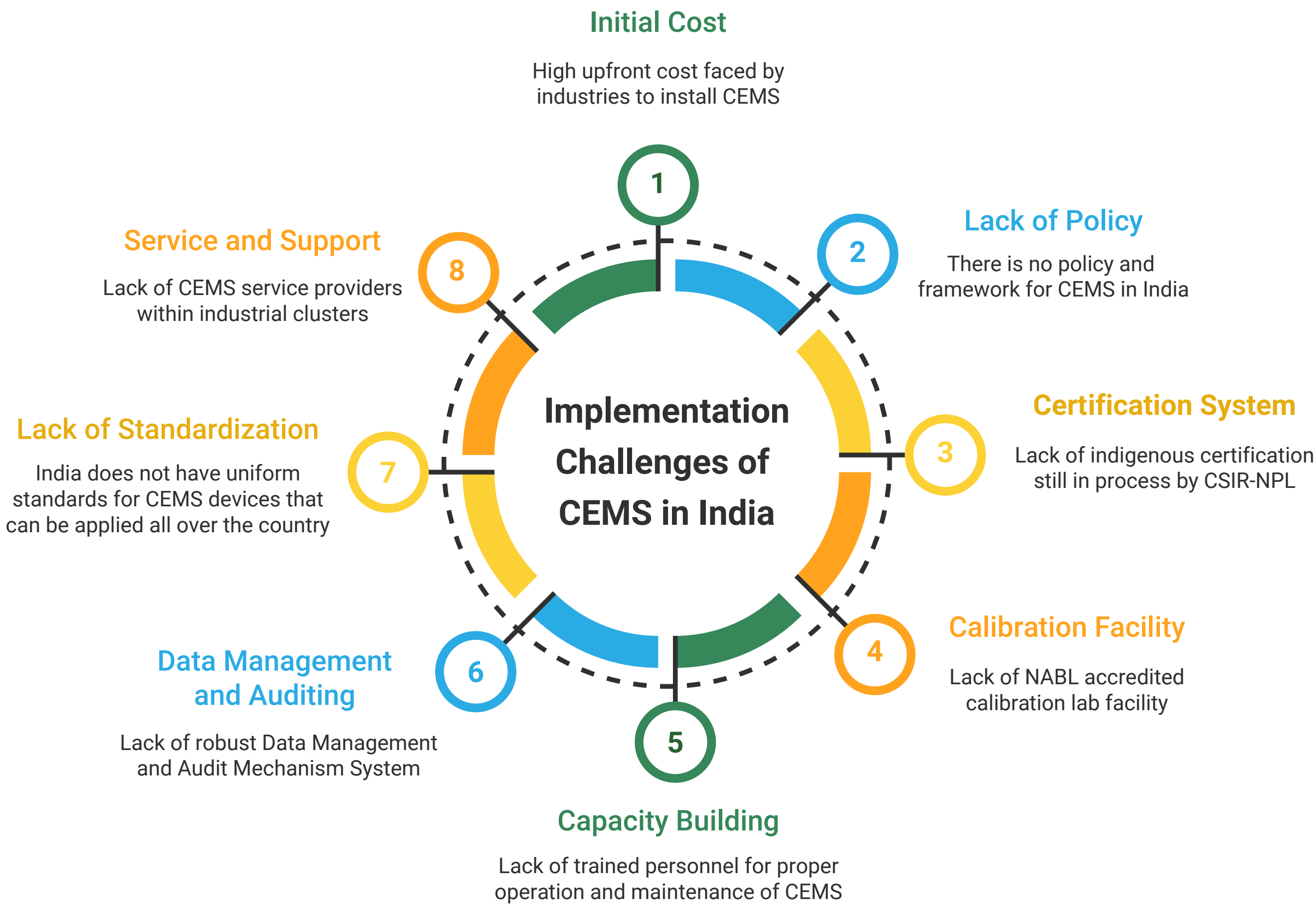


Figure 1: Snapshot of challenges in CEMS implementation

The implementation of CEMS in India faces several significant challenges, which include implementation gaps and financial constraints, particularly for small and medium-sized enterprises. To address these issues, this study proposes solutions aimed at bridging these gaps. The financial challenges related to CEMS implementation involve the high costs of equipment procurement, installation, maintenance and personnel training. Small-scale industries, crucial for India's industrial landscape, encounter difficulties due to cost, lack of awareness and infrastructure limitations, making compliance with environmental standards a challenge. To mitigate these financial hurdles, it is suggested that economy of scale should be leveraged to reduce costs and the total cost of ownership should be considered. Innovative financing models, including public-private partnerships and government incentives, can make CEMS more affordable. Additionally, recent policy interventions, such as the UP Industrial Investment and Employment Promotion Policy (UPIIEPP) 2022 and the Green Credit Policy (GCP) 2023, offer subsidies and incentives to further ease the financial burden on industries.

The absence of an indigenous certification system specific to Indian conditions and needs has led to Indian industries relying on foreign certification systems, which may not be fully suitable for the Indian context. To address this issue, India is in the process of establishing its own CEMS certification system, developed by CSIR-NPL, which aims to standardize and enhance the effectiveness of emission monitoring systems in the country. This holistic approach includes national standards, a testing laboratory, international accreditation and a comprehensive online application system. The proposed CEMS certification process involves a certification committee, accredited testing facilities and performance standards for various tests to ensure reliability.

Various organizations, such as the CSE, CPCB and international collaborations, have been instrumental in providing CEMS training programs and capacity-building initiatives. Despite these efforts, there remains a significant gap in the number of trained personnel required for CEMS installation, operation and maintenance. To bridge this gap, the Indian government has included a comprehensive CEMS training and capacity-building module in its Skill India mission. This module would ensure that the requisite skills and expertise are developed, thereby facilitating the successful implementation of CEMS across industries.

Data Acquisition Management (DAM) from emission monitoring systems also presents its own set of challenges in India. These include data quality, transmission frequency and data manipulation issues. To address these challenges, our research proposed the establishment of a Data Acquisition and Management System (DAMS) through Internet of Things (IoTs) to handle CEMS data effectively from industries to regulatory bodies.

In the CEMS ecosystem, multiple stakeholders play critical roles, including industries, regulators, vendors, certification bodies, manufacturers, service providers and researchers. These players are interconnected and must collaborate to overcome challenges related to certification, high initial costs, standardization, data quality, infrastructure limitations, regulatory compliance and industry resistance. Collaboration among these key stakeholders, supported by government initiatives are essential to enhance the efficiency and effectiveness of CEMS in India.

The findings and recommendations presented in this report address key challenges in the implementation of CEMS in India are shown in Figure 2.

1 Government Financial Support

Leverage government policies to provide financial support to MSMEs that are implementing CEMS to mitigate the high initial cost. Implement market-based mechanisms, such as tradable Green Credits, to incentivize environmental responsibility and encourage CEMS adoption.

Consistent CEMS Certification Process 2

Develop a consistent CEMS certification process in India to ensure product quality and adherence to performance standards (Already under process developed by CSIR-NPL).

3 Service Centers in Industrial Clusters

Establish service centers in industrial clusters to provide timely and cost-effective maintenance and support for CEMS users, reduce service costs to account for various factors, and foster competition among CEMS suppliers to reduce costs while ensuring performance quality.

Capacity Building and Training 4

Launch capacity building and training initiatives by CPCB and SPCBs calendar and add a training module certification system for CEMS in the skill development programme of GoI to bridge the O&M gap related to CEMS.

5 Data Acquisition and Management System (DAMS)

Setup DAMS to handle CEMS data properly and ensure its validity for compliance with environmental standard.

India needs a CEMS Policy 6

To implement CEMS properly in India, a clear and consistent policy is required. This policy should be developed with the participation and cooperation of various stakeholders and address the technical and financial aspects of CEMS.

Figure 2: Snapshot of key findings and recommendations for CEMS

These recommendations offer a comprehensive strategy to promote CEMS adoption in India, emphasizing financial support, quality assurance, capacity building, data management system and accessible maintenance services. These measures can help overcome the barriers and challenges that hinder the effective implementation and use of CEMS in India and enhance its benefits for the environment and health.

1. Introduction

1.1 Background

Air pollution is a rising global problem, posing severe threats to human health and the environment. Traditional methods of air pollution assessment have proven insufficient in addressing the dynamic and complex nature of pollution sources. The complex nature of pollutants requires real-time measurement, which is not possible without a device. That is why the role of Continuous Emission Monitoring Systems (CEMS) has emerged to measure the pollutants at sources in real-time and help in reducing air pollution in various ways through regulation. CEMS provides a real-time, automated and highly accurate means of monitoring emissions from industrial sources. By offering precise data on pollutant levels, CEMS not only enables the timely detection of irregularities and deviations from regulatory standards but also aid in identifying pollution sources with pinpoint accuracy. Various countries use CEMS to analyze pollution in real-time and issue guidelines for the proper implementation of CEMS.

Industrial emission is a significant contributor to air pollution. To effectively address this issue, continuous and accurate emissions monitoring is crucial. Real-time monitoring provides vital data for assessing air quality, identifying pollution sources and devising targeted control strategies (UNEP, 2019; WHO, 2021). The primary sources of air pollution are fossil fuel combustion, industrial operations and transportation, emitting pollutants such as particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOCs) (Kampa and Catanas, 2008). To safeguard the environment and ensure regulatory compliance, CEMS plays a pivotal role in quantifying pollutant concentrations from industrial processes. CEMS incorporate a variety of components including gas analyzers, sample conditioning equipment, calibration tools, maintenance provisions, data acquisition systems and reporting mechanisms (USGPO, 2023; Jahnke, 2022). Regulatory bodies worldwide, including the European Union (EU), the United State of America (USA): The Environmental Protection Agency (EPA) and the Central Pollution Control Board (CPCB), etc. have issued guidelines and protocols for implementing CEMS to monitor pollution control system performance and ensure adherence to specified standards (USEPA 2017; CPCB, 2018). CEMS are systems that continuously monitor and report emissions of air pollutants from industrial facilities in real time. They help reduce the environmental impact of air pollution by ensuring compliance with emission standards and enabling corrective actions in case of violations. CEMS enhances the efficiency and performance of industrial processes by optimizing combustion conditions, reducing fuel consumption and minimizing waste generation. Moreover, they improve transparency and accountability in pollution control by providing reliable, accessible data to the public and authorities. Additionally, CEMS reduces the cost and time associated with pollution monitoring by eliminating the need for manual sampling and analysis, which can be error-prone and time-consuming (CPCB, 2014). Various types of CEMS are available, depending on the parameters to be monitored, sampling techniques and analytical methods are shown in Table 3.

CEMS have been implemented in various countries to monitor and control air pollution like China conducted a study employing CEMS to measure sulfur dioxide (SO_2) levels in ambient air, revealing a significant link between SO_2 exposure and an elevated risk of lung cancer, underscoring the crucial role of CEMS in understanding the health impacts of air pollution (Zhang and Schreifels, 2011).

As India grapples with severe air pollution issues, there is a growing momentum to adopt CEMS. In response, the CPCB has issued a directive for continuous emissions monitoring to effectively manage pollution from various industries (CPCB, 2018). The objective of this report is to evaluate CEMS effectiveness, identify challenges and address policy and implementation gaps in India to fight against air pollution.

Table 3: Types of CEMS

Types of CEMS	Description
Extractive CEMS	Draws a sample of flue gas from the stack or duct.
Non-Extractive CEMS	Measures pollutants directly in the flue gas stream without extracting a sample.
Particulate CEMS	Measures the concentration or mass flow rate of particulate matter in the flue gas.

Source: (USEPA, 2017)

1.2 Global adoption of CEMS

Globalization and industrialization have increased the number and diversity of industrial emission sources, making it difficult to monitor them individually and physically. Therefore, there is a need for virtual monitoring, which involves measuring the pollution from sources through devices like CEMS, which monitor the emissions in real time. Virtual monitoring is a key aspect of environmental regulation and management in different countries, as it enables the verification and enforcement of emission standards and limits.

Different countries around the world have adopted CEMS at varying levels, depending on their economic, social and environmental conditions. The history of CEMS adoption can be traced back to the 1970s, when the United States was the first country to implement CEMS as a regulatory requirement for power plants and other major sources of air pollution under the Clean Air Act Amendments of 1970. The main reason was to monitor and enforce the emission standards for criteria pollutants such as SO_2, NO_x, CO and particulate matter (US EPA, 2017).

In the 1980s, the European Union followed the US example and introduced CEMS as a mandatory requirement for large combustion plants under the Large Combustion Plant Directive of 1988. The main reason was to reduce the transboundary air pollution and acid rain in Europe, which had significant impacts on human health and ecosystems. In the 1990s, Japan, Canada and Australia also adopted CEMS as a part of their environmental regulations for various industrial sectors such as power generation, cement, steel and chemical industries. The main reason was to comply with the international agreements on climate change and ozone depletion, such as the Kyoto Protocol and the Montreal Protocol, which aimed to reduce the emissions of greenhouse gases (GHGs) and ozone-depleting substances (CAA, 2023). China is one of the largest emitters of greenhouse gases and air pollutants in the world. It faces enormous challenges in controlling its industrial emissions and improving its air quality. China has been gradually adopting CEMS since the late 1990s, but its progress has been slow and uneven due to various barriers such as lack of standards, incentives, enforcement, data quality and public awareness. However, in recent years, China has made significant efforts to promote CEMS adoption in key industries such as power generation, steel, cement, petrochemicals, non-ferrous metals, waste incineration and pulp and paper. The main reason was to implement the National Action Plan on air pollution prevention and control (2013-2017), which aimed to reduce the emissions of major pollutants by 10-25% by 2017 compared to 2012 levels. Moreover, China has also been developing its own standards and technologies for CEMS to suit its domestic conditions and needs (Wang et al., 2019).

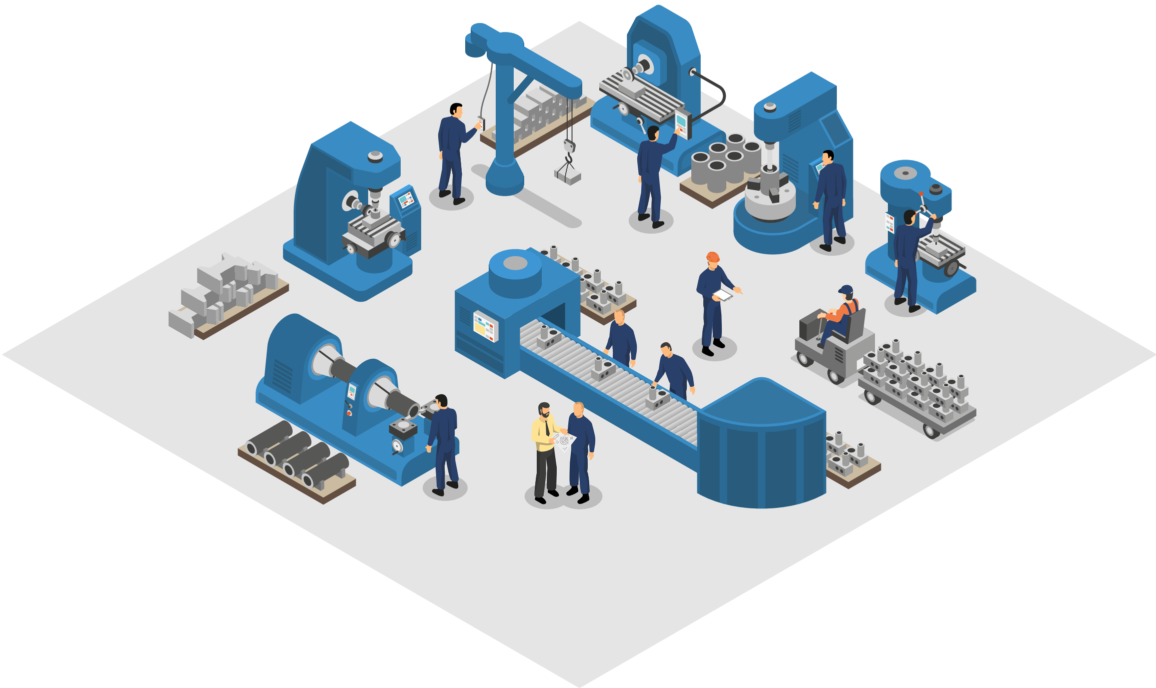
Chen et al. (2020) conducted a notable study that emphasizes the importance of China's real-time CEMS monitored data at the source level. Their research highlights three key advantages:

- Firstly, the ability to directly estimate industrial emission factors and absolute emissions using hourly source-level CEMS data.
- Secondly, improving the spatio-temporal resolution and representation of heterogeneous and time-varying characteristics of power emissions data and
- Thirdly, demonstrates the potential for other countries to adopt CEMS-based estimation methods for regulating power emissions.

The Chinese Industrial Emissions Database (CIED) crafted from up-to-date data from China's emission monitoring systems (CEMS) further enhances precision. By directly calculating emission factors and absolute emissions, this innovative approach minimizes assumptions. Rigorous uncertainty analysis confirms the dependability of the estimates with a margin of error of ±7.2% for factors and ±4.0% for emissions. Providing valuable insights into the concentrations emitted from smokestacks, as well as emission factors and absolute emissions, the CIED stands as a vital tool for researchers and policymakers (Tang et al., 2023). Wang et al. (2023) revealed that the atmosphere in China is heavily polluted by industrial air emissions. These emissions contain ultrafine particles (UFPs), VOCs, NH_3, and NO_x, which are harmful elements. Consequently, there is now a strong regulatory focus on implementing online monitoring of emission sources. This study also brought attention to advancements in pollution control, as well as the identification of areas prone to high levels of pollution.

It is worth noting that developed countries like Germany, United Kingdom, Japan and the United States dominate the CEMS market with their advanced technology and significant role in imports (MarketWatch, 2023a,b).

Driven by strict regulations and the need for advanced technology and sensor development, industries such as power generation, oil, gas and chemicals have been mandated by initiatives like Australia's National Pollutant Inventory (NPI) to install CEMS for monitoring and reporting emissions (Manisalidis et al., 2020).



CEMS are now considered essential tools in industries worldwide for monitoring and measuring pollutant concentrations emitted during industrial processes. The global market of CEMS is expected to experience substantial growth, with a projected Compound Annual Growth Rate (CAGR) of 6% from 2023 to 2030 (MarketWatch, 2023a,b). This increased demand can be attributed to the implementation of rules and regulations concerning pollution monitoring and environmental compliance across various sectors. Market trends also indicate that CEMS has a significant market size, with the Asia-Pacific region anticipated as the largest market for CEMS from 2022 to 2027 (Open, 2021). In response to growing concerns about air pollution, governments and regulatory bodies, such as the Government of China, have enacted emissions control regulations and enforced compliance with emission limits. They have further utilized data analysis from CEMS to study emissions from industries like thermal power production etc. (News Channel Nebraska, 2023).

These trends highlight the growing adoption of CEMS globally as industries strive to monitor and reduce emissions effectively. The global emission monitoring system market is predicted to rise at a CAGR of 6.5% from 2022 to 2032 and is estimated to reach US$ 10.7 billion by 2032 from US$ 5.3 billion in 2021. The emission monitoring system is also used by the power generation, chemicals, petrochemicals, refineries and fertilizer sectors (Fact, 2023). The Emission Monitoring System market is expected to reach US$ 4.5 billion by 2027 from US$ 3.0 billion in 2022 at a CAGR of 8.8% from 2022 to 2027 (Markets and Markets, 2021). According to Coherent Market Insights, 2023, the market of emission monitoring systems is estimated to be valued at US$ 6,564 million by 2030, registering a CAGR of 8.5% from 3,427.2 million in 2022. According to the recent analysis, the CEMS market is predicted to grow significantly in the coming years. The market is currently valued at US$ 2.72 billion in 2023 and is expected to reach US$ 4.22 billion by 2033, registering a CAGR of 4.5% during the forecast period (FMI, 2023). Another report suggests that the emission monitoring systems market is expected to grow at a CAGR of 9.2% during the forecast period and is projected to reach $8.7 billion by 2031 (Allied Market Research, 2023). The market is driven by factors such as stringent legal and environmental regulations made by governments across the globe, increasing health and safety issues, increasing awareness about environmental protection and growing usage of oil and gas and petrochemicals. The market is highly competitive owing to the presence of many players in the market supplying their products in domestic and international markets (Mordor Intelligence, 2023). The global market projections of CEMS are shown in Figure 3.

The global scenario for CEMS emphasizes their critical role in ensuring compliance with emission regulations. The market is experiencing growth due to these factors. CEMS data has sparked interest worldwide, developed countries and governments are actively promoting the implementation of CEMS for effective control and monitoring of pollution.

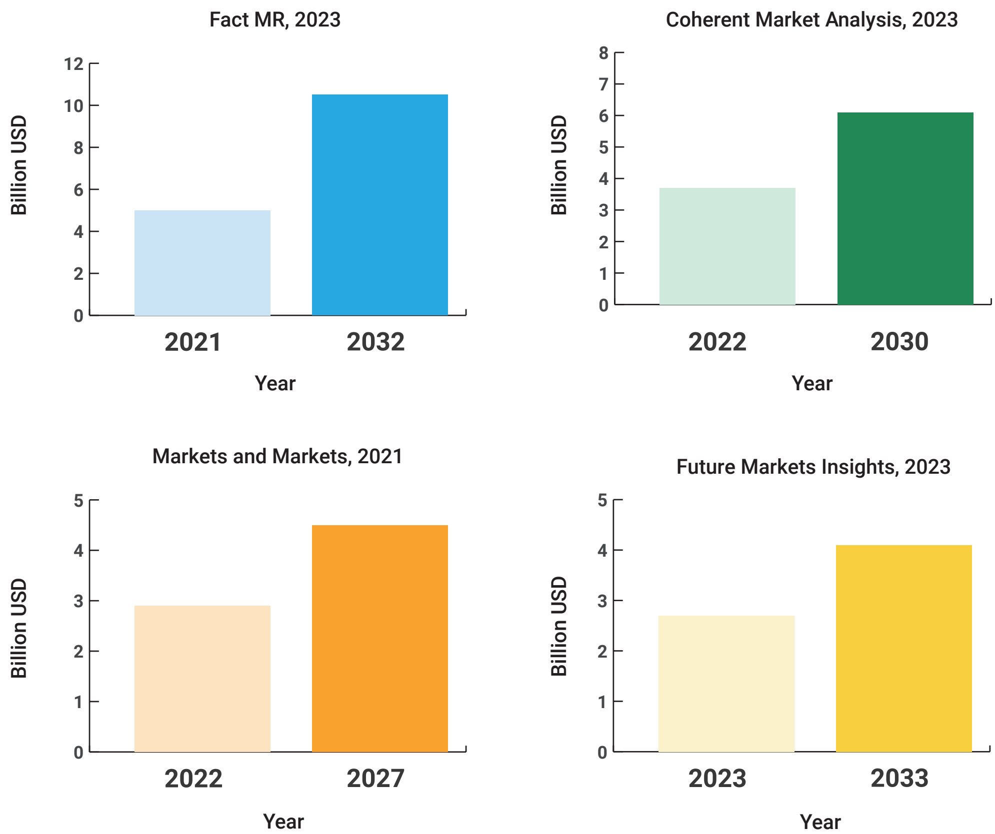


Figure 3: Global Market Projections of CEMS

1.3 Current Status of adoption of CEMS in India

Due to the enforcement of pollution monitoring regulations, the CEMS scenario in India is currently experiencing significant growth. The government, along with regulatory bodies, has taken proactive measures to tackle air pollution and ensure adherence to regulations. Key players in the Indian CEMS market include ABB Ltd., AMETEK, Inc., Emerson Electric Company, Thermo Fisher Scientific Inc. and Horiba Ltd. To address air pollution, the government has introduced initiatives like the National Clean Air Programme (NCAP). By 2024, the NCAP has set its sights on a 20%-30% decrease in air pollution levels. It is no wonder that the demand for CEMS in India is on the upswing, due to the efforts made by the NCAP (ABB, 2022). The Indian CEMS market is estimated to be valued at US$ 800-900 million and is mainly focused on monitoring pollutants such as dust, SO_2, NO_x and other pollutants. Compared to the United States and Europe, India later adopted CEMS technology to improve environmental management and achieve sustainable development goals (HCGA, 2016).

The increasing industry-wide adoption of CEMS in India is a direct response to pollution control measures as well as certification processes that ensure the reliability and performance of CEMS equipment during installation. The installation of CEMS equipment plays an important role in helping the industry meet emissions standards and reduce environmental pollution.

In India, most of the CEMS devices have been imported from foreign countries. However, CEMS manufacturing is currently underway in India, with companies like Respirer Living Sciences Pvt Ltd (led by Ronak Sutaria) taking the lead in indigenous production. These companies adhere to Indian environmental standards and CPCB guidelines, tailoring the manufacturing of CEMS devices to the specific requirements of the Indian context. To further promote the manufacturing sector for indigenous production of CEMS devices, the government of India has some schemes. One of them is the Atmanirbhar Bharat ('Self-Reliant India') Programme, which is a government initiative to enhance the competitiveness, efficiency and exports of Indian manufacturers by attracting investments in advanced technology and creating economies of scale. One of the components of this programme is the Production-Linked Incentive (PLI) scheme, which offers various incentives to different sectors of the economy.

The Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors (SPECS) is a PLI scheme that could help to promote indigenous manufacturing of CEMS in India. The SPECS scheme offers a 25% capital subsidy on a reimbursement basis for a period of upto five years to companies that invest in plant, machinery, equipment, utilities, R&D and technology transfer for manufacturing CEMS and other electronic goods. The scheme applies to both new units and expansions and is open for applications for three years. The scheme has a transparent application and disbursement process, which involves the submission, examination, acknowledgement, appraisal and approval of the Project Management Agency (PMA). After approval, the companies can submit their claims, which will be verified by the PMA and then disbursed. The SPECS scheme is expected to boost the domestic production of CEMS in India. The application process and claim for disbursement of Incentive to avail of this scheme are shown in Figure 4.

According to Greenstone et al., (2020), there had been about 1,000 CEMS devices installed in India as of 2018, overlaying about 10% of the industrial emissions sources. It is also mentioned that installation of CEMS devices increased by 50% from 2016 to 2018, indicating rapid growth in the CEMS market (Figure 5). According to the CPCB, there have been about 2,500 industries that installed CEMS as of February 2020, out of which about 1,500 were linked to the CPCBs online portal. The CPCB additionally said that it had issued guidelines to approximately 4,000 industries to install CEMS via March 2020 (3ie, 2020). According to the CSE evaluation, there had been approximately 17 SPCBs that shared their CEMS data in public domain as of October 2020, covering approximately 50% of the state pollution authorities in India.

The evaluation additionally identified that most industries have been working in offline mode, meaning that their CEMS statistics were no longer transmitted in actual time (Down to Earth, 2022).

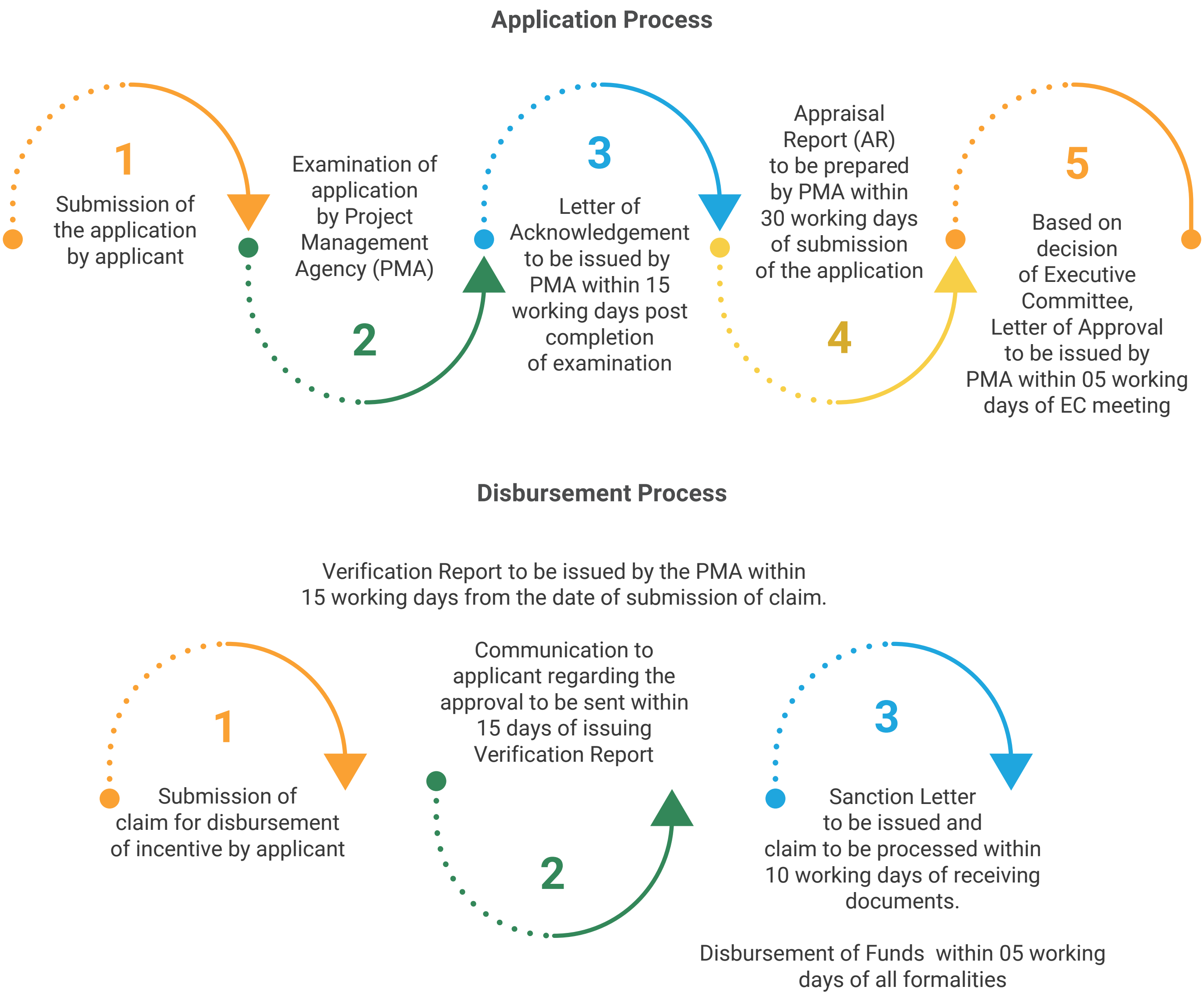


Figure 4: Snapshot of application and disbursement process of Incentive (Source: (Invest India, 2023; SPECS, 2023))

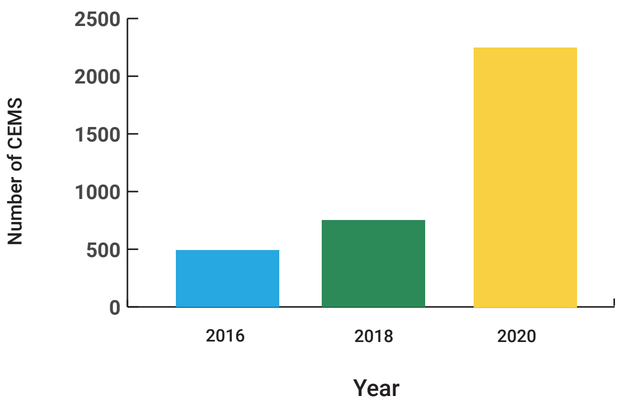


Figure 5: Number of CEMS installed from 2016 to 2020

According to Report of Mission Energy Foundation, CEMS in India is expected to develop at a CAGR of 12% from 2018 to 2023, attaining a market of USD 800-900 million by 2023. They also said that CEMS in India is predicted to cover about 30% of the Industrial emissions sources by 2023, up from 10% in 2018 (Mission Energy, 2023). According to ENVEA, a global leader in environmental monitoring solution, CEMS in India is expected to enhance its environmental governance with the aid of global technology and solution providers under a roof, bringing like-minded discussions, technical sessions and a gambit of networking possibilities. ENVEA additionally said that CEMS in India is predicted to provide recommendations, technical help and realistic solutions to help operators to meet environmental objectives (ENVEA, 2023).

The Press Information Bureau Report (PIBR) of the Government of India (GoI) reveals that from 2014 to 2022, only 712 out of the 4,247 industrial units have failed to connect their Online Continuous Emissions Monitoring Systems (OCEMS) to the servers of the CPCB and the SPCBs. These units are under closure orders for not complying with the environmental standards and self-regulation norms. The category-wise OCEMS connectivity status is given in Table 4.

Table 4: CPCB 17- categories industries status of installation of OCEMS

S. No.	Industries	Total Units Targeted	Units Installed and Connected	Units with Closure Directions
1	Aluminium	14	12	2
2	Cement	394	301	93
3	Chloralkali	33	33	0
4	Copper	3	3	0
5	Distillery	366	285	81
6	Dye & Dye Intermediates	122	96	26
7	Fertilizer	117	96	21
8	Iron and Steel	424	358	66
9	Pesticide	82	71	11
10	Petrochemical	36	30	6
11	Pharmaceuticals	774	673	101
12	Pulp and Paper	307	245	62
13	Refinery	23	23	0
14	Sugar	646	498	148
15	Tannery	458	417	41
16	Thermal Power Plant	443	391	52
17	Zinc	5	3	2
Total		**4247**	**3535**	**712**

Source: PIBR, 2022

In the same PIB Report, it is also mentioned that there are 3758 (functional) highly polluting industries under the CPCB guidelines for 17 categories of industries in India. Out of which 3430 industries installed CEMS and transferred their data to CPCB as per complying environmental standards, and for the rest of the 328 industries, appropriate action has been taken for non-complying with the environmental standards (PIBR, 2022).

The Ministry of Environment, Forest & Climate Change (MoEF&CC) in 2011 has initiated an important project to design and evaluate a pilot emissions trading scheme (ETS) for particulate matter from stationary sources in collaboration with three states- Gujarat, Maharashtra and Tamil Nadu with the CPCB as the Nodal Agency for the overall implementation of the program. This has been initiated as a way forward towards reducing particles in the ambient air. Therefore, the role of CEMS is to measure the total load of particulate matter (PM) coming from each stationary source. The implementation of CEMS in India started in 2013, when the CPCB initiated the process of mandating CEMS for major industries and common pollution treatment facilities. In February 2014, the CPCB issued a direction to install real-time effluent quality monitoring systems in 17 categories of highly polluting industries and common pollution treatment facilities. In March 2014, the MoEF&CC issued a Draft Notification on the use of CEMS for monitoring and reporting emissions and effluents. However, the draft notification was put on hold in April 2015. By March 2016, nearly 80% of 2764 plants had already installed or were in the process of installing CEMS. In August 2017, the CPCB released guidelines for implementing CEMS, specifying how suitable monitors will be selected, installed, operated and meet compliance requirements. The guidelines were revised in August 2018, incorporating more details on monitoring technologies, calibration, performance evaluation and data management. In August 2019, the NPL was appointed by MoEF&CC as a certification body for CEMS, but the certification system was still in the developing phase. The timeline of CEMS progress in India is given in Figure 6.

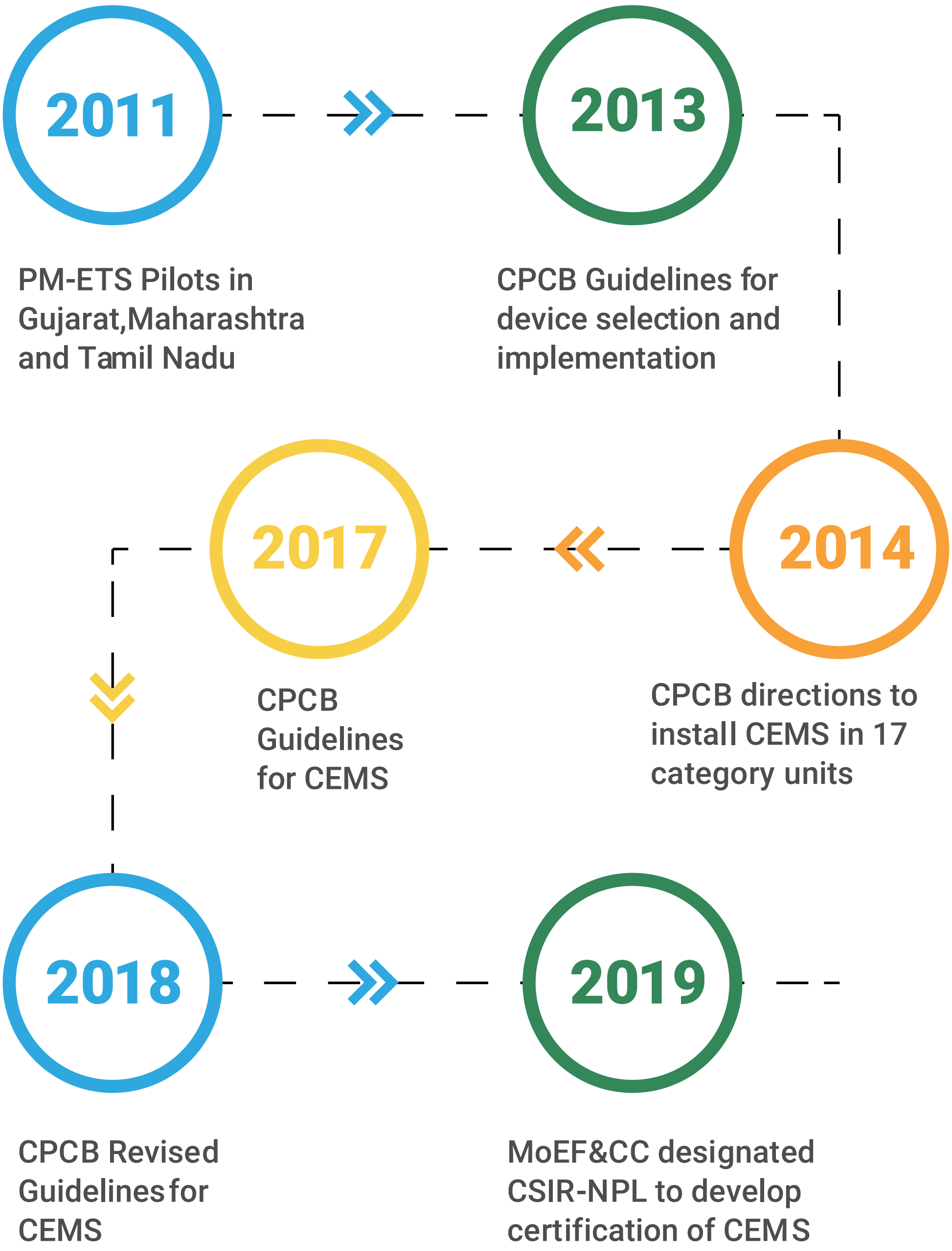


Figure 6: Timeline of CEMS progress in India

1.4 Current Scenario in Uttar Pradesh

The installation of CEMS in Uttar Pradesh (UP) has primarily been observed in thermal power plants. During a survey conducted in thermal power plants in Uttar Pradesh, it was noted that CEMS systems have been installed on each unit. However, data calibration is required to ensure accurate measurements. The Uttar Pradesh Pollution Control Board (UPPCB) has conducted inspections of various industries to enforce compliance with emission limits. During these inspections, it was found that CEMS systems were operational, indicating their use in monitoring and controlling emissions. The implementation of strict rules and regulations regarding pollution monitoring across industries is expected to drive the demand for CEMS in Uttar Pradesh. The certification system for CEMS necessitates well-framed certification and quality assurance systems, along with corresponding guidelines and protocols. The installation of CEMS devices in various industries across Uttar Pradesh is anticipated to assist these industries in complying with emission limits and reducing the release of pollutants. The presence of CEMS in thermal power plants and the emphasis on pollution monitoring regulations indicate the potential demand and utilization of CEMS systems in the State. The implementation of stringent pollution monitoring regulations is expected to generate further demand for CEMS across industries in the State (CSE, 2019; 2022).

According to the CPCB Real Time Data Monitoring System (RTDMS), 452 industries in Uttar Pradesh have installed CEMS to measure and report their emissions in real time enabling tracking of their emissions through real-time data monitoring systems. However, as per analysis done by the Directorate of Environment, only 279 industries have shared their data, while the remaining 173 have not shared their data with the CPCB. This indicates that there is still a major challenge in acquiring real-time data from all industries. The number of industries sharing data on the CPCB RTDMS Portal is shown in Figure 7. The survey used a random sampling method to collect questionnaire responses from 55 industries in Uttar Pradesh. The survey found that most of the industries (96.67%) already use CEMS, indicating high adoption. The remaining 1.7% are planning to install CEMS soon, showing potential growth. This data reflects a positive trend in CEMS adoption, driven by environmental awareness and compliance needs. The CEMS adoption in industries of Uttar Pradesh are shown in Figure 8.

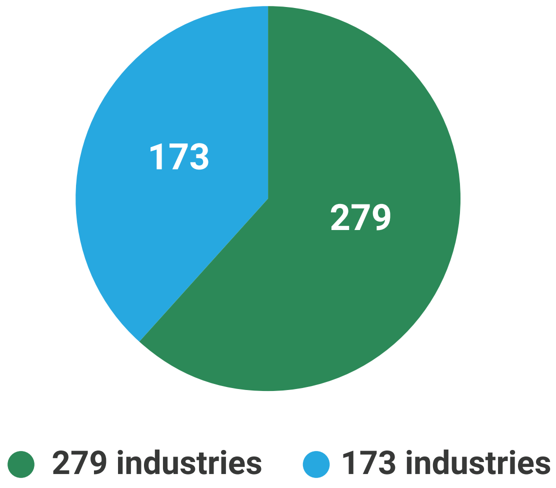


Figure 7: Number of industries sharing data on the CPCB RTDMS Portal

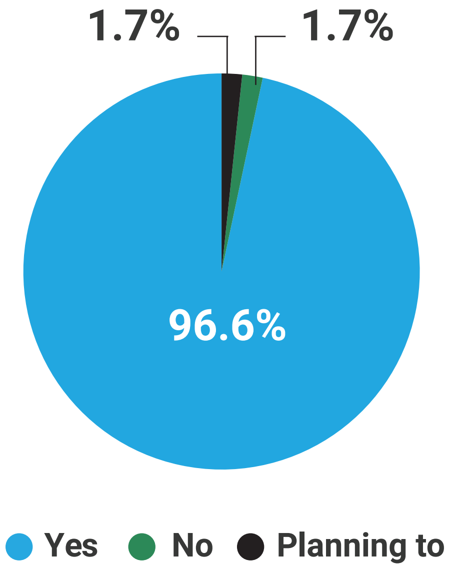
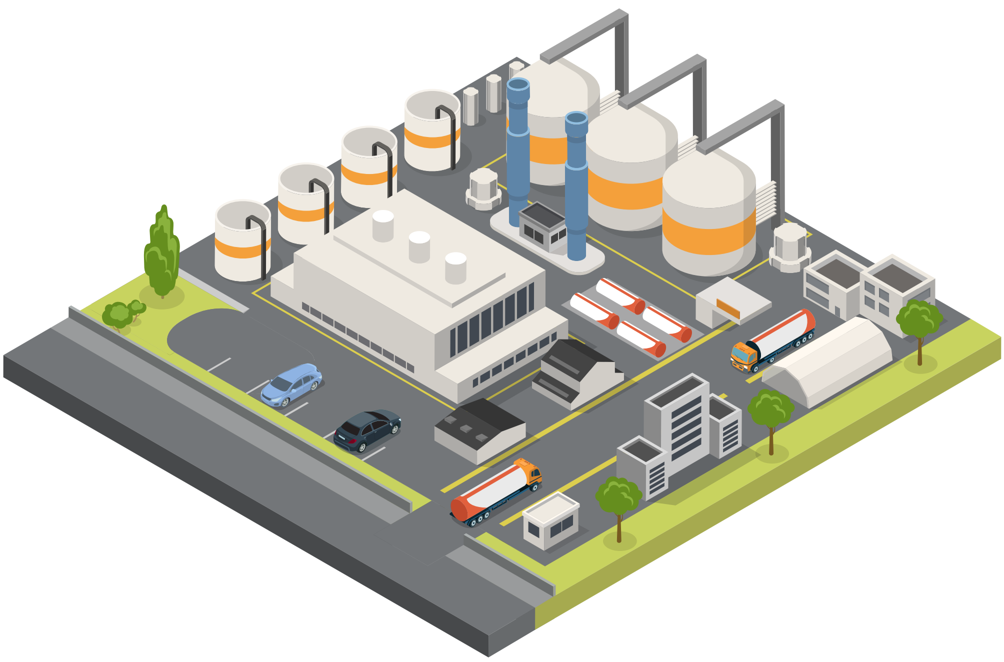


Figure 8: CEMS Adoption in Industries of Uttar Pradesh



2. Objectives

This report aims to comprehensively analyze the implementation and performance of CEMS in India with particular reference to the State of Uttar Pradesh. The report also examines the challenges encountered during CEMS implementation, such as high cost, technical limitations, lack of calibration facilities, indigenous certification system, data management issues and maintenance concerns. Additionally, it evaluates the existing policy frameworks while identifying gaps that require attention for successful implementation and widespread adoption of CEMS in India. By addressing these research objectives, this report will provide valuable insights for policymakers, regulatory bodies, industries and researchers involved in air pollution control efforts. The findings of this report will contribute to the development of informed policies, improved CEMS implementation strategies and overall enhancement of environmental management in India and particularly Uttar Pradesh.

3. Methodology

A comprehensive literature review on the Continuous Emission Monitoring System (CEMS) in India was summarized in the report. The research employed a detailed methodology, which began with an in-depth review of existing literature on performance evaluation, policy gaps and financial implications for effective air pollution control using CEMS in India. This literature review covered various aspects, such as policy frameworks, challenges, calibration services and the status of data monitoring related to CEMS in India. To collect authoritative secondary data on CEMS, scholarly search engines like Google Scholar, PubMed, ScienceDirect, ResearchGate, Scopus and SciFinder, as well as web addresses, published reports, government websites and surveys were used. In addition to this, this report is based on questionnaire-based survey with various industries in UP and also organized consultation of stakeholders with CEMS experts on May 17 and 19, 2023, to gather information about the current status of CEMS in India and these findings have also been integrated into this report.

The references included a diverse array of secondary sources, such as web pages, blogs, research papers, published reports, surveys, and concise articles. In total, 76 original articles were incorporated into the analysis. The data presentation in this report was executed with precision and clarity, using Microsoft PowerPoint, Excel and Word software applications to create tables and figures.

4. Policy Implementation

4.1 Global Policy Adoption of CEMS

The adoption of CEMS varies across different countries and regions, depending on the level of economic development, environmental awareness, political will and global influence. The United States has been at the forefront of adopting and implementing CEMS as a key component of environmental policies. This commitment to monitoring and regulating air emissions is evident in the Clean Air Act (CAA) and its amendments. Under the CAA, the U.S. Environmental Protection Agency (EPA) has defined specific requirements for the installation, certification, operation and maintenance of CEMS for various pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), oxygen (O_2), etc. These standards aim to ensure the accurate measurement and reporting of emissions, a fundamental aspect of effective pollution monitoring and reduction (EPA, 2017).

The EU's approach to CEMS adoption is reflected in the Industrial Emissions Directive (IED), which sets forth comprehensive requirements for monitoring emissions from industrial facilities. The IED mandates the use of CEMS to monitor emissions from a wide range of industrial activities, including energy production, waste management and chemical processing. Furthermore, the EU has established the European Environment Agency (EEA) to oversee environmental issues, including emissions monitoring. The EEA compiles data from member countries, assesses the environmental impact and supports the implementation of consistent standards and best practices across the European Union (EU, 2021).

The CEMS policies of Asian countries have stipulations typically based on guidelines from international and foreign agencies, such as the European Union (EU), European Commission (EC), United States Environmental Protection Agency (US EPA) and the Organization for Economic Cooperation and Development (OECD). Generally, these specifications have detailed guidelines on the monitoring of individual pollutants and the performance of the CEMS technologies. In Thailand and the Philippines, for instance, CEMS implementation guidelines (particularly on the data reporting requirements) are based on specifications from the US EPA. The Implementing Rules and Regulations of the Clean Air Act (or Department Administrative Order No. 2000-81) of the Philippines Environmental Agency (PEA) utilizes the CEMS related policies of Asian countries and also establishes platforms where data can be gathered and stored for use in emission analysis and regulatory activities. Depending on the policies and technological advancements of the countries, these platforms may already be using automated data acquisition and storage systems and thus may require sources to submit data more frequently. China, Thailand and the Philippines are countries with established central data acquisition and management systems, where regulated sources equipped with CEMS can regularly submit emissions data. These central data handling systems such as China Emissions Accounts for Power Plants (China), Pollution Online Monitoring System (Thailand) and Data Acquisition and Handling System (Philippines) are already connected to a substantial number of industrial and power facilities in the countries. In terms of emissions data reporting, policies of the various countries that were reviewed require the CEMS data to be regularly reported. Common to all reviewed policies, regulated emission sources are required to submit full emissions reports at least twice a year or quarterly. In some cases, the frequency of reporting will depend on the pollutant types being reported, as in Vietnam's Law on Environmental Protection (VLEP) 2020 and Decree No. 08/2022. For the countries with established central data management systems, such as Thailand and the Philippines, the regulated facilities are also required to transmit their CEMS data, as well as the updated closed circuit television photo capture of the stack, every five minutes or on an hourly basis. One significant benefit of these policies that require the use of CEMS is the improvement of regulatory process efficiency. With the CEMS data readily available at any given time, regulators and facility operators can be quickly alerted, either by the CEMS or by the regulator's central data handling system, about any exceedances of the monitored facilities over the pollutant emission limits. The regulators can then use this information to send out notifications or warnings, as well as any corresponding penalties, to the facility operators for corrective action. The installation and operation of CEMS are governed by various regulations. The Part 75 rule outlines the specific requirements for installing, certifying, operating and maintaining CEMS, covering pollutants such as SO_2, NO_x, CO_2, O_2, etc. Sources subject to permit requirements or state regulations must adhere to the state specific guidelines. To ensure accurate measurement and reporting of emissions, each CEMS is required to complete a cycle of operation every 15 minutes. Compliance with these regulations is crucial for effective pollution monitoring and reduction in the USA (CAA, 2023).

Policies on emissions monitoring are essential to reduce coal fire power plants (CFPs) emissions and their harmful impacts. Emissions monitoring provides environmental control agencies access to more information which serves as the basis for regulators to determine whether regulated facilities comply with emission standards or not (Clean Air Asia, 2023). Continuous emissions monitoring, when properly used and maintained, can strengthen the regulator's capacity to effectively and enforce emission standards would reduce the need for onsite inspection and manual reference method tests (Jahnke, 2022). The major economies and top coal consuming countries in the world implement policies requiring the use of CEMS as part of their emissions regulation programs for power plants and industrial facilities. Governments can regulate point sources of air pollutants by using CEMS data to support pollutant registration, pollutant discharge permit and operation regulation, which includes the temporary shutdown of facilities exceeding emission standards. Air pollution regulations in China also use CEMS data to implement a pollution control system for power and industrial facilities (Zhang and Schreifels, 2011). Apart from the regulatory aspect of monitoring, existing policies on the use of CEMS state that the CEMS data are to be used to verify the types and volume of emitted pollutants. It can also help in tracking ambient air quality and potential air pollutants.

4.2 Guidelines for CEMS in India

To combat air pollution, the Central Pollution Control Board (CPCB) has issued directives under Section 18(1)(b) of the Water (Prevention and Control of Pollution) Act, 1974, and the Air (Prevention and Control of Pollution) Act, 1981. These directives are aimed at ensuring environmental compliance in the industrial sector by instructing State Pollution Control Boards (SPCBs) and Pollution Control Committees (PCCs) to direct industries falling under 17 highly polluting categories, as well as Common Effluent Treatment Plants (CETPs) and facilities for biomedical and hazardous waste, to install online monitoring systems. These actions align with the objective of monitoring and controlling pollution. Furthermore, the CPCB has issued additional directions under Section 5 of the Environment (Protection) Act, 1986, specifically for industries within the 17 highly polluting categories, mandating the installation of Continuous Emission and Effluent Monitoring Systems (CEEMS) and the establishment of data connectivity with SPCBs/PCCs and CPCB servers. In cases where existing industries within these categories are found to operate without OCEMS, SPCBs/PCCs are instructed to issue closure orders. For new establishments within these categories commissioned after February 28, 2017, a specific condition of installing and connecting OCEMS must be included in the Consent to Operate (CTO).

Mandatory regulations dictate that the installation of Continuous Emission Monitoring Systems (CEMS) is required for 17 categories of highly polluting industries and biomedical/hazardous waste incinerators. These industries are responsible for data submission, facilitated by instrument suppliers who install servers in regulatory bodies to enable seamless data transfer from CEMS. To enhance efficiency, it is recommended to establish a unified protocol for direct data transfer. Additionally, industries must secure 5-year maintenance contracts with authorized service partners, ensuring timely issue resolution within 72 hours, spare parts availability for 7 years, and calibration validation.

Furthermore, according to the CPCB Guidelines, 2018, specific industries utilizing boilers, such as Sugar, Cotton Textile, Composite Woollen Mills, Synthetic Rubber, Pulp and Paper, Distilleries, Leather Industries, Calcium Carbide, Carbon Black, Natural Rubber, Asbestos, Caustic Soda, Small Boilers, Aluminium Plants, and Tanneries are also mandated to install CEMS. To promote self-regulation, it is advisable to extend the concept of CEMS beyond highly polluting industries, encouraging other sectors to consider installing CEMS for self-regulatory purposes. A technological advancement in this regard is the adoption of cloud-based server installation, where providers install their servers in the cloud and transmit real-time data to CPCB, SPCBs, or other government bodies in consultation, signifying a shift towards cloud-based data management and transmission (CPCB, 2018).

CPCB issued the first guidelines for CEMS in 2014 and revised it in 2017. Further, some more industries in 17 categories of industries were added in 2018 and revised their guidelines again. The guidelines aim to provide a framework for implementing CEMS to monitor and report emissions from various industries in real time (CPCB, 2018). The guidelines for implementing the CEMS in India is given in Figure 9.

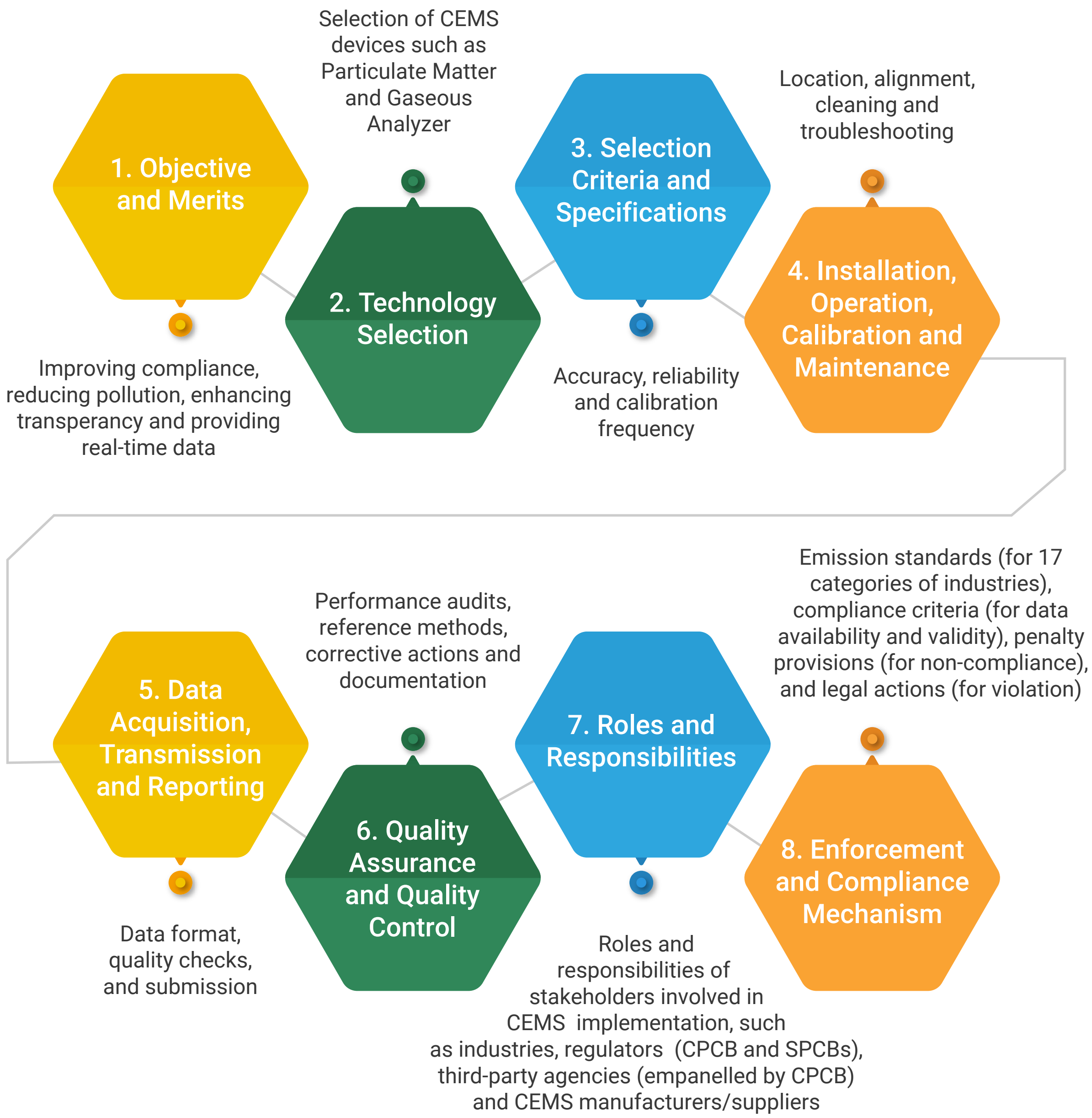


Figure 9: Guidelines of CPCB for implementing CEMS in India

5. Policy and Implementation Gaps

Implementation of CEMS in India has revealed several policy gaps, which were identified through research reports, surveys, including the questionnaire-based survey, as well as stakeholder consultation in CEMS ecosystem under this research (CSE, 2016; DoE, 2023). Some of these gaps are shown in Figure 10. Though CEMS regulations have been brought in quite early in 2014 but a comprehensive policy for CEMS adoption addressing its complete value chain including the issues related to costs, indigenous certification system, accreditation of labs for periodic CEMS calibration, data validation and transparency, use of CEMS for regulatory purposes, green skill development for CEMs operation and maintenance etc. is needed (DoE, 2023).

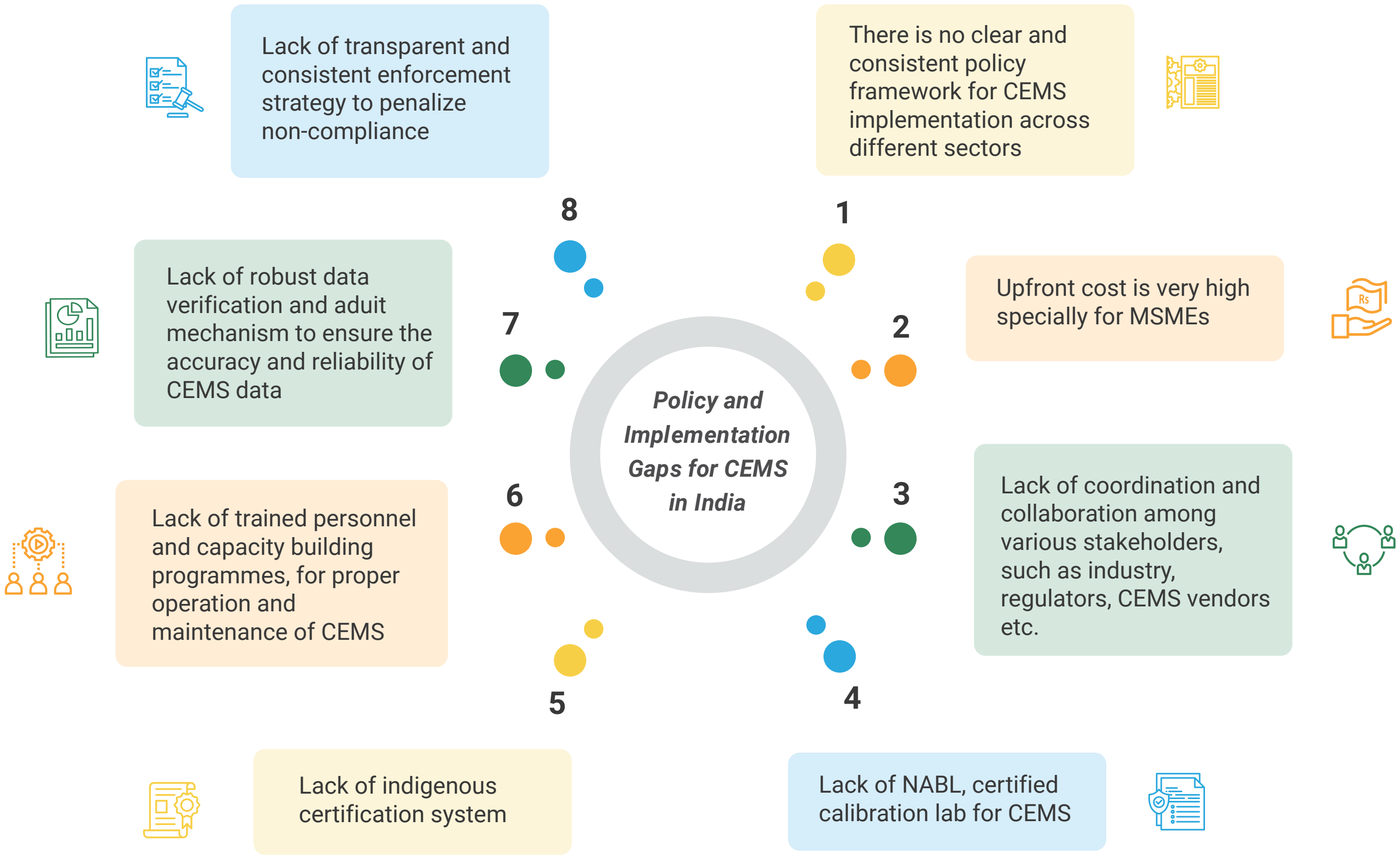


Figure 10: Snapshot of Policy and Implementation Gaps for CEMS in India

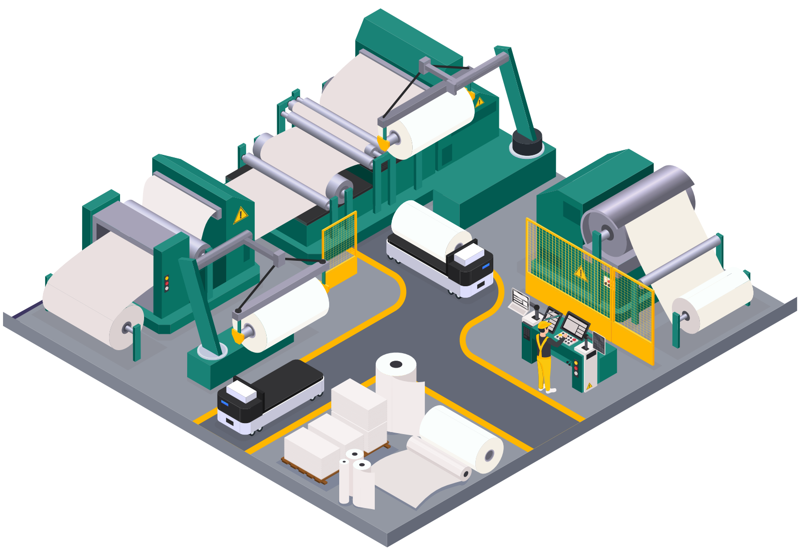
5.1 Financial Gaps

Industries particularly micro and small are facing multifaceted financial challenges for adoption of CEMS in India. The high cost involved in CEMS equipment procurement, installation and personnel training, poses a significant obstacle, particularly for small and medium-sized enterprises (CSE, 2015; Kanchan and Bahel, 2016). Additionally, the absence of empanelled calibration labs locally also increases implementation costs that hinders regulatory compliance. The long-term sustainability of CEMS demands continuous funding for operation, maintenance and calibration, which can be challenging for industries in India. Moreover, investing in adequate training and capacity building programs for operators and technicians constitutes another financial burden for industries seeking to establish effective and reliable CEMS implementations. Addressing these financial challenges is crucial for successful CEMS adoption and environmental compliance in India (Greenstone et al., 2020).

Small-scale industries that are vital to the progress of the country account for more than 40% of the gross industrial value added of the Indian economy and contribute significantly to employment generation and rural industrialization (Shylaja, 2014). However, small-scale industries faced problems when trying to install CEMS. These challenges included a lack of awareness about CEMS benefits, high installation costs, issues with data accuracy and inadequate infrastructure like power and internet connectivity. Non-compliance with pollution control guidelines was also common due to weak enforcement. Industry associations and stakeholders were resistant to CEMS adoption due to fears of increased regulations. These challenges made it difficult for small-scale industries to accept CEMS technology and meet environmental standards (ED, 2018; YAL, 2019; JETIR, 2020).

The questionnaire based industrial survey data identified that the most common challenge in installing CEMS is the high initial investment and maintenance costs, mentioned by a significant majority of respondents. The lack of clear regulatory guidelines and standards is another obstacle. Additionally, a notable number of respondents cited a lack of technical expertise and support as a challenge. Some respondents face a combination of these challenges, highlighting the complexity of CEMS installation issues. Addressing these challenges may require a multifaceted approach, including cost reduction strategies, improved regulatory guidance and investments in training and technical support for CEMS implementation in the industry.

The survey conducted by Directorate of Environment (DoE) also shows that most respondents (87.5%) are aware of the capital costs of CEMS installation in their industries, indicating good financial knowledge. However, about 12.5% are not aware, possibly due to varying roles in organizations. This suggests a need for internal communication and training to bridge this knowledge gap. The data underscores the importance of educating all stakeholders on these costs for informed decisions in emissions monitoring and compliance (Figure 11A-B).



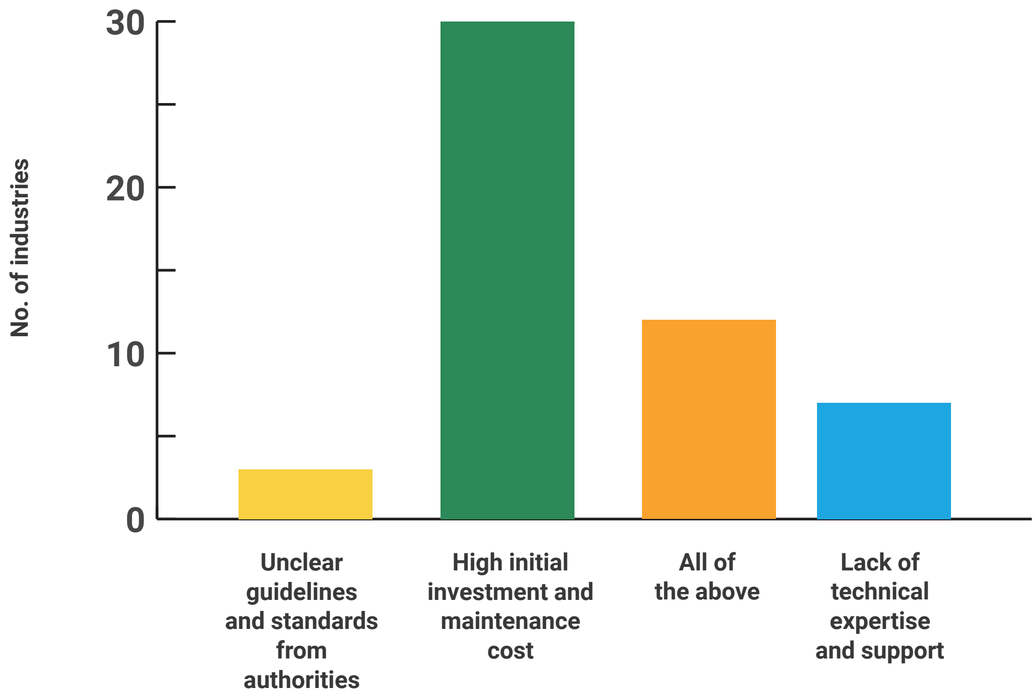


Figure 11A: Challenges faced by industries in installing CEMS

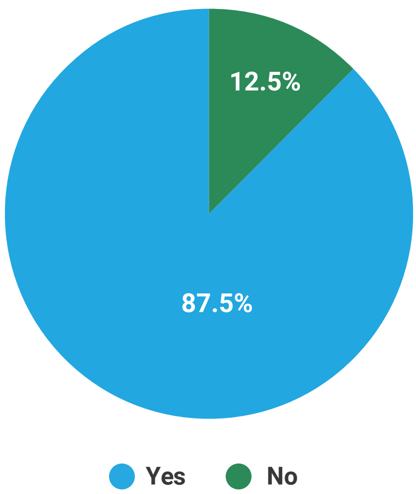


Figure 11B: Information about capital cost for CEMS

5.2 CEMS Installation, Operation, Maintenance and Calibration

The major challenge in CEMS installation is the technology selection such as the appropriate sampling method and analyzer technique for the specific pollutant and source. Each technique has its own principle of operation, range of detection, accuracy, precision, response time, calibration frequency, etc. Therefore, the selection of the analyzer technique depends on the type and concentration of the pollutant to be measured, as well as the performance requirements of the CEMS. The other challenge is the determination of the optimal sampling location and number of measurement points in the stack. The sampling location should be representative of the average emission concentration and flow rate of the source and should avoid areas where there are turbulence, stratification, leakage or dead zones. The number of measurement points depends on the size and shape of the stack, as well as the variability of the emission concentration across the cross-section (USAID, 2020; CSE, 2022a; DoE, 2023).

Successful CEMS implementation relies on standardized procedures and the quality of data generated. For that purpose, a code for empanelled laboratories is mandatory for the proper regulation of CEMS in India. CPCB is formulating a code of conduct or a set of guidelines for the laboratories that are involved in the installation, operation, maintenance and calibration of CEMS. However, without a code of empanelled laboratories, there is no uniformity or consistency in the way the CEMS are operated, maintained and calibrated. This can affect the quality and reliability of the emission data and lead to errors and discrepancies. Therefore, the CPCB must develop a code of empanelled laboratories that specifies the criteria, procedures and responsibilities of the laboratories that are engaged in the CEMS activities. The code of empanelled laboratories should also define the roles and functions of the CPCB, the State Pollution Control Boards (SPCBs) and the Pollution Control Committees (PCCs), third party verification agencies in overseeing and verifying the CEMS performance. The code of empanelled laboratories should be based on the best practices and standards available in the field of CEMS and should also be periodically reviewed and updated to incorporate the latest developments and innovations. CPCB in 2019 already designed the "Draft Proposal for Empanelment of Laboratories for CEMS Related Activities" for laboratory empanelment in India for (CEMS) related activities which are still under process.

Until the proper empaneled laboratories are not established by CPCB, for various CEMS-related tasks including testing, installation, operation, calibration checks and third-party verification, international standards for empaneled labs (ISO 17025) should be followed.

The main challenge in CEMS operation involves ensuring the quality assurance and quality control (QA&QC) of the data generated by the system. The calibration cost of CEMS is highly variable, often expensive and time consuming. This is primarily due to the distance of the calibration lab from CEMS installations. Many of these labs lack accreditation from the National Accreditation Board for Testing and Calibration Laboratories (NABL), which limits their credibility. As a result, calibration costs can vary, lacking standardization. Furthermore, in many industries, there is a lack of regular checks and periodic calibration, which contributes to the data generated by CEMS not being as authentic and reliable as desired. (DoE, 2023).

A systematic audit process, including evaluations like cylinder gas audits (CGA), linearity tests and relative accuracy test audits (RATA), which serve to validate the accuracy and reliability of CEMS, is notably absent. On the maintenance front, there is a lack of trained personnel, particularly those with the requisite training or certification to manage complex or specialized CEMS. Some maintenance personnel also encounter difficulties in accessing or diagnosing CEMS due to their location or intricate configurations (DoE, 2023).

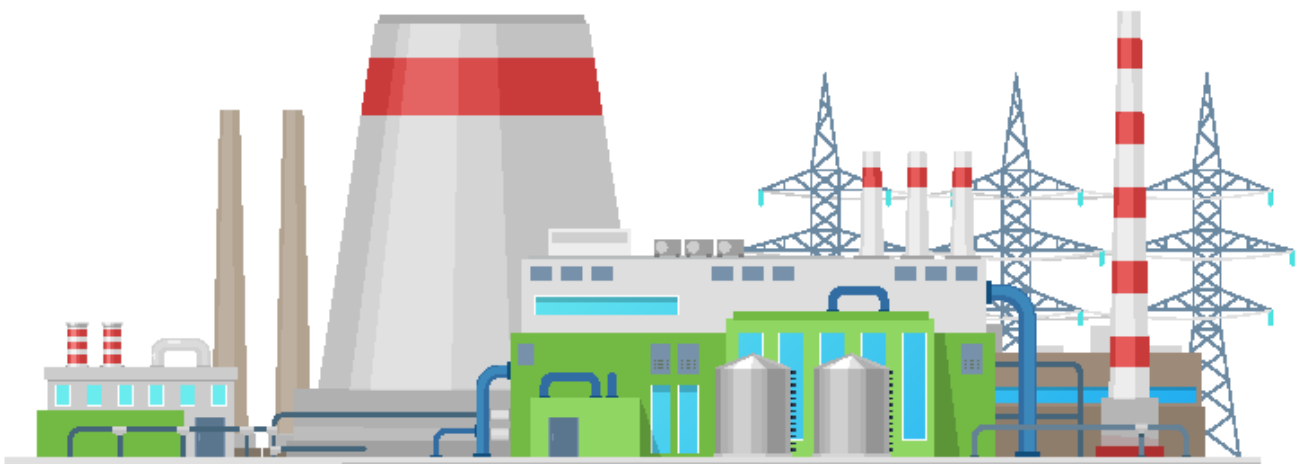
There is a lack of standardization and certification of CEMS devices and technologies in the type, quality and performance used by different industries. There is also no accreditation or certification system for CEMS devices and technologies in India. This leads to difficulty in selecting, installing and operating suitable CEMS devices for different emission sources and pollutants (CSE, 2022b).

During the stakeholder discussion held under this research, it was identified that local vendors are deceiving industries. They do this by selling sensor-based devices that are not officially approved by the CPCB. These vendors make false claims that their devices adhere to CPCB standards. In reality, however, these devices lack the essential qualities of reliability, accuracy and durability. This results in, these devices often falling short of meeting emission standards, leading to the wastage of resources, money and time for the industries.

Inadequate facilities for auto calibration, zero check and span check of CEMS devices pose another challenge because calibration is the process of adjusting the CEMS device to ensure that it measures the emission accurately. Zero check and span check are methods of verifying the calibration of the device. However, many industries do not have proper facilities or equipment for auto calibration, zero check and span check of their CEMS devices. This affects the data quality, compliance and enforcement of CEMS in India (DTE, 2022).

The high operation and maintenance costs of CEMS devices continue to challenge industries. Regular maintenance, cleaning and replacement of parts and consumables are essential for maintaining optimal device performance. These activities come at a significant cost, particularly for industries with numerous emission sources and pollutants to monitor. Moreover, CEMS devices are exposed to corrosive gases, vibration and high temperatures that can damage them over time (Greenstone et al., 2020).

The limited utilization of CEMS data for decision-making is a prevailing issue. This data holds the potential to offer valuable insights for both industries and regulators in their efforts to monitor, control and mitigate emissions. Unfortunately, there exists a deficiency in the analysis, interpretation and feedback mechanisms necessary to harness CEMS data for effective decision-making. Furthermore, there's a lack of data transparency and public disclosure, which hinders the promotion of awareness and accountability among stakeholders. The main challenge towards this is the data validation due to the lack of a robust CEMS ecosystem that includes periodic calibration and proper operation and maintenance (DoE, 2023).



The questionnaire-based survey on operating and maintaining CEMS in industries done by DoE, revealed key concerns among respondents. A significant number highlighted technical issues about sampling, analysis and data transmission challenges, emphasizing the complexity of emissions monitoring technology. Operational problems, including power supply, safety and accessibility, also occurred as significant hurdles that directly impact CEMS reliability. Regulatory issues, such as compliance and reporting, underline the importance of staying up-to-date with evolving environmental standards. Notably, many respondents faced a combination of these challenges, suggesting a wide array of problems in effective CEMS management. When assessing employee training for CEMS, 82.1% of respondents confirmed their employees received training, while 17.9% reported no training. This diversity in training approaches within surveyed industries suggests some are well-prepared for regulatory compliance and accurate emission data, while others require more attention to ensure proper employee training for CEMS operation and maintenance (Figure 12A-B).

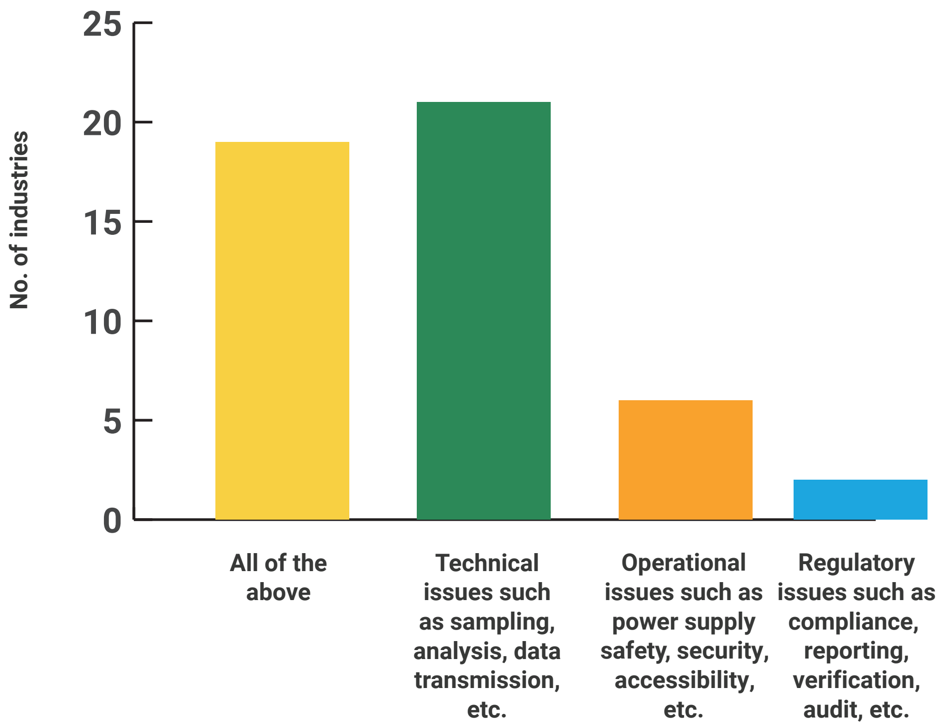


Figure 12A: Challenges in operating and maintaining CEMS

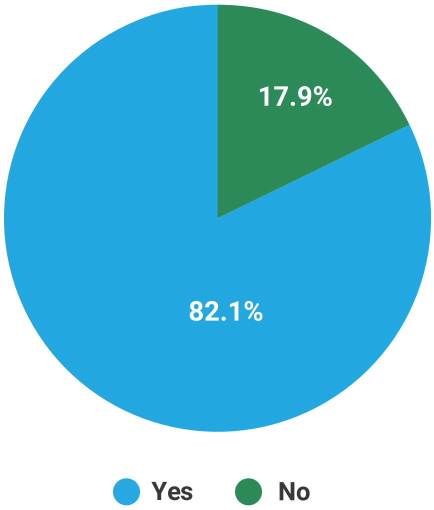


Figure 12B: Employees training for CEMS operation and maintenance

In the survey, it was examined that how industries calibrate their CEMS devices. The study shows that most industries, nearly all of them, prefer to use calibration services offered by labs or vendors. This means they hire experts from outside to make sure their CEMS devices are accurately calibrated. It's the common choice among the surveyed industries. Interestingly, there was one company that said they do their calibration in-house. This suggests that only a few industries have the resources and know-how to do calibration internally, giving them more control over the process. The fact that most industries rely on external calibration services shows that they trust the expertise and precision of these specialized service providers. It also shows that calibrating CEMS devices is a complex job that needs special equipment and knowledge. This study investigates whether industrial facilities using CEMS have calibration experts nearby or not. It was found that 37.5% of these facilities do have local calibration experts, offering convenience and potentially calibration services. However, 48.2% of the respondents do not have calibration experts nearby, which means they may need to rely on experts from a more distant location. Interestingly, 14.3% of the respondents were uncertain about the presence of nearby calibration experts, suggesting a lack of awareness about local calibration services. To understand opinions about having a calibration facility nearby the industries will help for calibration of CEMS or not. A large majority (87.3%) expressed a strong belief in the benefits of proximity to such a facility, while a smaller group (12.7%) disagreed. This clearly underlines the need and potential advantages of local calibration services in enhancing the efficiency of emissions monitoring, data validity and regulatory compliance efforts, highlighting the value organizations place on convenient support for maintaining and optimizing their CEMS devices (Figure 13A-C).

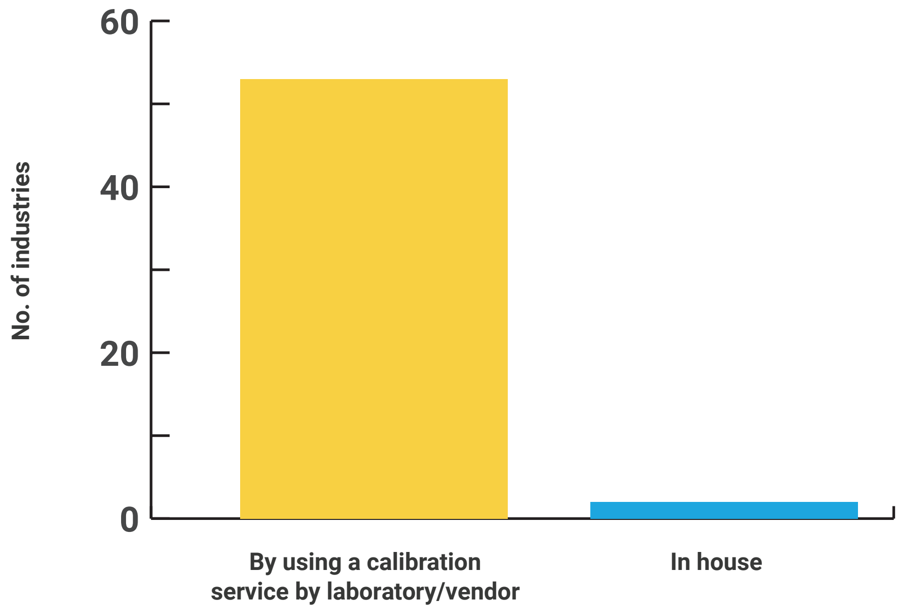


Figure 13A: Calibration of CEMS devices in industries

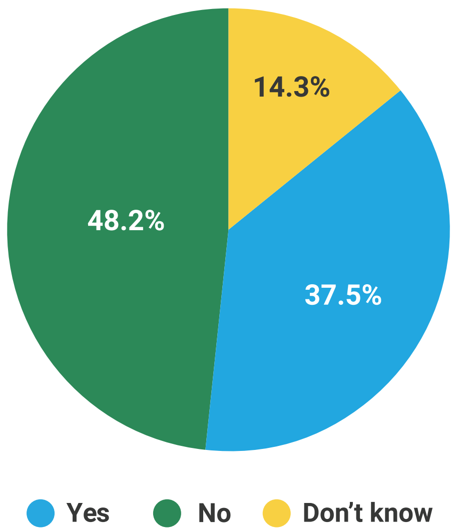


Figure 13B: Availability of calibration vendors in industrial vicinity

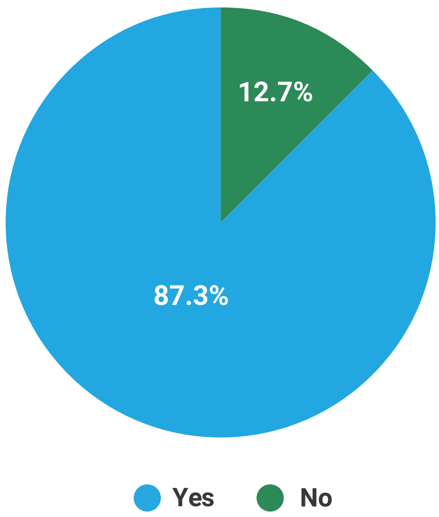


Figure 13C: Opinion on the presence of nearby calibration facility

5.3 Certification System

The regulations and certification systems for CEMS can vary between countries. Some countries have established formal certification systems, while others may not. In India, the formal certification system for CEMS quality assurance is being developed by the Council of Scientific and Industrial Research- National Physical Laboratory (CSIR-NPL). However, CPCB mandates the installation of CEMS in certain industries. Most CEMS instruments in India are imported and come with certification from recognized agencies such as United States Environmental Protection Agency (USEPA), Technischer Uberwachungs-Verein (TUV), or Monitoring Certification Scheme (MCERTS). The criteria for certification of CEMS instruments are determined by agencies like USEPA, TUV, or MCERTS. Certificates issued by these agencies indicate that the instruments meet specific standards and performance specifications. USEPA, TUV and MCERTS are globally recognized certification agencies for CEMS and their certified analyzers for emissions are acknowledged for use as CEMS. It is essential to note that any modifications to certified analyzers can invalidate the certification.

The CPCB guidelines in India specifically acknowledge the use of USEPA, TUV and MCERTS certified analyzers for emissions as CEMS. To ensure compliance with required standards, both domestic and foreign analyzer manufacturers must adhere to the CPCB guidelines. All manufacturers, regardless of their origin, must comply with these guidelines to ensure their instruments meet the necessary standards (CSE, 2022a). To implement CEMS effectively, it is essential to establish well-structured certification and quality assurance systems that guarantee the accuracy, reliability and comparability of data. Various countries have adopted distinct approaches to regulating CEMS installation, operation, maintenance and verification of data quality and compliance. India has faced specific challenges in adopting certification systems from these countries. The key characteristics, challenges associated with CEMS certification systems in different countries, are summarized in Table 5.

Table 5: Challenges faced by India in adopting certification Systems from different countries

Country	Main Features	Challenges	References
European Union (EU)	CEMS certification system based on EN-14181 standards. Three quality assurance levels (QAL 1-3) and annual surveillance test (AST). Independent testing and verification by accredited laboratories or notified bodies.	High cost and complexity of the certification process. Need for more guidance and training for operators and regulators.	CPCB, 2018; Greenstone et al., 2020; DTE, 2022; CSE, 2022a,b; DoE, 2023
United States (US)	CEMS performance specifications (PS) and quality assurance procedures (QAP) based on 40 CFR Part 60 and 754. Relative accuracy test audit (RATA) and relative accuracy audit (RAA) for data quality verification. Data validation by electronic reporting tool (ERT) or continuous emission monitoring system data acquisition and handling system (CEMS DAHS).	High cost and complexity of performance testing. Lack of consistency and transparency in data validation. Limited availability of qualified auditors or testers.	
Germany	CEMS certification system based on DIN EN 15267 standards. Annual quality assurance tests and data validation. Emissions data submitted to the Umweltbundesamt (UBA) for evaluation.	High cost and complexity of the certification process. Limited availability of designated testing facilities.	
United Kingdom (UK)	Environment Agency's Monitoring Certification Scheme (MCERTS), which aims to deliver quality environmental measurements. The MCERTS product certification scheme provides for the certification of products according to the Environment Agency's performance standards, based on relevant CEN, ISO and national standards. The process consists of three phases: laboratory testing, field testing and surveillance	Low quality and reliability of CEMS devices. Lack of consistency and transparency in data validation. Limited availability of qualified third-party testing agencies.	

In developed countries such as EU and USA, CEMS certification systems have been established for decades and have proved to be effective in regulating emissions and improving air quality. These countries have well-framed certification and quality assurance systems of devices, extensive testing and verification of devices by independent agencies having defined roles, responsibilities and guidelines for all the stakeholders involved in CEMS implementation.

On the other hand, no CEMS certification system in India are available that is why most of the CEMS devices are certified by certification systems of the other countries and when they are functional in Indian environment condition, CEMS devices face various kinds of issues which are summarized in Table 6.

The certification systems of other countries, such as Europe and USA, may not be suitable for India, as they are based on different assumptions, standards and regulations. Figure 14 summarizes some of the problems that Indian industries may face and indicates why India urgently needs to develop its own CEMS certification system that is personalized to its specific needs and challenges.

Table 6: Problem faced by Indian industries to avail the certification system of the USA and EU

Country	Certification System	Problems in India	References
Europe	EN-14181 standards and MCERTS or TUV schemes	The European standards and schemes are based on the environmental and climatic conditions of Europe, which may not be suitable for India. The emission limits, measurement methods, sampling techniques, etc. may vary depending on the type and size of the industry in India. The certification process is also complex and costly for Indian industries.	CSE, 2022 a,b; DoE, 2023)
USA	USEPA performance specifications and quality assurance procedures	The USEPA specifications and procedures are based on the regulatory framework and emission standards of USA, which may not be compatible with India. The performance criteria, test methods, data quality objectives, etc. may differ from the Indian requirements. The certification process is expensive for Indian industries.	

1 Lack of Certification Body

India does not have a designated certification body for CEMS products. The NPL was appointed by the MOEF&CC in 2019, but the certification system is still in the developing phase. This creates uncertainty and confusion among the industries and regulators about the quality and reliability of CEMS products.

2 Lack of Quality Assurance System

India does not have a comprehensive quality assurance system for CEMS performance. There are no defined roles, responsibilities and guidelines for testing, verification and calibration of CEMS devices. This leads to inconsistent and inaccurate data from CEMS devices that cannot be used for legal and compliance purposes.

3 Lack of Standardization

India does not have a uniform standard of CEMS devices that can be applied across different sectors and regions. The CEMS devices used in India are based on different standards for EU, USA, etc. that may not be suitable for Indian conditions and requirements.

4 High Cost and Maintenance

The CEMS devices used in India are mostly imported from EU, USA etc. that are expensive and require high maintenance. The industries have to bear the cost of installation, operation and maintenance of CEMS devices that may not be affordable or feasible for small and medium enterprises. Moreover, the availability of spare parts, technical support and trained personnel may be limited or lacking in India.

Figure 14: Summary of problems experienced by Indian industries in adopting CEMS

The questionnaire based industrial survey revealed that most respondents certified their CEMS devices under the globally recognized TUV system. Some used USEPA certification and a few had MCERTS certification, specific to the UK. It shows the importance of certification in ensuring accurate emissions data and environmental compliance. Certification systems used by industries are shown in Figure 15.

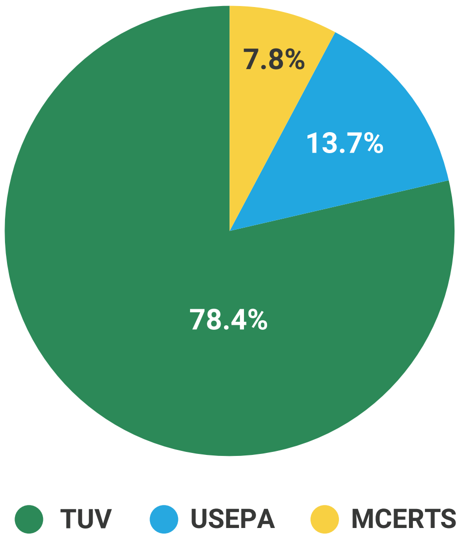
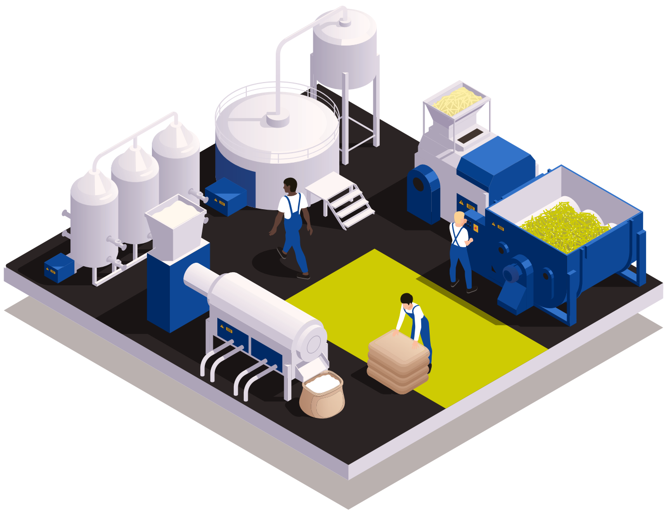


Figure 15: Certification System used by Industries for CEMS device

The CPCB mandated installation of CEMS in major industries and common pollution control facilities which have limited scope in view of CEMS quality assurance until an indigenous certification system is developed. This means that there is no guarantee that the CEMS devices installed in India are accurate, reliable and suitable for the Indian conditions. The functional mechanism for to check whether the CEMS devices are properly installed, operated, maintained and calibrated is also lacking due to the limited capacity of SPCB. This poses a serious challenge for the credibility of CEMS data and its use for regulatory and legal purposes.

5.4 Capacity Building

Industries in India face several challenges related to capacity building for CEMS. Many industries struggle to find and retain skilled personnel who can effectively operate and maintain CEMS equipment. The shortage of trained professionals can hinder the successful implementation of CEMS. The cost associated with setting up and maintaining CEMS may enhance in case trained manpower in the industries for operation and maintenance is not there. Industries may face financial constraints in acquiring the necessary equipment and training their staff, which can be a significant challenge. Collecting, managing and analysing the data generated by CEMS also requires capacity building. Industries require a suitable data management systems and foundational and refresher trainings of personnel to make use of the CEMS data for decision-making to improve compliances. Industries need to carefully select reliable vendors and maintain a strong working relationship with them. Some industries may be hesitant to handle the operation and maintenance of CEMS themselves due to the associated operational risks, when dealing with sensitive and expensive equipment. Moreover, relying on third-party vendors for CEMS support may be a challenge, as the quality of vendor services can vary. There may be a lack of understanding about the benefits of CEMS and the importance of real-time monitoring. Information, awareness and communication about the advantages of CEMS would be needed to overcome this challenge. Reliable power supply and internet connectivity are essential for real-time monitoring.



Integrating CEMS into existing industrial processes and control systems can be complex and require careful planning and expertise. Regular maintenance and calibration of CEMS equipment are crucial for accurate data collection. Industries may struggle with ensuring the ongoing upkeep of these systems (DoE, 2023).

The survey identified that methods used by industries in training and educating their staff on CEMS installation, operation and maintenance. The most commonly selected method for training staff on CEMS-related activities is in-person onsite/offsite training. A large majority of respondents indicated that they use this method, with some industries opting for both onsite and offsite training. In-person training is often considered effective for hands-on learning and is likely preferred for the technical and practical aspects of CEMS. Online courses represent another training approach chosen by a subset of respondents. While not as widely selected as in-person training, online courses offer flexibility and accessibility, making them a valuable option, particularly for remote learning. This blended approach ensures that employees have the practical skills and theoretical understanding needed to effectively work with CEMS. The survey also assesses whether industries have designated employees responsible for overseeing CEMS within their units or not. A majority of respondents confirmed that they have employees tasked with looking after CEMS within their units. Although a majority of industries have said that they have a person responsible for operation and maintenance of CEMS but the industries are yet to develop an understanding that a well capacitated and dedicated resource for CEMS operation and maintenance is required (Figure 16A-B).

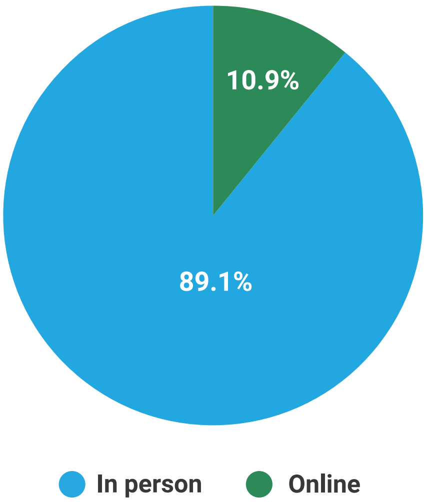


Figure 16A: Training and education practices for CEMS in industry

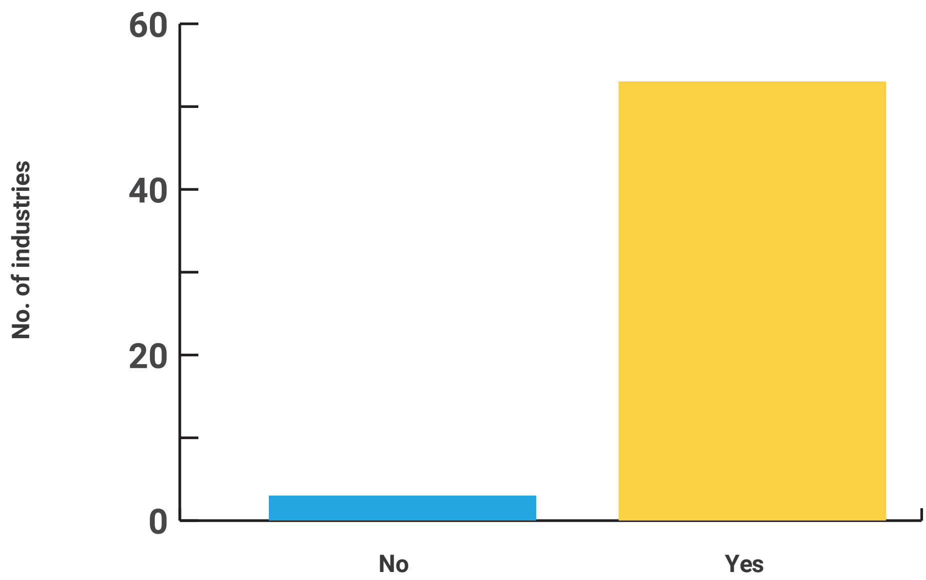


Figure 16B: Employment of staff for CEMS oversight

5.5 Data Acquisition Management System (DAMS)

Data acquisition is one of the major challenges for successful CEMS operations. This is because the CEMS must be fed with continuous data to detect changes in emission levels. Data must be collected from a variety of sources, including real-time and periodic readings. Additionally, the accuracy of the data must be verified, as it accurately affects all CEMS readings. Quality control is also a major challenge for CEMS implementation as the data must be validated to ensure accuracy and reliability. Quality control involves careful calibration of the system to ensure the accuracy and reliability of the readings. CEMS sensors are sensitive to environmental conditions and must be regularly monitored to ensure accurate and reliable data. The data must also be validated and checked for errors and any discrepancies must be resolved before the data is used. Quality control measures can be expensive, time consuming and labor intensive which can delay the availability of data (Eisenmann et al., 2014; CPCB, 2018). CEMS has developed a cost-effective solution to increase the frequency of data monitoring and improve enforcement of environmental regulations. In 2007, the Chinese government's Ministry of Ecology and Environment enacted a self-monitoring program that requires state controlled major pollution sources to operate with CEMS that manage more than 65% of the country's industrial pollution and are mandated to upload high-frequency CEMS data to the public online platforms (Wang et al., 2022). Despite significant investments and data collection, the utilization of CEMS data for local environmental law enforcement has been limited due to concerns about data quality. While some studies have emerged that utilize CEMS data to evaluate pollution reduction efforts, but few have explicitly discussed data quality. Technical issues such as unreliable data under irregular conditions and improper installation or calibration have been identified (Zhang and Schreifels, 2011). Furthermore, deliberate data manipulation by firms poses a significant concern, as evidenced by studies on air quality and CEMS data. To address these challenges, a comprehensive evaluation framework encompassing three data quality criteria: completeness, accuracy and authenticity. By applying this framework to key polluting firms in Henan province, China provides policy recommendations for improving CEMS data quality and enhancing its application in environmental law enforcement (Ghanem and Zhang, 2014; Ministry of Ecology and Environment, 2017).

CEMS needs to sample and analyze the flue gas stream continuously and representatively, which requires suitable sampling probes, transport lines, analyzers and calibration gases. The sampling and analysis methods should be compatible with type, concentration and variability of the pollutants and flue gas conditions. The sampling and analysis techniques should also meet the performance specifications and quality assurance requirements of the relevant standards and regulations. CEMS need to undergo regular quality control activities to ensure that they are operating properly and producing valid data. These activities include calibration checks, system audits, preventive maintenance, repair programs, spare parts inventory and record keeping. The frequency and procedures of these activities should follow the guidelines and protocols of the applicable standards and regulations (US EPA, 2022).

CEMS needs to have a DAHS that collects, processes, stores, and reports the emission data from the analyzers and other sensors. The DAHS should be capable of handling large volumes of data, performing data validation and correction, calculating emission rates and averages, generating reports and alarms, and transmitting data to external systems. The DAHS should also be secure, reliable, user-friendly and compliant with the data format and reporting requirements of the regulatory authorities (CPCB, 2017; FE, 2023).

However, CEMS quality assurance and quality control involves various technical, operational and regulatory challenges that need to be addressed properly to ensure the reliability and accuracy of the CEMS data in India.

Several critical issues exist in the context of CEMS in India. Primarily, due to the absence of a certification system for CEMS equipment and service providers, the reliability and accuracy of the data generated is undermined. Secondly, the lack of a standardized protocol for calibration, maintenance and audit of CEMS contributes to data inconsistency and incomparability. Furthermore, the absence of clear guidance on how to apply international standards such as EN 14181 and EN 16442 for QA & QC of CEMS creates confusion and ambiguity among stakeholders. Another concern is the lack of a robust data management system for CEMS data, which hinders the verification, validation and reporting of this critical information. Lastly, inadequate awareness and capacity among industry and regulatory bodies regarding the benefits and requirements of CEMS may impair the effective implementation and enforcement of CEMS practices in India (CSE, 2022a,b; Kanchan and Bahel, 2023).

In India, using systems to collect and manage data from emission monitoring systems (CEMS) comes with several challenges. These include making sure that the data works well with different systems, keeping the data safe and dealing with issues related to how the data is sent and shared. One of the major issues is maintaining the frequency of data transmission, as industries often fail to send data at the minimum desired level of 85% of their operation time. Data quality is also very challenging, as there are often missing or null values that arrive at the server. Data manipulation is another problem, as some instances have been reported by CPCB. Data science techniques can be deployed to identify and prevent such fraudulent or inaccurate data. Development of data science cells or data analytics teams is essential to properly analyze, monitor and validate data regularly. Development of algorithms that can detect data disruption is also needed (DoE, 2023).

The survey revealed how industries utilize CEMS data to enhance their operations. The majority of industries focus on optimizing emission control parameters, while many also use the data to identify and correct emission deviations and ensure continuous compliance with environmental regulations. A notable portion of respondents adopted a comprehensive approach that incorporates all of these strategies, highlighting the adaptability of CEMS data in improving environmental performance and regulatory compliance.

The survey revealed that how industries utilize CEMS data to enhance their operations. The majority of industries focus on optimizing emission control parameters, while many also use the data to identify and correct emission deviations and ensure continuous compliance with environmental regulations. A notable portion of respondents adopted a comprehensive approach that incorporates all of these strategies, highlighting the adaptability of CEMS data in improving environmental performance and regulatory compliance.

The survey investigated the methods employed by organizations to analyze CEMS data in their industrial operations, revealing that the most dominant approach involves using software or systems provided by CEMS vendors or providers. Many industries rely on these tools for effective data analysis. A significant number of respondents also indicated utilizing a combination of methods, implying a mix of vendor-provided software and additional tools or approaches. Additionally, a few organizations mentioned their use of self-regulation and in-house data analysis methods, representing the diversity of strategies used to extract valuable insights from emissions data.

The survey was meant to discover how industries secure the quality and reliability of their CEMS data and the findings reveal a multi-faceted approach. Periodic calibration, involving regular adjustments and verification of instrument accuracy, is a primary method. Additionally, many organizations state the importance of adhering to standard operating procedures and quality assurance protocols, which establish guidelines for data collection, maintenance and quality control. Notably, a significant number of respondents adopt a comprehensive strategy, selecting "All of the above," which suggests a combination of periodic calibration, adherence to Standad Operating Procedures (SOPs) and potentially other quality assurance measures.

The challenges faced by industries when it comes to utilizing CEMS data are multiple and include various aspects. One of the most prominent challenges is the lack of effective data interpretation or communication. This indicates that while data might be collected, industries struggle to derive meaningful insights or effectively communicate findings. Ensuring that data from CEMS systems seamlessly integrates into existing data infrastructure is another challenge. Compatibility issues can hinder the utilization of CEMS data. It's notable that many respondents selected "All of the above," indicating that they face a combination of these challenges in their industry. These challenges highlight the importance of not only collecting CEMS data but also investing in the necessary resources, expertise and technology to extract value from this data effectively (Figure 17A-D).

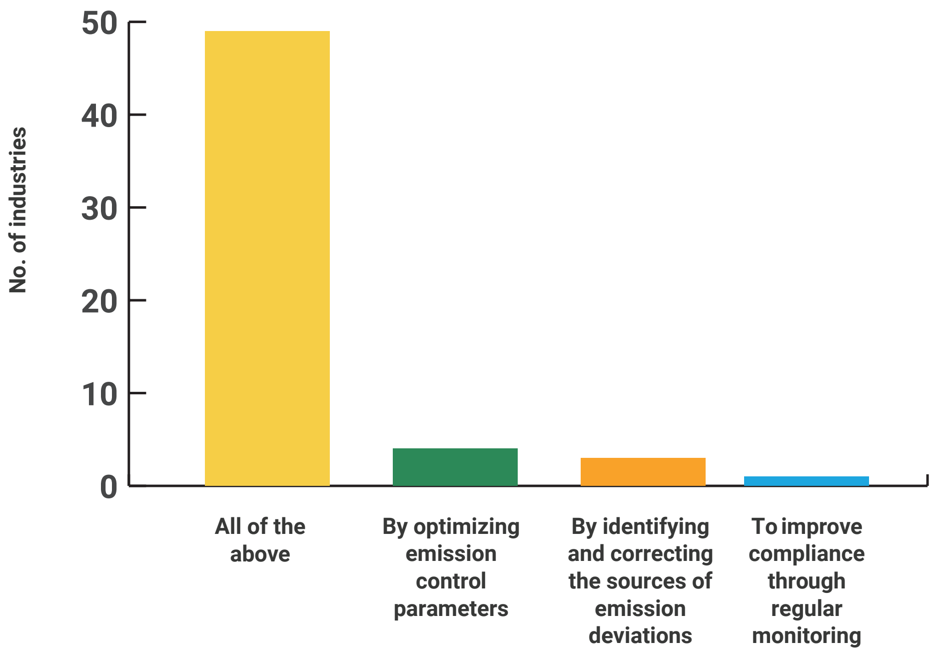


Figure 17A: CEMS data utilisation

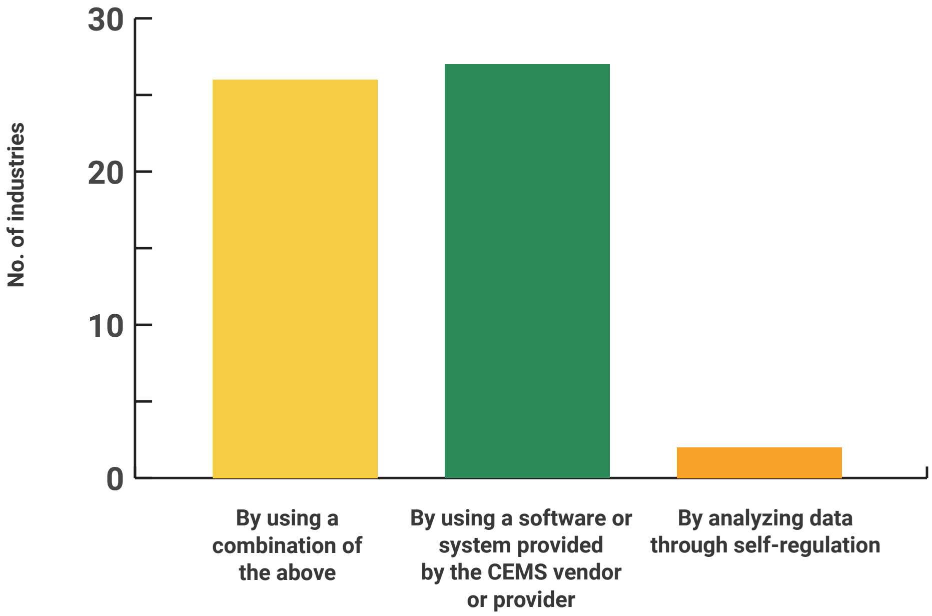


Figure 17B: Analysing CEMS Data in industry operations

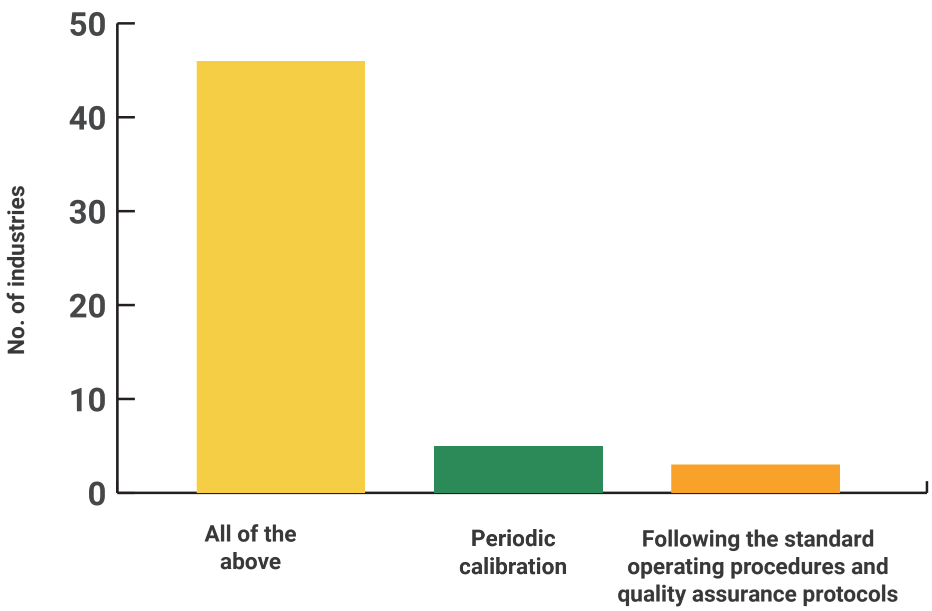


Figure 17C: Quality and reliability of CEMS data

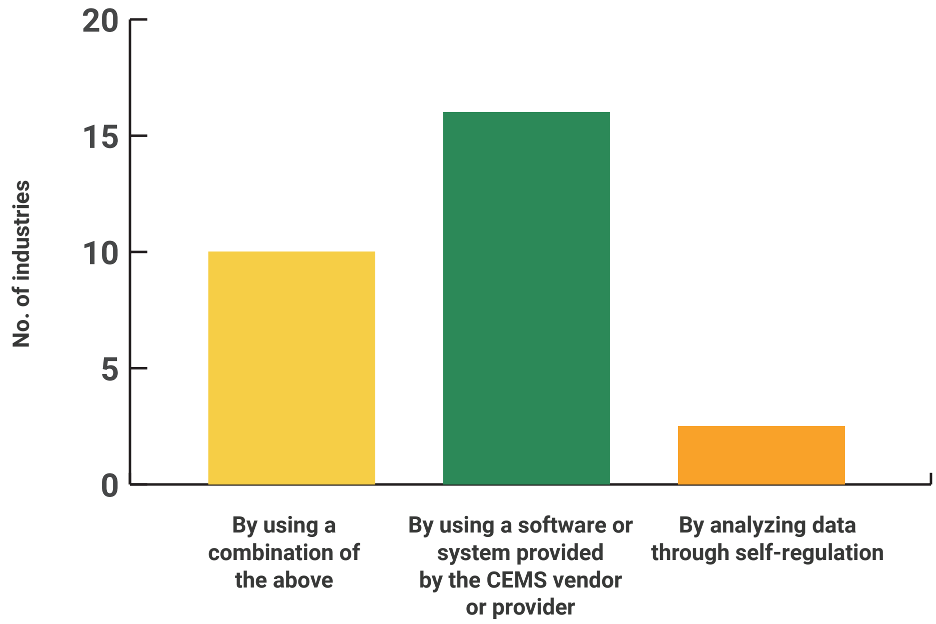


Figure17D: Challenges faced by industries using CEMS data

The survey provides valuable insights into how industries report and share their CEMS data with regulatory authorities. The majority of respondents reported that they utilize a data acquisition and handling system to report their CEMS data to the relevant authorities. This system likely serves as a sophisticated digital infrastructure for collecting, storing and transmitting emissions data. A substantial number of respondents also reported using both data acquisition and handling system as well as an offline approach, specifically through manual reports. This suggests that some organizations also prepare physical or electronic reports that contain CEMS data, which are submitted separately to the regulatory authorities.

Based on the responses to the survey question regarding problems related to the server of the CPCB, it is evident that some industries have faced issues, while others have not. Out of the total respondents, 18% of industries indicated that they have faced problems related to the CPCB server, while the remaining 82% reported no such issues. The types of problems reported by the minority of industries that faced server-related problems are primarily related to connectivity and network issues. Some respondents mentioned connectivity problems, which could imply difficulties in establishing a stable connection with the CPCB server. A subset of respondents specifically mentioned network-related problems, which could indicate that issues arise due to poor network conditions or occasional data transmission failures. It's worth noting that a few respondents provided additional context, mentioning that these issues occur "sometimes".

For the majority of industries that reported no server-related problems suggest that they have experienced a smooth and reliable interaction with the CPCB server. This is a positive sign, as it indicates the server's reliability and performance for a significant portion of respondents. The nature of the problems appears to be primarily related to connectivity and network challenges, which may require further attention and improvement to ensure seamless data transmission and communication with the CPCB server (Figure 18A-B).

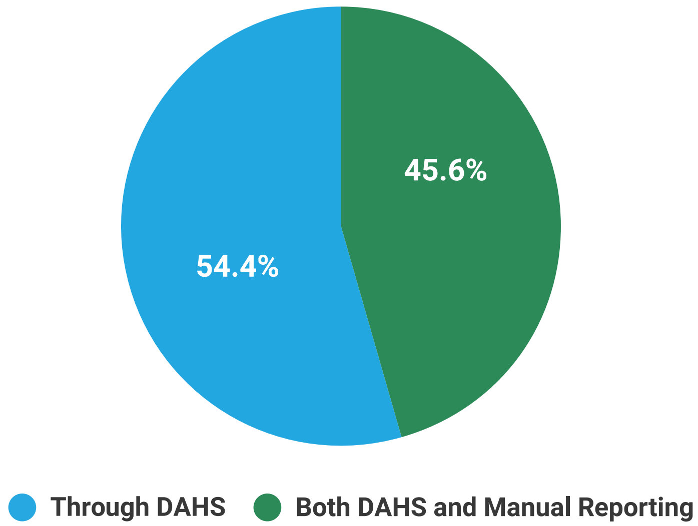


Figure 18A: Reporting and sharing CEMS data with the authorities

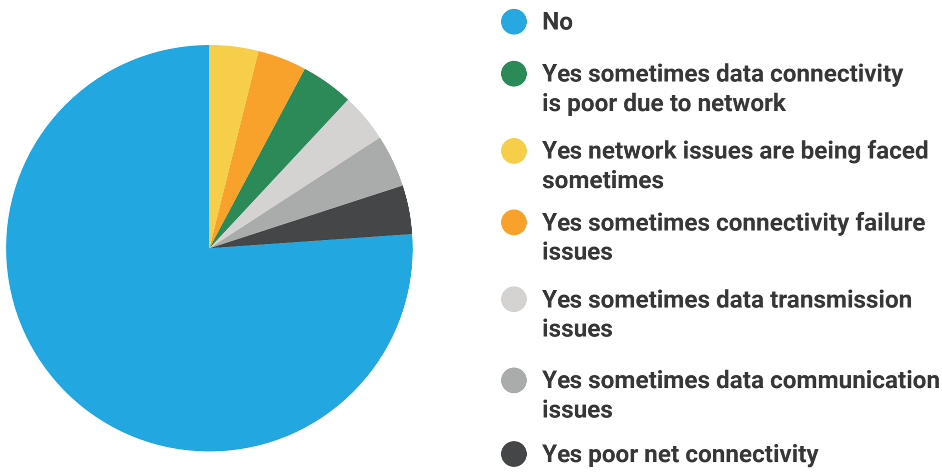


Figure 18B: Server related issues and feedback

5.6 Snapshots of Challenges in CEMS Ecosystems

The questionnaire-based survey and stakeholder consultation with CEMS experts under this research revealed that several key players are involved in the CEMS market in India and their roles in the adoption and monitoring system of CEMS. They are pioneers in technology and environmental responsibility, actively supporting pollution reduction and sustainable industry initiatives. However, despite the advancements, implementing CEMS in India faces multiple challenges. These issues of CEMS ecosystem are detailed in Figure 19.

Successful implementation of CEMS in India relies on the collective efforts of key players such as industries, regulators, vendors, service providers, manufacturers, researchers, etc., each fulfilling a vital role within the CEMS ecosystem. The structured role of these key players, their interconnections and the prevalent challenges they face when seeking to establish CEMS at ground level are as follows:

Industries encompass a broad spectrum of entities, from large corporations to small and medium-sized enterprises, constituting the primary users of CEMS. These organizations play a pivotal role in the deployment of CEMS to effectively monitor and regulate emissions. Regulators such as CPCB and SPCBs serve as regulatory authorities responsible for formulating, enforcing and overseeing regulations related to emissions monitoring. They are the custodians of standards and guidelines for the seamless implementation of CEMS. Certification Bodies are charged with the critical task of evaluating and certifying the performance and accuracy of CEMS equipment. In the Indian context, the National Physical Laboratory (NPL) is actively engaged in developing a certification system.

Manufacturers and suppliers of CEMS equipment and technology are the bedrock of CEMS infrastructure, supplying the necessary hardware and software for the accurate monitoring of emissions. Their role is instrumental in ensuring the reliability and precision of the monitoring process. Service providers offer services such as installation, maintenance and calibration of CEMS. Researchers and academic institutions are engaged in the advancement of knowledge and best practices in emissions monitoring. They contribute to research, training and the dissemination of expertise in the field.

The various key players within the CEMS ecosystem are interlinked, establishing a collaborative network essential for the successful implementation of CEMS. Industrial organizations depend on vendors for the procurement of CEMS equipment and may enlist service providers for installation and maintenance. Government agencies collaborate with certification bodies to uphold compliance to ensure that emissions monitoring adheres to established standards and guidelines. Researchers provide the knowledge and expertise crucial for effective CEMS implementation and continuous improvement. Lack of Certification of CEMS in India is a major challenge regarding the quality and reliability of monitoring equipment.

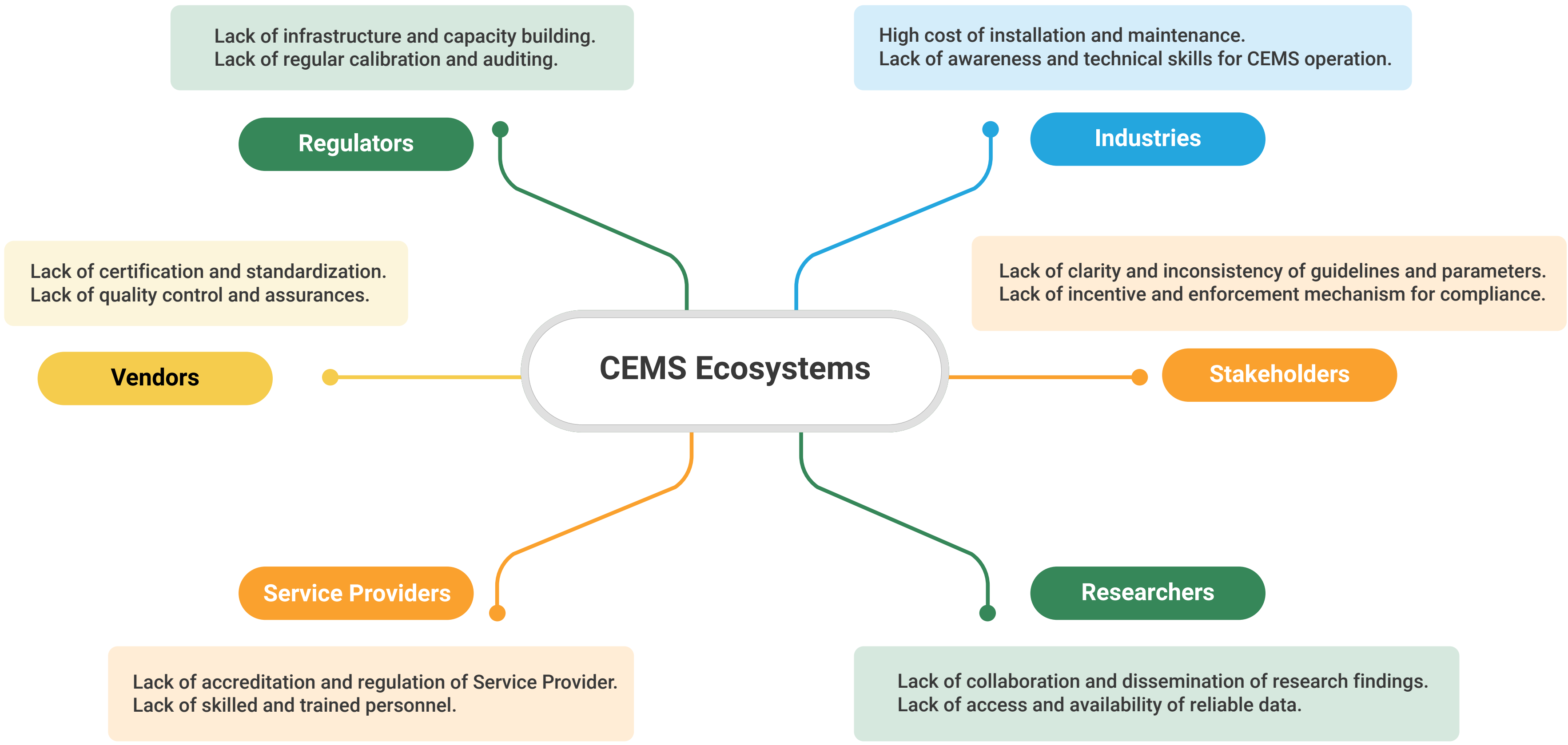


Figure 19: Snapshot of challenges in the CEMS Ecosystem

High Initial upfront costs involved in CEMS implementation, installation and training pose a substantial barrier, particularly for smaller industries. Lack of Standardization of uniform standards for CEMS devices in India introduces variations in emission limits, measurement methods and sampling techniques creating challenges in achieving compliance.

Infrastructure limitations associated with consistent power supply and internet connectivity can impair CEMS operation, especially in remote or underdeveloped areas. Regulatory loopholes and non-compliance of some industries may result in non-compliance with emission standards.

Similarly, the lack in the availability of accredited laboratories is another challenge in CEMS ecosystem. Accredited laboratories play a key role in the CEMS adoption by providing the necessary calibration, validation and certification services for the monitoring equipment. Their role is crucial in ensuring the accuracy, reliability and compliance of CEMS data. This shortage of accredited labs poses a challenge to the effectiveness of CEMS in ensuring environmental compliance and data accuracy. It implies that, without access to accredited labs, industries may face hurdles in obtaining the necessary certifications and validations for their CEMS equipment.

The collaborative efforts of the key players within the CEMS ecosystem in India, including industrial organizations, government agencies, certification bodies, technology providers, service providers, research and academic institutions are instrumental in addressing the challenges and hurdles faced in the effective implementation of CEMS (DoE, 2023).

6. Opportunities for Reforming CEMS Sector

6.1 Strengthening Policy Frameworks

Although CPCB has mandated CEMS installation in certain industries through a regulation but a policy to support CEMS adoption that deals with the whole ecosystem is lacking in India. To implement CEMS properly in India, a clear and comprehensive policy framework addressing the challenges in complete value chain is required. This policy should be developed with the participation and cooperation of various stakeholders and address the technical, legal and financial aspects of CEMS. It is important that all industrial units (17-categories of industries as per CPCB guideline), especially those within designated industrial clusters, must install duly certified CEMS and operate and maintain CEMS as per the guidelines through a completely transparency in data sharing. This requirement ensures that emissions are accurately monitored and reported, promoting environmental responsibility and compliance.

To further enhance the effectiveness of CEMS, the establishment of a domestic certification system is crucial. This certification system should be recognized by regulatory authorities and ensure that CEMS data adheres to the highest standards of accuracy and reliability.

After certification protocols have been developed by CSIR-NPL, a state of the science laboratory is needed for product certification at national level. Each industrial cluster should have a dedicated CEMS laboratory equipped to calibrate the CEMS equipment. Each dedicated CEMS laboratory for calibration should be National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited (preferably empanelled with NPL). This laboratory infrastructure will facilitate the accuracy and reliability of emissions data, essential for real time monitoring of the stacks and will pave the way for its use for regulatory compliance.

The implementation gaps identified in this study have been addressed by the suggestions and solutions proposed by the stakeholder consultation with CEMS experts. To overcome or fill the gaps for the CEMS implementation, this research suggested solutions that are presented in Figure 20. These solutions can help resolve the issues related to the policy gaps shown in Figure 10.

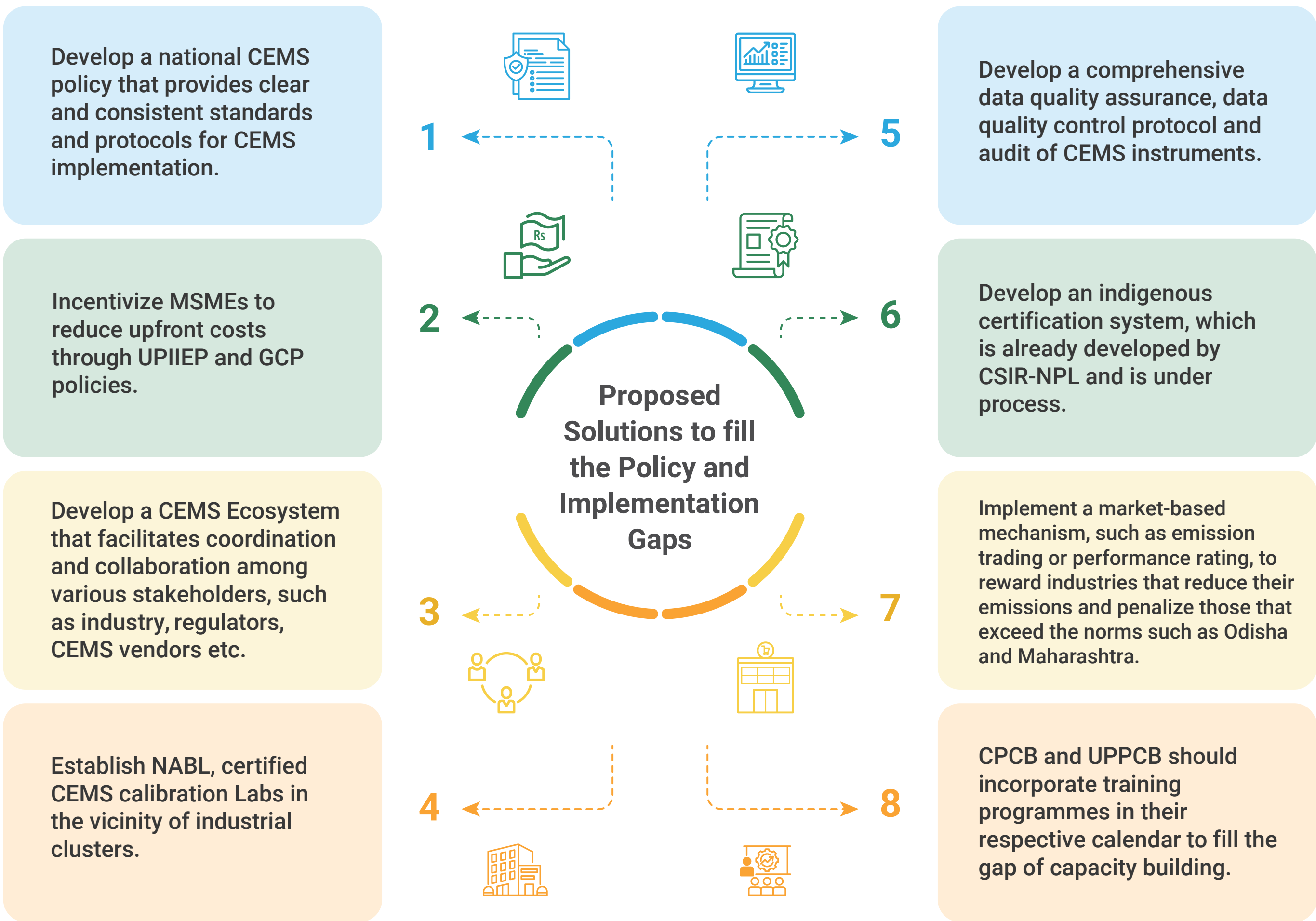


Figure 20: Proposed Solutions to fill the Policy and Implementation Gaps

6.1.1 Skill Development

The operation and maintenance of CEMS require specialized skills. To address this need, we propose the development of 'Green Skilled Workforce' linked with Skill India Mission.

The Government of India (GOI) launched the Skill India Mission, a skill development initiative scheme that aims to enable Indian youth to take up industry-relevant skill training that will help them in securing a better livelihood. Under this mission, the Pradhan Mantri Kaushal Vikas Yojana (PMKVY) is a flagship scheme that provides grants for training and certification of various personnel. A module can be developed for CEMS training which can be registered under the PMKVY scheme to avail the grant (PMKVY, 2023). This can help to fill the gaps in proper management of CEMS operation and maintenance with the help of the following steps:

- States will conduct their skill gap assessment for CEMS with the help of professional agencies and academic institutions. They can also seek technical support from National Skill Development Corporation (NSDC) and Sector Skill Council (SSCs) in designing this gap assessment.
- Then, SSCs will design a standard curriculum and resource material for CEMS training that is aligned with the National Skills Qualification Framework (NSQF), defining the eligibility of the individuals undergoing the training. Table 7 summarizes the suggested criteria to be considered for eligibility and course certification for CEMS by SSCs for the individuals undergoing the CEMS training:
- SSCs are mandated to conduct training of trainers (ToTs) for certification of trainers. Any established Training Institutes of repute (Govt. Institutions/ Govt. Universities/Industry partners), identified by SSC to conduct ToT/ToA may get an exemption from accreditation and affiliation process, as per discretion of the SSC.
- The training experts of CEMS or training provider (TP) will register themselves on the Skill Management and Accreditation of Training Centre (SMART) portal and submit the proposal for CEMS training under the Short-Term Training (STT) component of PMKVY 4.0 scheme and provide their details of training centre, trainers, infrastructure, equipment, target beneficiaries and expected outcomes. The proposal will be evaluated by NSDC or State Skill Development Mission (SSDM), depending on whether the trainer is applying for the Centrally Sponsored Centrally Managed (CSCM) or the Centrally Sponsored State Managed (CSSM) component of the scheme. Provide details about your organization, training infrastructure, trainers, courses, etc. and pay a registration fee. They will also have to undergo a due diligence process by NSDC or SSDM to verify your eligibility and quality standards.
- Then the proposal for training module of CEMS will be approved by Ministry of Skill Development and Entrepreneurship (MSDE) and the trainer will be allocated targets/ funds for CEMS training under PMKVY 4.0 scheme.
- Trainers will conduct the CEMS training as per the approved curriculum and training schedule by MSDE. The responsibility of assessment and certification of the candidate lies with SSCs and will be facilitated by NSDC.
- Later the trainers will submit the claims and reports to NSDC, as per the prescribed format. They need to provide evidence of the training delivery, assessment, certification, placement and post-placement outcomes. They will receive the grant as per the fund disbursement mechanism of the scheme, based on the verification of claims and reports by the Project Management Agency (PMA) (PMKVY, 2023; MSDE, 2023). The training program of CEMS under Skill India is shown in Figure 21.

Table 7: Number of Trained Personnel required for Installation, Operation, Maintenance and calibration of CEMS

S. No.	Number of personnel required		
	Vendor	Industry	Calibration Lab
1	For Installation, Operation and Maintenance Eligibility: ITI in IT and Electronics System Maintenance	For Technology Selection and Monitoring Eligibility: ITI in IT and Electronics System Maintenance	For Calibration Eligibility: ITI in IT and Electronics System Maintenance

Why CEMS Training?

There is a huge demand for trained personnel for operation and maintenance of CEMS in India.

1. Skill Gap Assessment

States will conduct their skill gap assessment with the help of professional agencies and academic institutions

2. Curriculum Development

Sector Skill Council (SSC) will design a curriculum for CEMS training

3. Submission of Proposal

Trainer will register on SMART Portal and submit proposal for CEMS training under PMKVY 4.0

4. Fund and Support

Trainer will receive target/funds for CEMS training under PMKVY 4.0

5. Conduction of Training

Trainers will conduct the CEMS training as per the CEMS training as per the approved curriculum by MSDE

6. Grant Disbursement

Submit claims and reports and receive grant for CEMS training by NSDC

Figure 21: Snapshot of Training Program of CEMS under Skill India

6.1.2 Innovative Financing Models

To overcome the financial gaps related to capital cost, operation, maintenance and calibration etc. firstly the capital cost of CEMS can be reduced by taking advantage of economy of scale. The economy of scale refers back to the cost benefits that arise while the manufacturing of a product or service increases. In the case of CEMS, the cost per unit can be reduced by growing the number of devices produced. This may be accomplished by encouraging greater industries to adopt CEMS that can help to grow the demand for emission tracking equipment and cause lower costs. Another way to make CEMS more feasible is to keep in mind the total cost of the ownership. The overall cost of ownership consists of the preliminary value of buying and installing a tracking device, as well as the ongoing expenses of operation, calibration and maintenance including the cost incurred for manually tracking the emissions and that for non-compliances. The cost incurred in non-compliances may include losses owing to closure of the production, legal cost etc. that arises out of enforcements by the regulators for non-compliances. The industries could take informed decisions about maximum cost-effective monitoring answers. Innovative financing models can also help to make CEMS low priced eg. Public-Private Partnerships (PPPs) can be set up to share the cost of imposing CEMS. The government can offer incentives to industries that adopt CEMS, together with tax credits or subsidies. The implementation of CEMS in India has been tough because of various financial factors. However, taking advantage of the financial model of economy of scale, considering the total cost of ownership and exploring innovative financing models, the cost of CEMS may be decreased (3ie, 2020; CSE, 2016; Mongabay India, 2018).

Lowering the cost of CEMS by demand aggregation is another strategy that can help reduce the cost of installing and operating CEMS for small scale industries. It involves pooling the demand and resources of multiple industries that want to invest in CEMS and leveraging economies of scale to negotiate better prices and terms with the suppliers and service providers of CEMS technology. It can also help create a network of industries that can share best practices and learn from each other's experiences with CEMS. In addition to this, providing capital subsidy will also enable the development of a platform for providing financial incentives. Some examples of cost lowering by demand aggregation are:

- The Gujarat Pollution Control Board (GPCB) has initiated a pilot project to install CEMS in 55 small and medium enterprises (SMEs) in the chemical sector in Vapi, Gujarat. The project involves creating a consortium of SMEs that can collectively procure, install and operate CEMS with the help of a third-party agency (GPCB, 2023).
- Centre for Science and Environment (CSE) has launched a stakeholder initiative to facilitate the adoption of CEMS in India. The initiative provides a common platform for the industries, regulators, device manufacturers and service providers to share their experience and discuss on the challenges and solutions for CEMS installation and operation. The initiative also helps in creating demand aggregation among the industries that want to invest in CEMS and connecting them with the suppliers and service providers of CEMS technology (CSE, 2017).

Policy interventions like the UP Industrial Investment and Employment Promotion Policy (UPIIEPP), 2022 and the Green Credit Programme (GCP) could offer subsidies and incentives to support expenditures on CEMS in Greenfield projects. The UPIIEPP (2022), launched by the Government of Uttar Pradesh, aims to make the state a one-trillion-dollar economy by 2030. It is an umbrella policy that provides a strategic framework for the sustainable industrial development of the state over the next five years. The policy aims to attract investments, create employment opportunities and promote sustainable and inclusive growth. The policy also provides for incentives on investment in installation plant for pollution control measures, including disposal of emission or gaseous hazardous waste as eligible investment under Plant and Machinery head of Capital Investment.

Therefore, UPIIEPP (2022), could provide support for installation of CEMS by extending some of these incentives and subsidies to the industries that invest in CEMS technology and demonstrate their environmental performance and compliance.

The GCP can be leveraged to recover capital expenditure and operational costs for these industries. It is a market-based mechanism that aims to incentivize voluntary environmental actions by various stakeholders, including industries. The program covers eight sectors, including air pollution reduction and allows participants to earn tradable credits for compliance with pollutant emission standards. Green Credits will be made available for trading on a domestic market platform and activities generating Green Credits may also receive Carbon Credits (GCP, 2023). The Green Credit Program is shown in Figure 22.

In addition to existing practices, the installation of CEMS can be considered for base lining the emissions/air pollution and its tracking after the best practices have been adopted by the industry so that authentic and validated Green Credits may be generated. Thus, CEMS may be utilized not only to generate the Green Credits but also to validate it. This research has proposed specific methodologies for CEMS, as depicted in Figure 23.

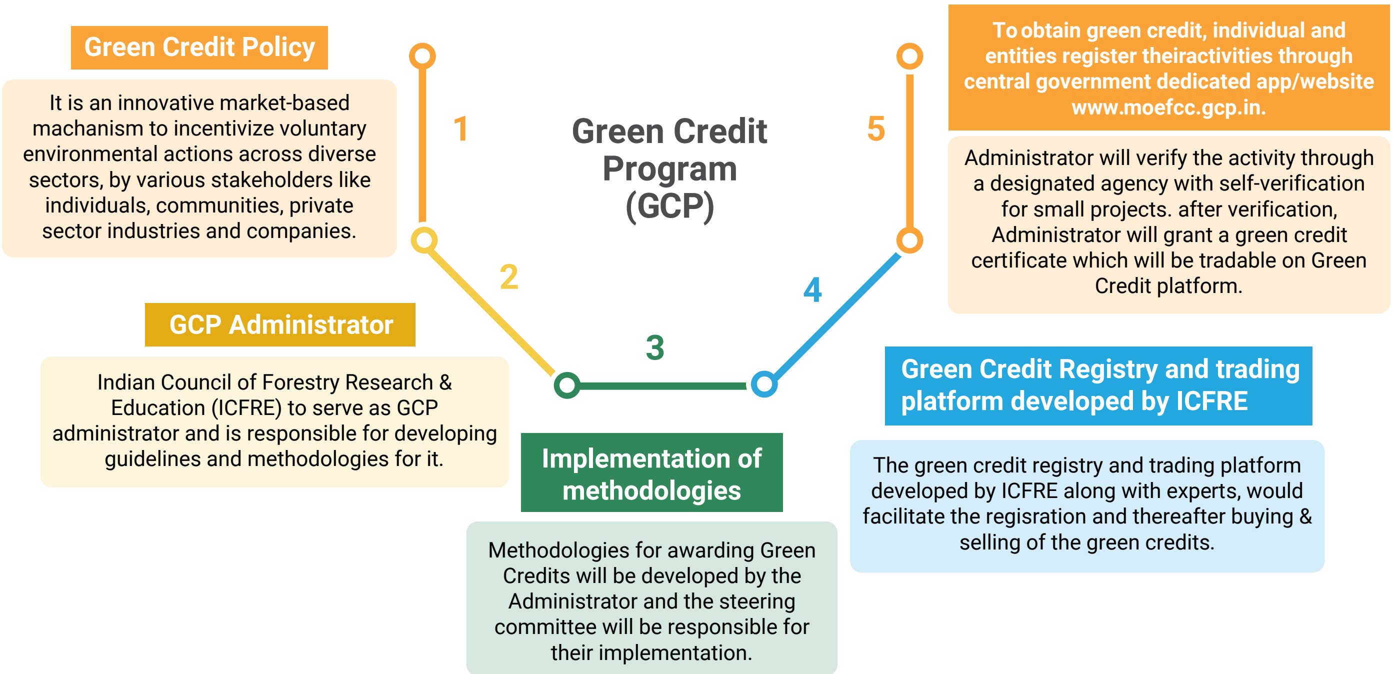


Figure 22: Green Credit Program (GCP)

1. Include CEMS installation as an eligible activity and develop specific methodologies

To boost CEMS adoption by industries, make CEMS installation and operation part of the Green Credit Program. Collaborate with experts and stakeholders to create transparent methods for calculating Green Credits, consisting of emission reduction potential, accuracy and CEMS scale.

2. Benchmarking of Industrial Emissions

Establish emissions benchmarks for generation of green credits so that the environmental impact is accurately assessed.

3. Promote Awareness and Capacity Building

Launch an awareness campaign to inform industries about the benefits of CEMS installation, including regulatory compliance and sustainability. Provide capacity-building programs and resources to help industries understand the installation process.

4. Market Stability Mechanism

Administrator should also develop guidelines for a market stability mechanism for the trading of CEMS-related green credits.

5. Role of Steering Committee for leveraging CEMS in GCP

Engage inter-ministerial Steering Committee to provide support for CEMS installation as a priority within the Green Credit Program. The committee can help in crafting policies and incentives that align with the program's objectives and ensuring that CEMS installations are audited regularly by independent auditors.

6. Collaboration with Industry Associations

Collaborate with industry associations and organizations to promote CEMS adoption.

Figure 23: Suggestions for incentivizing industries to install CEMS using the GCP

6.1.3 Certification System and Quality Control

To tackle the problems related to the certification system, India needs to establish its own CEMS certification system which is being developed by Council of Scientific and Industrial Research- National Physical Laboratory (CSIR-NPL). The CSIR-NPL website states that they are developing a national certification scheme for CEMS in collaboration with the Ministry of Environment, Forest and Climate Change (MoEF&CC) and the CPCB. This certification system includes several essential components including the development of national standards and protocols designed for the certification of CEMS. Additionally, a crucial aspect of this initiative is the establishment of a national CEMS testing laboratory, situated at CSIR-NPL. To ensure the credibility and competence of the certification process, CSIR-NPL is set to gain accreditation as a certification body from the National Accreditation Board for Certification Bodies (NABCB). Finally, the scheme's practical execution will be facilitated through an online application system, including testing, verification and the subsequent issuance of certificates. This comprehensive approach aims to standardize and enhance the effectiveness of emission monitoring systems within the country (CSIR-NPL-AR, 2019-20 and 21-22).

CSIR-NPL performs CEMS certification by evaluating the design, specifications and features of specific CEMS devices or models. It tests them against technical requirements to ensure their functionality, accuracy, durability, safety and compatibility. CSIR-NPL can also certify CEMS technology by examining their measurement principles and methods and providing certificates or reports.

Having developed the indigenous certification system for CEMS by CSIR-NPL, the CEMS may be brought under the ambit of the Bureau of Indian Standard (BIS) Act, 2016 in order to ensure its standardization, conformity assessment and quality assurance. BIS should mandate the device certification of CEMS and issue a certificate or mark of conformity to the products that comply with the relevant standards (BIS, 2023). Figure 24 describes how to obtain the BIS Registration under the BIS compulsory registration scheme (CRS).

Also, the adoption of CEMS in India is increasing, hence it is suggested that all the CEMS devices whether they are imported or indigenously developed should undergo mandatory product certification under the BIS Act, 2016.

Proposed Product Certification for CEMS as per CSE

Until the above CEMS certification system is developed by CSIR-NPL, this research also proposed a CEMS product certification as per CSE.

For product certification of CEMS device, manufacturer or client download the application from SPCBs site and submit the application for product certification then a certification committee is essential for CEMS certification system, as it will oversee all the certification processes for any CEMS device. The committee should consist of independent experts who can provide technical support for certification process. The committee also obtain international accreditation and follow established standards such as ISO/ IEC 17025 to ensure international traceability.

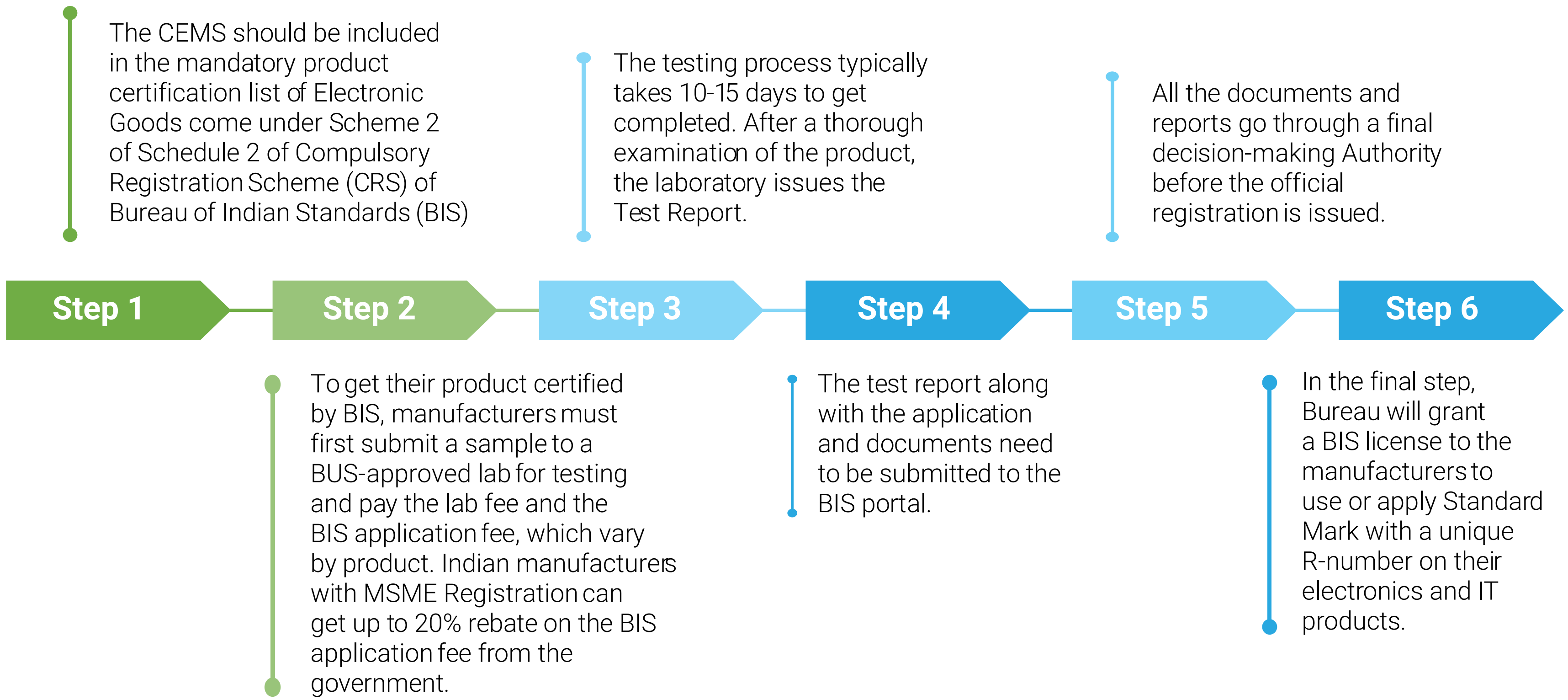
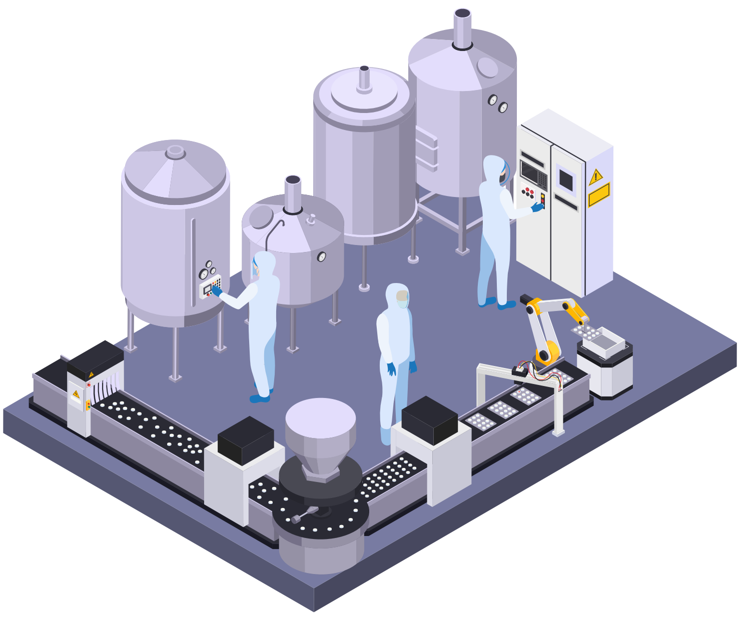


Figure 24: BIS Product Certification Process for CEMS

A testing facility is required to perform the tests directed by the Certification Committee. The testing facility should be accredited by an authorized body and comply with the standards of ISO 17065 and 17025. The testing facility should have the equipment and capability to test and calibrate different types of CEMS devices, both in the laboratory and in the field. The testing facility should also be able to conduct field testing on-site for three months, as per the international norms, NPL should designate some laboratories as testing facilities. The testing facility should have the basic infrastructure and skilled manpower to perform the tasks related to CEMS.

To certify the CEMS, performance standards for different tests are required, which can be based on the existing ones in Europe. These standards have been followed by many countries for decades and ensure the reliability of the CEMS. The testing facility should also account for the environmental conditions that may affect the test results. A test report should be prepared and submitted to the certification committee for review after completing the tests after that certification issue or rejected based on the decision on certification committee (CSE, 2022 b).

Until the indigenous certification system is in place, the certification process proposed by CSE may be employed and pollution control boards, regulatory bodies, etc. can observe the Real-time data obtained from the industry emissions using CEMS online. In the case of exceeding emissions limits, on-ground inspections can be conducted only for units or industries that consistently exceed these limits. This will save time, resources and energy for regulatory agencies and enhance compliance. This data can be used for initial level of intelligence and insights which means, while it may not be used as real evidence in legal matters, it can serve as a foundational source of information and knowledge for industries and authorities to understand emission patterns, identify potential issues and take proactive measures to improve environmental compliance and performance.



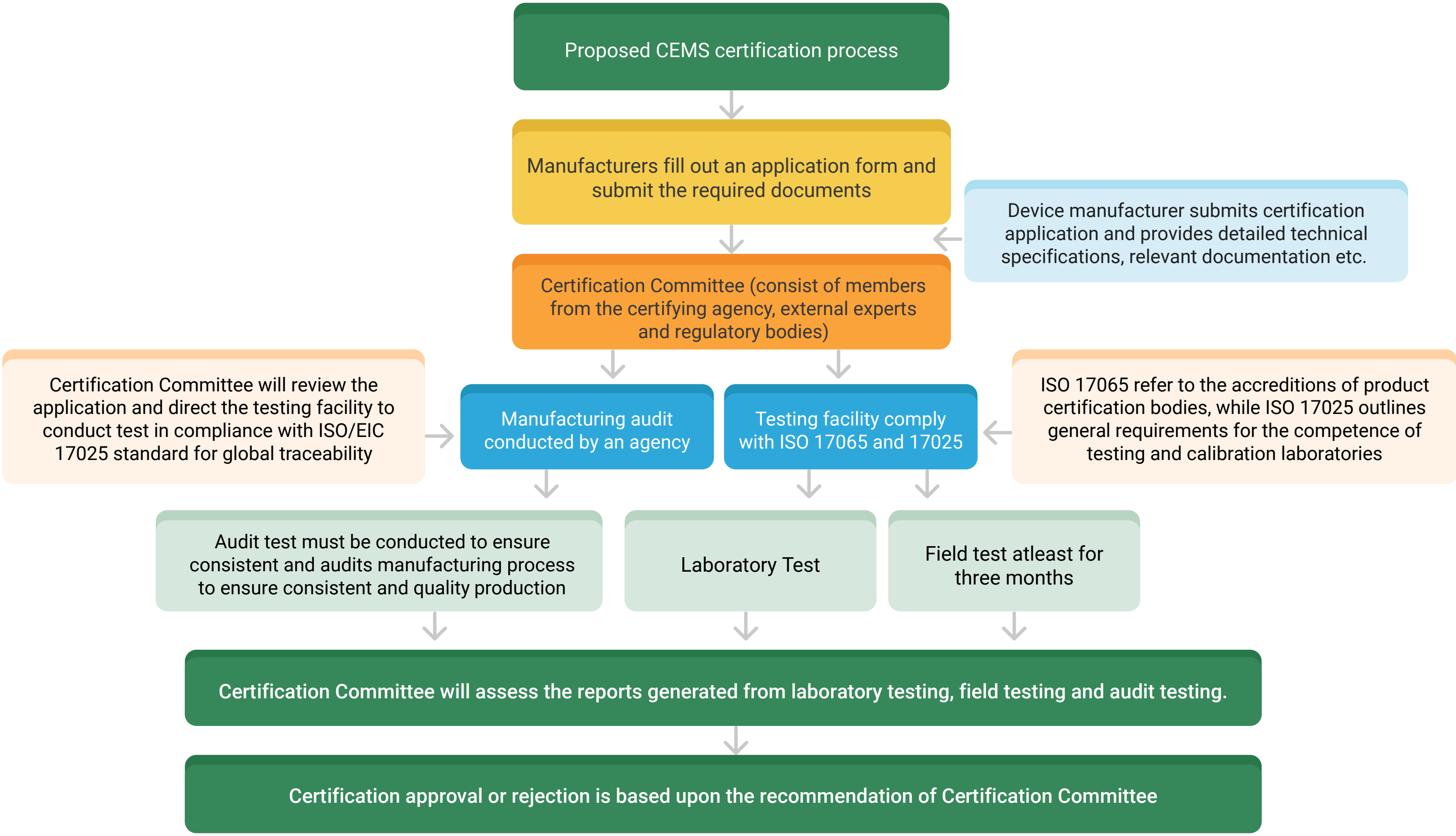


Figure 25: CEMS Certification Process

6.2 Capacity Building Initiatives

Capacity building on CEMS involves enhancing the knowledge, skills and capabilities of individuals, organizations or regulatory bodies to effectively understand, implement and manage CEMS for environmental monitoring and compliance purposes.

The Environmental Training Unit (ETU) of the CPCB, Delhi organized an online training programme of three days with ESCI, Hyderabad. The detail of training programs is mentioned in Table 8A. Apart from the training conducted by CPCB, most of the training and capacity building programs for CEMS in India were conducted by CSE, India. The list of training programs conducted by CSE, India is given in Table 8B.

Table 8A: Training Program for CEMS conducted by CPCB

Pollution Control (Waste Management, Clean Technologies)					
S. No.	**Training Program**	**Duration**	**Date**	**Venue**	**Expert**
1	Air Pollution Control Devices & OCEMS for various sectors	3 days	Jan 19-21, 2021	ESCI, Hyderabad	Ms. Anita Aggarwal, Faculty & Head I/C, Environment Management Division, Engineering Staff College of India, Gachi Bowli, Hyderabad – 500 032

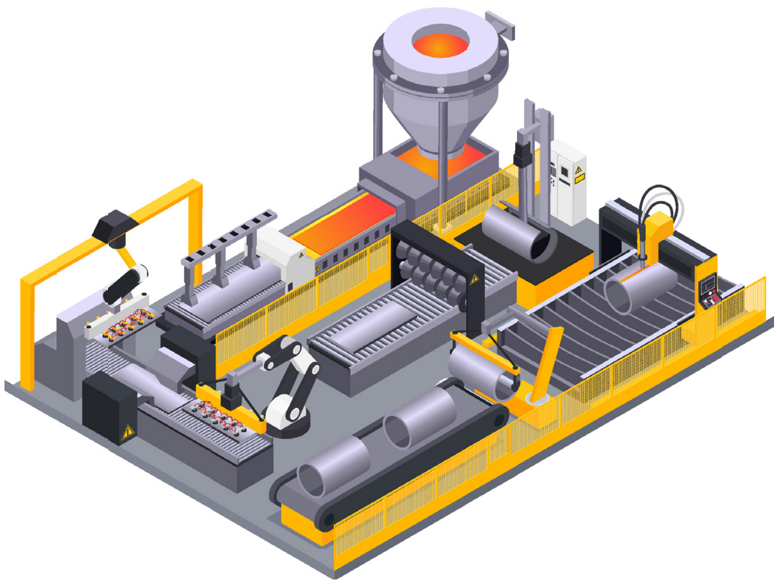


Table 8B: Training Program for CEMS conducted by CSE, India

Year	Training Program	Target Audience	Contents Covered	Collaboration/ Partnership
2016	CEMS Training Program with JSW Steel	Environmental Regulators	• Device selection • Installation • Operation • Maintenance • Data transmission • Inspection • Compliance check	Collaboration with JSW Steel
2018	CEMS and CEQMS Training Program	Environmental Professionals	Knowledge base and skill development	No specific partnership mentioned
2020	Integrated Online and Onsite Training Program	Environmental Professionals	• Basic learning • Advanced learning	No specific partnership mentioned
2021a	CSE-SEPA Online Training Program on CEMS and CEQMS	SPCB Officials	• Device selection • Installation procedures • Operation techniques • Maintenance practices • Data transmission • Inspection protocols • Compliance verification	Collaboration with Swedish Environmental Protection Agency (SEPA)
2021b	Capacity Building Initiative for Regulators of CEMS and CEQMS	Environmental Regulators	• Addresses implementation of training program learnings by PCBs • IncorporSates Swedish experts' perspectives on effective execution of action plans and policies	Collaboration with Swedish Environmental Protection Agency (SEPA)
2021	Online Course on CEMS and CEQMS	Environment Professionals (Industries, Consultants, Academicians)	• Measurement techniques • Instrumentation • Calibration • Audit methodology • Data management • Reporting • Theoretical and practical aspects of CEMS and CEQMS	No specific partnership mentioned

Training for CEMS operation is essential to ensure the quality and reliability of emissions monitoring. However, India does not currently have any official training system for CEMS operation, unlike the UK and the USA, which have established systems for training and certifying individuals who carry out emissions monitoring. These systems cover CEMS and additional areas of stack testing, such as manual monitoring, wet chemical methods, data handling and health and safety on site.

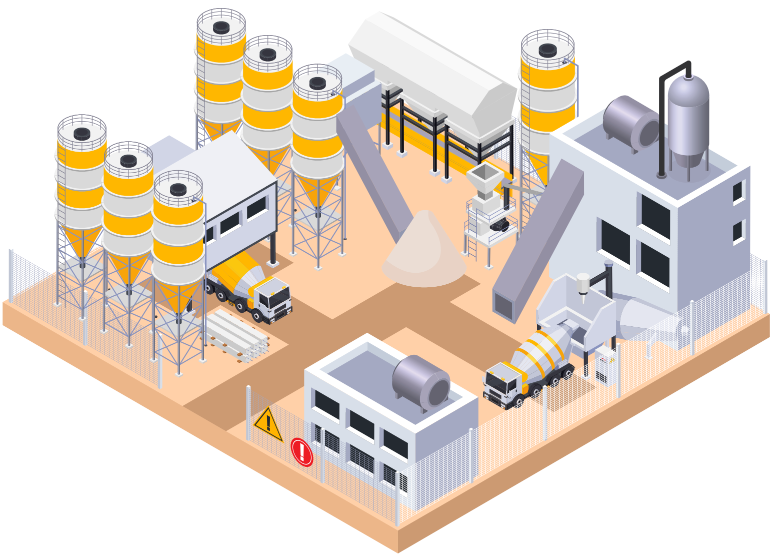
In the UK, the MCERTS scheme established by UK Environment Agency (UKEA) covers all areas of emission and effluent monitoring. This training is commonly delivered via the UKEA or through the UK Source Testing Association (STA). The courses for CEMS operation include CEMS operation, data management and competence certification for personnel. Individuals and organisations can obtain certification at different levels of competency. Certification can be obtained both at the individual level and the organisation level. Individuals can advance through three levels of competency from trainee to team leader.

Similarly, in the USA, the US Source Evaluation Society (SES) has established the Qualified Source Testing Individual (QSTI) and Qualified Source Testing Observer (QSTO) certification scheme to demonstrate that qualified staff have the knowledge and skills required to apply source testing methods correctly. The qualification is voluntary but is approved by the USEPA (Kanchan and Bahel, 2023).

In India, there are only a few generic training courses on CEMS, which have been organised by the CPCB and some independent organisations such as CSE. However, there is no CEMS related training provided by the UPPCB or any other organisation in Uttar Pradesh. This is not sufficient to ensure that CEMS are operated correctly and that the data are valid for compliance reporting. This lack of training and capacity building will result in poor data quality and implementation challenges.

To address this gap, the International Centre for sustainable Carbon (ICSC) delivered four training workshops in India in 2022 under a US Department of State funded programme. However, these materials need to be updated and maintained by Indian stakeholders. Therefore, the ICSC has established CEMS-India, a stakeholder working group that focuses on advancing CEMS training and use in India (Kanchan and Bahel, 2023).

Recently, DoEF&CC, GoUP has proposed Uttar Pradesh Clean Air Management Project under the World Bank Program for Air Shed Management in Uttar Pradesh. The Apex Institute will act as a central hub for the UP Clean Air Management Project. It will provide crucial support to the 15 Knowledge Centres located in various educational institutions across the state. The Apex Institute will offer comprehensive capacity building support to the Knowledge centres. Since, there is a lack of institutions that provide CEMS related training in UP, it will also facilitate the development of training programs, workshops and refresher courses related to air quality monitoring devices including CEMS to enhance the knowledge and skills of professionals engaged in air quality management. These programs will be delivered through online and offline platforms.



This research proposed the following solutions to address the gap of trained personnel. The number of persons required for the installation and data transfer of CEMS in an industry may vary depending on various factors, such as the type and size of the industry, the number and location of the emission sources, the complexity and compatibility of the CEMS equipment and software and the availability and expertise of the staff. However, based on the guidelines for CEMS installation and operation, the following persons are required for CEMS, which are as follows:

- For installation, operation and maintenance of CEMS, at least one person is required from the CEMS vendor who will ensure proper installation and commissioning of the CEMS device.
- For technology selection and proper monitoring, at least one person is required from the industry who is responsible for monitoring and maintaining the data acquisition system (DAS), which is a computer with internet connection that collects and stores the CEMS data.
- To calibrate CEMS as a third-party, trained and dedicated personnel are also needed, who have the skills and knowledge of calibration procedures for CEMS.

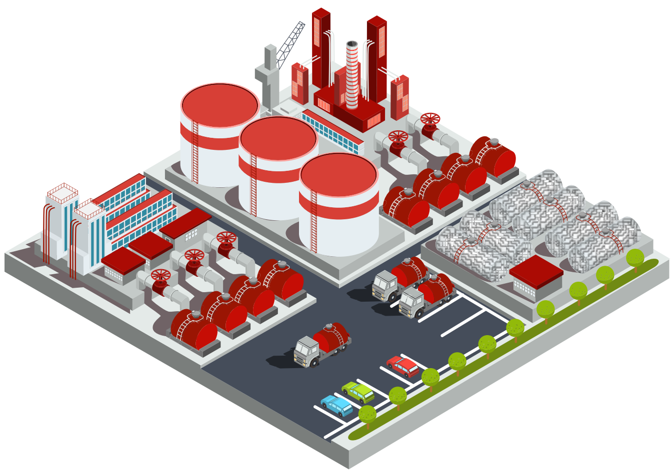
Therefore, at least 03 persons are required from installation to data transfer and calibration from each point of CEMS process in an industry. However, this number may vary depending on the specific requirements and conditions of each industry.

The number of trained personnel to maintain CEMS depends on various factors, such as the type and number of CEMS devices, the frequency and method of calibration, the level of automation, and the availability of technical support. The CPCB Guidelines, August 2018 suggested that each industry should have at least one trained person for each CEMS device installed. However, this may not be sufficient or feasible in practice, as CEMS devices may require regular maintenance, troubleshooting, and verification by external agencies. Therefore, the actual number of trained personnel to maintain CEMS may vary across industries and regions (CPCB, 2018; Greenstone et al., 2020).

Furthermore, it was found evident that installation, operation and maintenance of CEMS require careful planning and preparation, as there are several parameters that need to be checked before implementation. These technical parameters for implementation of CEMS are well explained in the CPCB Guidelines (2018), but industries find it difficult to follow these guidelines meticulously due to lack of understanding of the CEMS. Hence, it is recommended that CPCB should come out with a capacity building program of CEMS guidelines for industrial stakeholders for proper implementation of CEMS in industries.

After discussing with various stakeholders and CEMS experts, it was identified that the workforce or trained personnel required for CEMS processes is only 10-20% for their proper installation, operation and maintenance in India. This indicates a large gap in this area, so we must train these people and build their capacity to fill this gap and ensure proper implementation of CEMS in India.

For this, the Government's Skill India Program should include a training and capacity building module for CEMS in India, which would provide proper training and management courses for CEMS. This way, the gap can be filled and the requirement of trained personnel can be met for CEMS implementation in India. Some of the key points for training the person and building their capacity to address the gap of capacity building for proper implementation of CEMS are given in Figure 26.



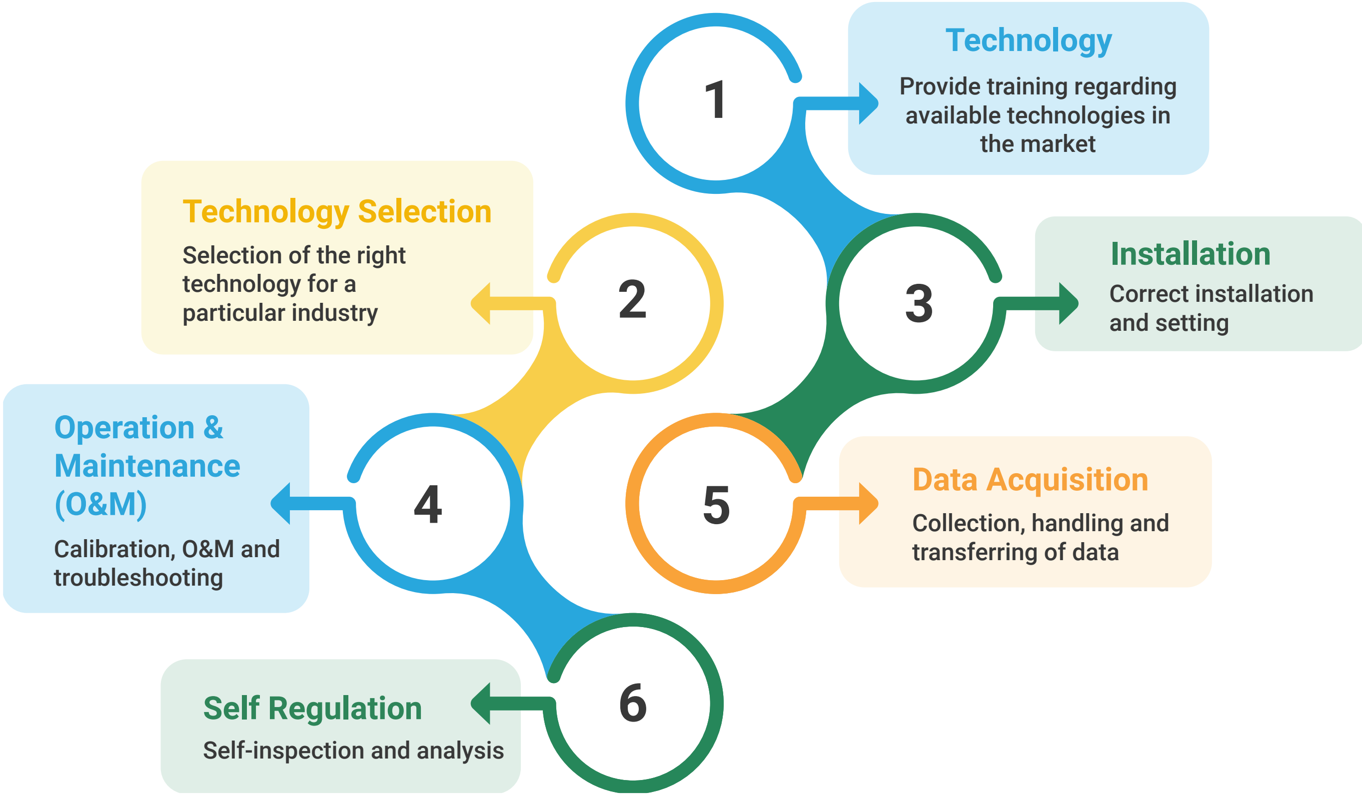


Figure 26: Key Points for CEMS training and capacity building programs

6.3 Creating Data Acquisition and Management System (DAMS)

To address the challenges of data management from CEMS, this research proposed to establish a Data Acquisition and Management System (DAMS) for proper handling of CEMS data is summarized in Figure 27.

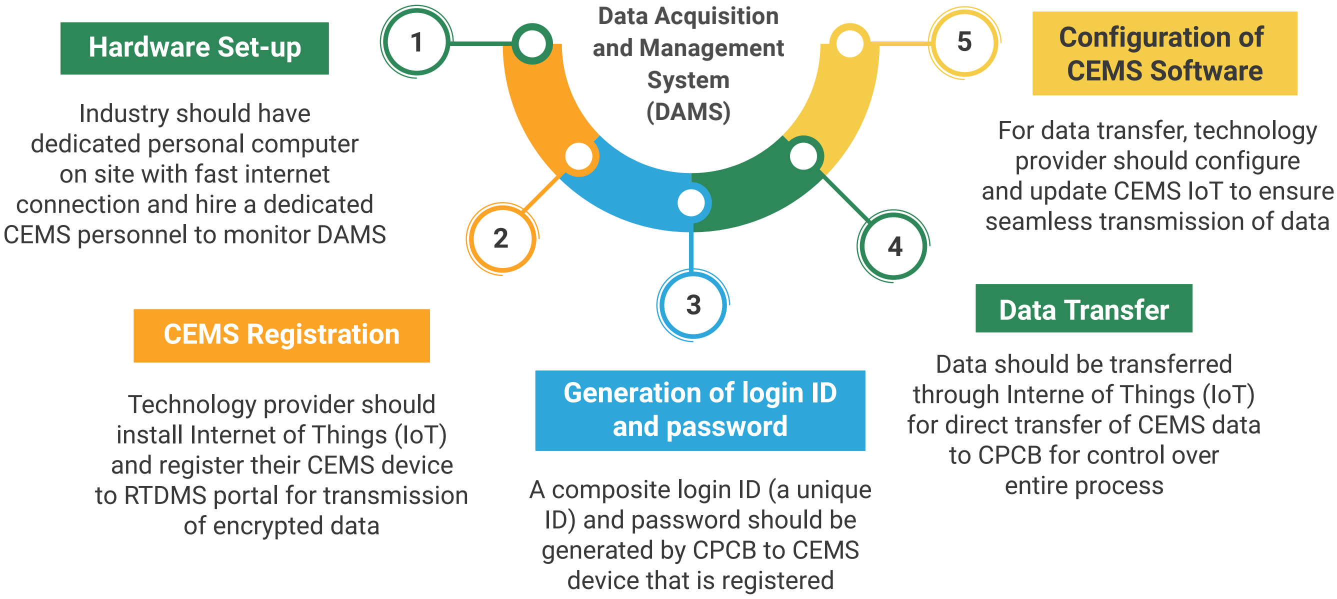
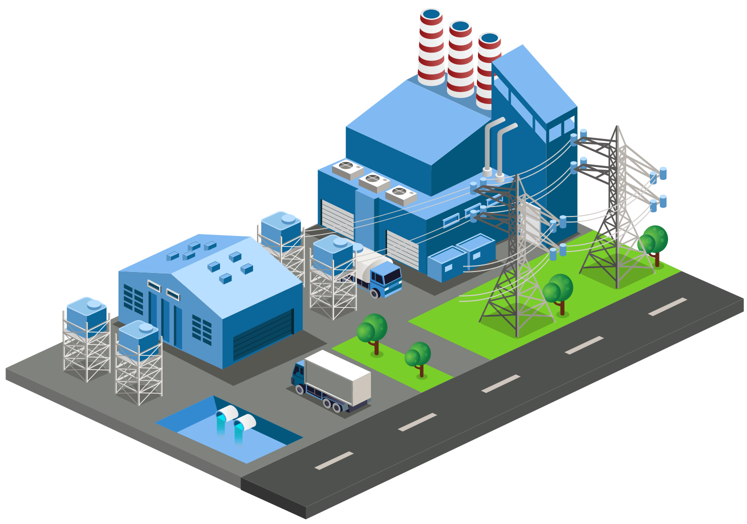


Figure 27: Data Acquisition and Management System (DAMS)



6.4 Establishing an Internal Monitoring Mechanism

The UP Clean Air Management Plan, developed by the Department of Environment (DoE), aims to combat air pollution in Uttar Pradesh. It involves establishing an Apex Institute at IIT Kanpur and 15 Knowledge Centres within educational institutions across the state. The Apex Institute will coordinate and support the activities of the Knowledge Centres, collectively strengthening efforts against air pollution. It will provide capacity-building support through online and offline training programs, including stack monitoring, emission inventory and CEMS training. The Knowledge Centres will offer well-equipped labs, contribute to a skilled workforce, support the CEMS ecosystem, establish an internal monitoring mechanism, conduct source apportionment and impact assessments and also play a crucial role in understanding and mitigating the effects of air pollution in Uttar Pradesh. Every industrial cluster has a Common Facility Centre in which the Industrial Development Authority will provide free space for establishment of CEMS laboratory. This will encourage the creation of CEMS labs in every industrial cluster through a public-private partnership model. In this model, the industrial cluster offers space for labs and the government offers financial support in the form of a Capital Subsidy to establish CEMS labs. The Government of Uttar Pradesh (GoUP) is offering a 10% subsidy for establishing CEMS labs as part of the UP Clean Air Management Plan (UPCAMP Draft DPR, 2023).

To establish an internal monitoring mechanism for air pollution, project propose a CEMS ecosystem in the industrial areas. The internal monitoring mechanism are summarized in Figure 28.

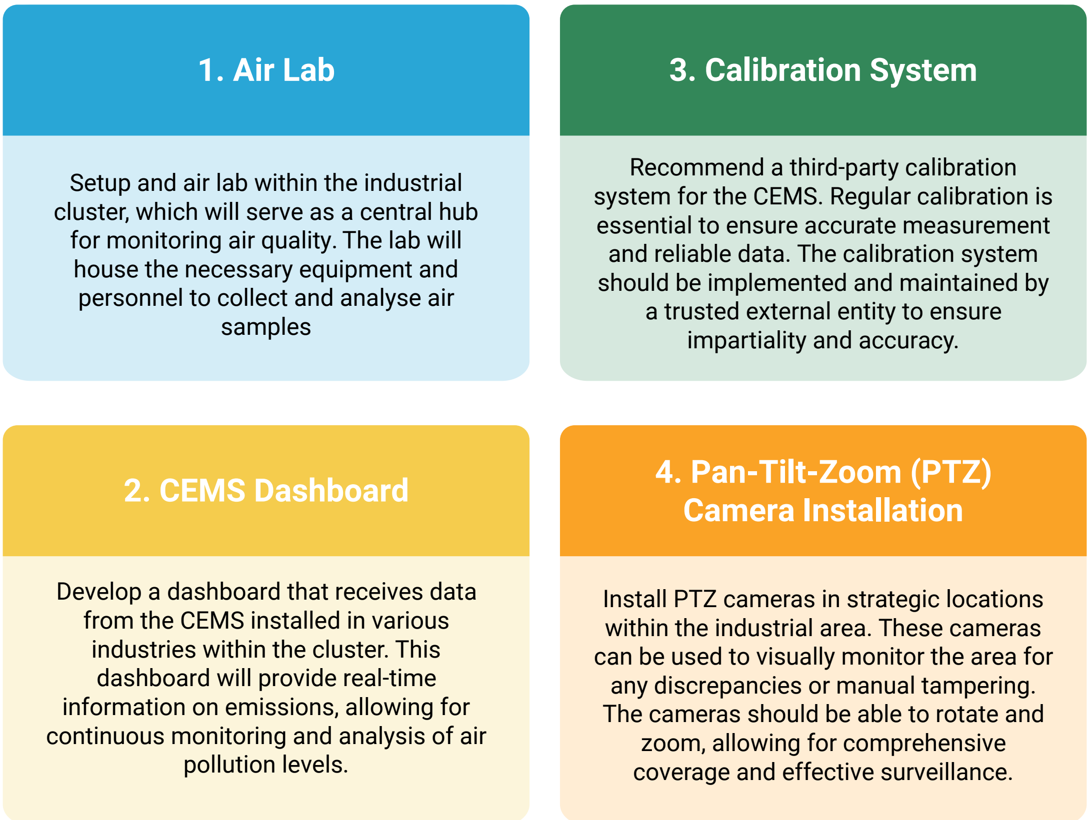


Figure 28: Internal Monitoring Mechanism

By incorporating these additional measures, this study can create a more comprehensive and multi-faceted internal monitoring mechanism, effectively addressing various sources of air pollution within the industrial area and facilitating timely corrective actions.

6.5 Implementation Strategy for CEMS in India

There are some technical aspects of CEMS that need to be documented for their implementation and to assist the industry in selecting the right instruments and ensuring their long-term operation and performance evaluation. The technical operationalization of CEMS is summarized in Figure 29.

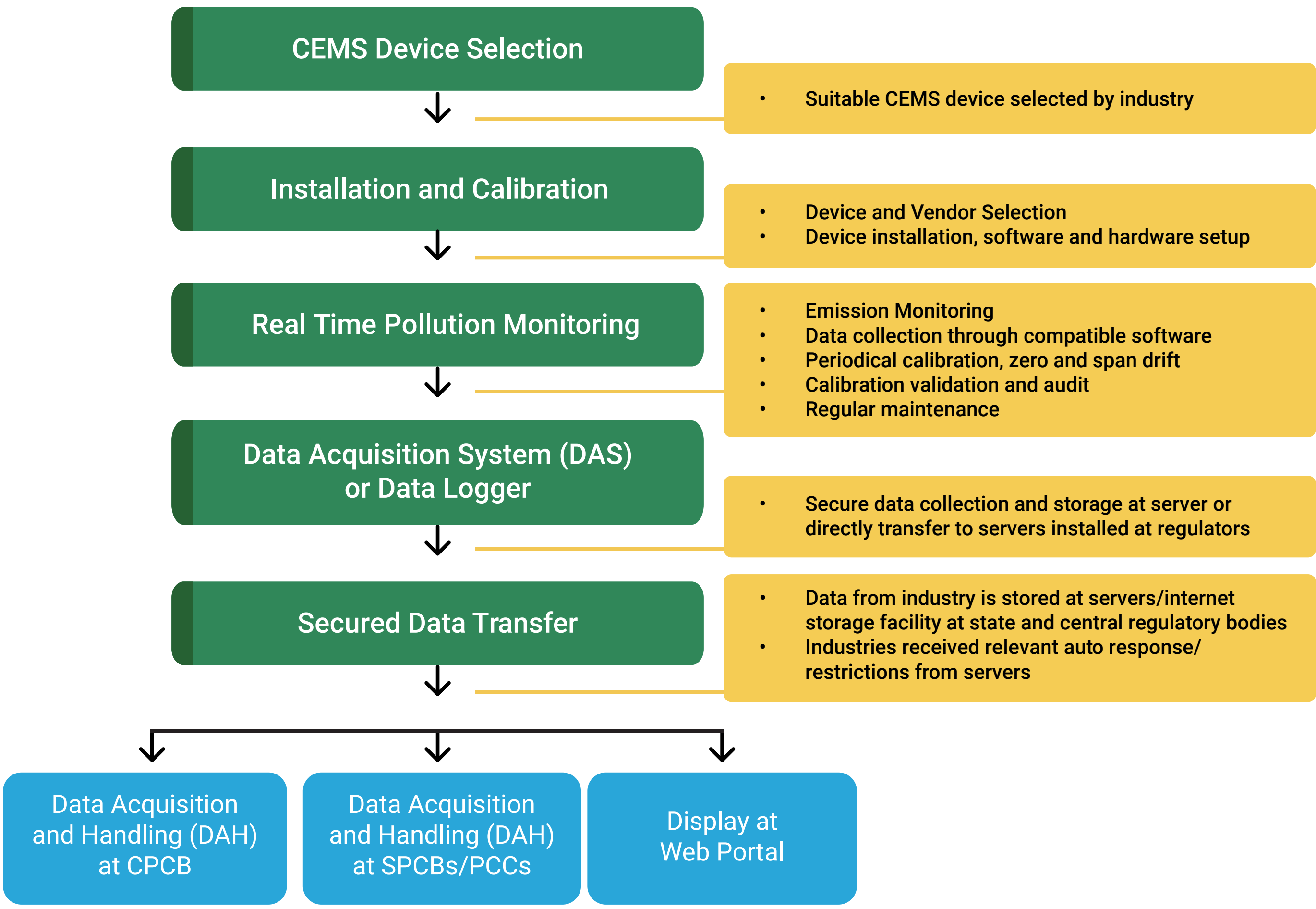


Figure 29: Technical Operationalization of CEMS

7. Findings and Recommendations

7.1 Policy Framework

India should adopt a clear and consistent policy to implement CEMS properly in the country. The policy should involve various stakeholders and address the technical, legal and financial aspects of CEMS, such as device selection, calibration, verification, data certification, data compliance, data accountability, incentives, subsidies, markets and platforms etc. Currently, CEMS data cannot be used for legal and compliance purposes as it is not considered admissible evidence under the Air (Prevention and Control of Pollution) Act, 1981. Once there is a certified system in place, the Air (Prevention and Control of Pollution) Act, 1981 can be amended to allow use of CEMS data for legal and compliance purposes.

7.2 Up-scaling of CEMS

The government should introduce policies to support the adoption of CEMS by small and medium-sized enterprises (SMEs). One way to do this is to provide financial incentives for SMEs to cover the upfront costs of installing and operating CEMS devices such as GCP and UPIIEPP. Another way is to encourage the establishment of CEMS labs on a public-private partnership (PPP) model, where the government and the private sector can share the costs and benefits of CEMS data analysis and quality assurance. Furthermore, industrial development authorities may allocate spaces for the CEMS labs free of cost, either through a specific scheme under UPIIEPP or through other incentives. These policies can help SMEs to overcome the financial barriers and access the benefits of CEMS.

7.3 Certification System

This research suggests implementing a consistent CEMS certification and quality assurance process in India, in line with indigenous certification systems. This calls for the establishment of a clear, well-defined process that begins with product certification. This involves rigorous testing and verification of CEMS devices to meet specified standards, with the certification dependent on the outcomes of various tests, including field, laboratory and audit tests, to ensure that CEMS devices consistently meet quality and performance benchmarks. Until the domestic certification system is fully developed, we utilize the global certification system for monitoring purpose rather than regulation. This enables to inspect industries based on compliance with established guidelines and take strict actions when industries do not adhere to these standards.

7.4 Capacity Building and Training

To ensure the quality and reliability of CEMS, all the personnel involved in CEMS should receive appropriate training in QA and QC. This includes the vendors who supply the CEMS devices, the installers who set up the devices, the operators who run the devices on a daily basis and the auditors who check the CEMS operations. The training should cover the key aspects of CEMS such as the availability and selection of suitable technologies and its installation; the calibration, operation, maintenance and troubleshooting of the devices; the data acquisition and handling; the regulatory requirements and evalutation of self-inspection and analysis. The training and certification should cover both CEMS and manual monitoring methods, as well as data handling and health and safety on site.

7.5 Data Acquisition System (DAS)

The CPCB and SPCBs should develop standard operating procedures (SOPs) for DAS implementation, including criteria for selecting appropriate analyzers, installation methods, calibration frequency, data transmission format, quality assurance and quality control measures, inspection and verification protocols, etc., strengthening the capacity of industries and regulators to operate and maintain the DAS devices, through training programs, workshops, manuals, etc., enhancing the transparency and accountability of the DAS data, by making it publicly available online, using tamper-proof devices, imposing penalties for non-compliance or data falsification, etc., and encouraging innovation and competition among DAS technology suppliers and service providers, by creating a platform for sharing best practices, feedback, challenges and solutions. This study recommends that CPCB may explore option of IoTs for direct transfer of CEMS data and control over entire process of data collection to improve the data quality and management.

7.6 Service and Support

To address limited access to CEMS maintenance in industrial areas, this study proposes establishing service centres near these clusters. These centres, equipped with expertise and tools, would swiftly handle maintenance and repairs. These centres must provide maintenance contracts on monthly, quarterly, or yearly schedules, including regulatory compliance audits. Their services should encompass hardware and software support, on-site repairs (done by manufacturers), preventative maintenance and emergency phone support. They should also offer annual support agreements, featuring quarterly on-site visits, operator training and compliance testing.

References

3ie (2020). Continuous Emissions Monitoring Systems (CEMS) in India. Retrieved from https://www.3ieimpact.org/evidence-hub/publications/impact evaluations/continuous-emissions-monitoring-systems-cems-india.

ABB (2022). Customer Information Guide Continuous Emission Monitoring Systems (CEMS). Retrieved from https://library.e.abb.com/public/25eb24be97bd478889d711e84d23d157/PB_CEMS_CUSTOMER_INFORMATION_GUIDE_EN_A.pdf.

Allied Market Research (AMR) (2023). Emission Monitoring System Market Size, Share and Analysis | Forecast - 2031. Retrieved from https://www.alliedmarketresearch.com/emission-monitoring-system-market-A17131.

BBC News (2023). India's ambitious plan to fight pollution. Retrieved from https://www.bbc.com/news/world-asia-india-58922398.

Bureau of Indian Standards (BIS) (2023). Product Certification Scheme. Retrieved fromfromhttps://www.bis.gov.in/.

CEMS India (2023). ENVEA, Retrieved from https://www.envea.global/cems-india-2023/.

CEMS INDIA (2023). Mission Energy. Retrieved from https://missionenergy.org/cemsindia/index.html.

Central Pollution Control Board (CPCB) (2014). Guidelines for continuous emission monitoring systems. Retrieved from https://cpcb.nic.in/uploads/Projects/Air_Quality/Guidelines_for_CEMs.pdf.

Central Pollution Control Board (CPCB) (2017). Guidelines for Continuous Emission Monitoring Systems. Retrieved from https://cpcb.nic.in/upload/thrust-area/Guidelines_on_CEMS_02.08.2017.pdf.

Central Pollution Control Board (CPCB) (2018). Guidelines for Continuous Emission Monitoring Systems. Retrieved from https://cpcb.nic.in/upload/thrust-area/revised-ocems-guidelines 29.08.2018.pdf.

Centre for Science and Environment (CSE) (2016). Roundtable on "Continuous Emission Monitoring System (CEMS) in India-challenges and way ahead" Centre for Science and Environment. Retrieved from https://www.cseindia.org/roundtable-on--6599.

Centre for Science and Environment (CSE) (2016). Training on Continuous Emission Monitoring System- From Understanding to Implementation. Retrieved from https://www.cseindia.org/training-on-continuous-emission-monitoring-system-from-understanding-to-implementation-6604.

Centre for Science and Environment (CSE) (2017). Continuous Emission Monitoring System (CEMS). Retrieved from https://www.cseindia.org/continuous-emission-monitoring-system-cems-6595.

Centre for Science and Environment (CSE) (2018). Training Programme on Continuous Emission and Effluent Quality Monitoring System for Environment Professionals. Retrieved from https://www.cseindia.org/training-programme-on-continuous-emission-and-effluent-quality-monitoring-system-for-environment-professionals-8397.

Centre for Science and Environment (CSE) (2019). Coal power stations in UP: An assessment of their compliance with new norms. Retrieved from https://cdn.cseindia.org/attachments/0.25853600_1563184364_Overview.pdf.

Centre for Science and Environment (CSE) (2021a). CSE-SEPA Online Training Programme on CEMS & CEQMS. Retrieved from https://www.cseindia.org/cse-sepa-online-training-programme-on-cems-ceqms-10986.

Centre for Science and Environment (CSE) (2021b). Online Impact workshop on Capacity building initiative for Regulators on CEMS & CEQMS. Retrieved from https://www.cseindia.org/online-impact-workshop-on-capacity-building-initiative-for-regulators-on-cems-ceqms-11064.

Centre for Science and Environment (CSE) (2021c). Online Training Programme on CEMS and CEQMS- Technology selection, its installation, Data Handling and its Audit Methodology. Retrieved from https://www.cseindia.org/online-training-programme-on-cems-and-ceqms-technology-selection-its-installation-data-handling-and-its-audit-methodology-10811.

Centre for Science and Environment (CSE) (2022a). CEMS Certification System in India - CSE Proposal. Retrieved from http://www.indiaenvironmentportal.org.in/content/472464/cems-certification-system-in-india-cse-proposal/.

Centre for Science and Environment (CSE) (2022b). Guidance Manual for CEMS with Proposed Corrections. Retrieved from https://cdn.cseindia.org/userfiles/guidance-manual-for-CEMS-with-proposed-corrections.pdf.

Centre for Science and Environment (CSE), (2020). Integrated Online and Onsite Training Programme on Continuous Emission and Effluent Monitoring System. Retrieved from https://www.cseindia.org/integrated-online-and-onsite-training-programme-oncontinuous-emission-and-effluent-monitoring-system-11388.

Chen, X., Liu, Q., Sheng, T., Li, F., Xu, Z., Han, D., Zhang, X., Huang, X., Fu, Q., & Cheng, J. (2019). A high temporal-spatial emission inventory and updated emission factors for coal-fired power plants in Shanghai, China. Science of The Total Environment, 688, 94-102. https://doi.org/10.1016/j.scitotenv.2019.06.201

Clean Air Asia (CAA) (2023). Continuous Emissions Monitoring to Achieve Air Quality Targets: Policy Brief. Retrieved from https://www.cleanairasia.org/sites/default/files/2023-03/Continuous%20Emissions%20Monitoring%20to%20Achieve%20Air%20Quality%20Targets%20Policy%20Brief.pdf

Clean Air Asia (CAA) (2023). Continuous Emissions Monitoring to Achieve Air Quality Targets. Retrieved from https://cleanairasia.org/sites/default/files/2023-03/Continuous%20Emissions%20Monitoring%20to%20Achieve%20Air%20Quality%20Targets%20Policy%20Brief.pdf.

Council of Scientific and Industrial Research - National Physical Laboratory (CSIR-NPL) (2023). National Certification Scheme for Continuous Emission Monitoring Systems (CEMS). Retrieved from https://www.nplindia.org/index.php/institutional-resources/annual-report/.

Directorate of Environment (DoE), 2023. Stakeholder Consultation held on May, 2023.

Down to Earth (DTE) (2022). India urgently needs certification system for industrial emissions monitoring devices. Retrieved from https://www.downtoearth.org.in/blog/governance/india urgently-needs-certification-system-for-industrial-emissions-monitoring-devices-81375.

Economics Discussion (ED) (2018). Problems of Small-Scale Industries. Retrieved from https://www.economicsdiscussion.net/india/industries-india/problems-of-small-scale-industries/32232.

Eisenmann, T., Bianchin, D. R., & Triebel, D. (2014). Predictive Emission Monitoring (PEM): Suitability and application in view of US EPA and European regulatory frameworks. In 11th International Conference and Exhibition on Emissions Monitoring (CEM) (p. 15). Retrieved from https://dokumen.tips/download/link/predictive-emission-monitoring-pem-suitability-predictive-emission-monitoring.htmlEMC: Continuous Emission Monitoring Systems | US EPA.

Environmental Protection Agency (EPA). (2017). Continuous emission monitoring systems (CEMS). Retrieved from https://www.epa.gov/emc/continuous-emission-monitoring-systems-cems.

European Commission (EC) (2021). Industrial Emissions Directive. European Commission. https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-emissions-directive_en.

European Union (EU) (2021). Industrial Emissions Directive (IED). Retrieved from https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-emissions-directive_en.

Fact, MR (2023). Emission Monitoring System Market Forecast, Trend Analysis & Competition Tracking - Global Review 2022 to 2032. Retrieved from https://www.factmr.com/report/emission-monitoring-system-market.

Fuji Electric (FE) (2023). Continuous Emission Monitoring System. Retrieved from https://www.fujielectric.fr/en/product/continuous-emission-monitoring-system.

Future Market Insights (FMI) (2023). Continuous Emission Monitoring System Market. Retrieved from https://www.futuremarketinsights.com/reports/continuous-emission-monitoring-system-market.

Ghanem, D. & Zhang J. (2014). "Effortless perfection": Do Chinese cities manipulate air pollution data? Journal of Environmental Economics and Management, 68 (2): 203–25.

Government of Canada (GoC) (2021). Consultation on Changes to Continuous Monitoring of Gaseous Emissions Protocol. Retrieved from https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/consultation-continuous-monitoring-gaseous-emissions-protocol/changes-continuous-monitoring-gaseous-emissions-protocol.html.

Government of Uttar Pradesh (GoUP) (2022). Uttar Pradesh Industrial Investment and Employment Promotion Policy. Retrieved from https://invest.up.gov.in/wp-content/uploads/2022/11/Final_UP_New-Industrial-Policy_041122.pdf.

Greenstone, M., Pande, R., Ryan N., & Sudarshan A. (2020). Continuous Emissions Monitoring Systems (CEMS) in India. 3ie Impact Evaluation Report 111. Retrieved from https://www.3ieimpact.org/sites/default/files/2020-03/IE111-DPW1.1067-India-Pollution-CEMS.pdf.

Gujrat Pollution Control Board (GPCB) (2023). Guidelines and Standard Operating Procedure. Retrieved from https://gpcb.gujarat.gov.in/webcontroller/viewpage/guidelines-and-standard-operating-procedure.

Harvard Centre for Geographic Analysis (HCGA), (2016). BCURE Case: Improving industrial monitoring to cut air pollution in India. Retrieved from https://egc.yale.edu/bcure-case-improving-industrial-monitoring-cut-air-pollution-india.

He, S., Zhao, L., Ding, S., Liang, S., Dong, L., Wang, J., Feng, Y., & Liu, L. (2019). Mapping economic drivers of China's NO_x emissions due to energy consumption. Journal of Cleaner Production, 241, 118130. https://doi.org/10.1016/j.jclepro.2019.118130.

International Environmental Technology (IET) (2022). CEMS Voyage for India's Environmental Governance. Retrieved from https://www.envirotech-online.com/article/air-monitoring/6/international-environmental-technology/cems-voyage-for-indiarsquos-environmental-governance/3131.

International Initiative for Impact Evaluation (IIIE) (2019). Continuous Emissions Monitoring Systems (CEMS) in India. Retrieved from https://www.3ieimpact.org/evidence-hub/impact-evaluation-repository/continuous-emissions-monitoring-systems-cems-india.

Invest India (2023). Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors (SPECS). Retrieved from https://www.investindia.gov.in/schemes-for-electronics-manufacturing.

Invest India (2023.). Atmanirbhar Bharat Abhiyaan. Retrieved from https://www.investindia.gov.in/atmanirbhar-bharat-abhiyaan

Jahnke, J. A. (2022). Continuous emission monitoring. John Wiley & Sons.

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. Environmental pollution, 151(2), 362-367.

Kanchan, S. K. (2023). International Center on Sustainable Carbon. Best practices in CEM (Continuous Emissions Monitoring). Retrieved from https://wedocs.unep.org/20.500.11822/43063

Kanchan, S. K., & Bahel, K. (2016). Survey of implementation of continuous emission monitoring system in India. Centre for Science and Environment. https://www.cseindia.org/survey-of-cems-implementation-in-india-6602.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. Front. Public Health, (8). https://doi.org/10.3389/fpubh.2020.00014.

Manwani, H. (2020). Critical analysis on small scale industries and its impact on Indian economy. Journal of Emerging Technologies and Innovative Research, 7(4), 1039-1045. Retrieved from https://www.jetir.org/papers/JETIR2204352.pdf.

Markets and Markets (M&M) (2021). Emission Monitoring Systems Market by System Type, Offering, Industry, and Region - Global Forecast to 2026. Retrieved from https://www.marketsandmarkets.com/Market-Reports/emission-monitoring-systems-market-72002872.html.

MarketWatch (2023a). Latest Trends and Strategies for CEMS Market During 2023-2030. Retrieved from https://www.marketwatch.com/press-release/latest-trends-and-strategies-for-cems-market-during-2023-2030-2023-04-25.

MarketWatch (2023b). The Continuous Emission Monitoring Systems (CEMS) Market Size is Projected to Expand at a 6% CAGR Forecasted from 2023 - 2030: With a Report that Covers Market Sales, New Technologies, Market Development, and Demand-Supply Situation. Retrieved from https://www.marketwatch.com/press-release/the-continuous-emission-monitoring-systems-cems-market-size-is-projected-to-expand-at-a-6-cagr-forecasted-from-2023---2030-with-a-report-that-covers-market-sales-new-technologies-market-development-and-demand-supply-situation-2023-05-31.

Massachusetts Institute of Technology (MIT), News (2022). Getting carbon out of India's heavy industries. Retrieved from https://news.mit.edu/2022/getting-carbon-out-india-heavy-industries-0705.

Ministry of Ecology and Environment (MEE) 2017. The Belt and Road Ecological and Environmental Cooperation Plan. http://english.mee.gov. cn/ Resources/Policies/policies/Frameworkp1/201706/t20170628_ 416869.shtml.

Ministry of Environment, Forest and Climate Change (2023). Green Credit Programme (GCP) implementation rules 2023 [Notification]. Retrieved from https://egazette.gov.in/WriteReadData/2023/246825.pdf.

Ministry of Skill Development and Entrepreneurship (MSDE) (2023). Pradhan Mantri Kaushal Vikas Yojana (PMKVY) 4.0. Retrieved from https://msde.gov.in/en/schemes-initiatives/short-term-training/pmkvy-4.0.

Mongabay-India (2018). CPCB pushes for broader adoption of emissions monitoring systems. Retrieved from https://india.mongabay.com/2018/09/cpcb-pushes-for-broader-adoption-of-emissions-monitoring-systems/.

Mordor Intelligence (2023). Emission Monitoring Systems Market Size & Share Analysis - Industry Research Report - Growth Trends - Mordor Intelligence. Retrieved from https://www.mordorintelligence.com/industry-reports/emission-monitoring-systems-market.

News Channel Nebraska (2023). Continuous Emission Monitoring System (CEMS) Market. Retrieved from https://rivercountry.newschannelnebraska.com/story/48684734/continuous-emission-monitoring-system-cems-market.

Open PR. (2021). Continuous Emission Monitoring System (CEMS) Market Industry. Retrieved from https://www.openpr.com/news/2505685/continuous-emission-monitoring-system-cems-market-industry.

Pradhan Mantri Kaushal Vikas Yojna (PMKVY) (2023). Short-Term Training. Retrieved from https://www.pmkvyofficial.org/stt.

Press Information Bureau (PIB), Government of India (GoI) (2022). Retrieved from https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=1813174.

Shylaja, K. (2014). Globalization and small-scale industries in India- A literature review. Sahyadri Journal of Management, 2(1), 1-6.

Tang, L., Jia, M., Yang, J., Li, L., Bo, X., & Mi, Z. (2023). Chinese industrial air pollution emissions based on the continuous emission monitoring systems network. Scientific Data, 10, 153. https://doi.org/10.1038/s41597-023-02054-w.

U.S. Environmental Protection Agency (USEPA) (2022). EMC: Continuous Emission Monitoring Systems | US EPA. Retrieved from https://www.epa.gov/emc/emc-continuous-emission-monitoring-systems.

U.S. Government Publishing Office (USGPO) (2023). Title 40: Protection of Environment - Part 75: Continuous Emission Monitoring. Retrieved from https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-75.

United State Agency International Development (USAID) Technical Brief (2020). Continuous Emissions Monitoring Systems (CEMS) - Emissions Trading Scheme, Surat, Gujarat, India. Retrieved from https://epic.uchicago.in/publication/continuous-emissions-monitoring-systemscems-emissions-trading-scheme/.

United States Environmental Protection Agency (USEPA) (2023). Clean Air Act. Retrieved from https://www.epa.gov/laws-regulations/summary-clean-air-act.

UPCAMP Draft DPR, Department of Environment, Forest and Climate Change Governmnet of Uttar Pradesh (2023).

Wang, H., Zhou, J., Li, X., Ling, Q., Wei, H., Gao, L., He, Y., Zhu, M., Xiao, X., Liu, Y., Li, S., Chen, C., Duan, G., Peng, Z., Zhou, P., Duan, Y., Wang, J., Yu, T., Yang, Y., Wang, J., Zhou, Z., Gui, H., & Ding, Y. (2023). Review on recent progress in on-line monitoring technology for atmospheric pollution source emissions in China. Journal of Environmental Sciences, 123, 367-386. https://doi.org/10.1016/j.jes.2022.06.043.

Wang, X., Xu, L., Zhang, Q., Zhang, D., Zhang, X. (2022). Evaluating the data quality of continuous emissions monitoring systems in China. Journal of Environmental Management, 314, 115081. https://doi.org/10.1016/j.jenvman.2022.115081.

World Health Organization (WHO) (2023). Exposure to air pollution. Retrieved from https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/exposure-air-pollution.

Your Article Library (YAL) (2019). 10 Major Problems faced by the Small-Scale Industries of India. Retrieved from https://www.yourarticlelibrary.com/industries/10-major-problems-faced-by-the-small-scale-industries-of-india/23457.

Zhang, X., & Schreifels, J. (2011). Continuous emission monitoring systems at power plants in China: Improving SO2 emission measurement. Energy Policy, 39(11), 7432-7438. https://doi.org/10.1016/j.enpol.2011.09.011.

The Authors

Dr. Ravi Prakash Srivastava is PhD in Botany from the University of Lucknow, where he worked as a CSIR-Junior Research Fellow (JRF) and Senior Research Fellow (SRF) for six years. He has successfully qualified for several competitive exams, including the Council for Scientific and Industrial Research (CSIR)-National Eligibility Test (NET), CSIR-JRF, Graduate Aptitude Test in Engineering (GATE) and Course on Computer Concepts (CCC). Dr. Srivastava has received 03 Best Research Paper Awards and Best Thesis award i.e. "**Ruchi Ram Sahani Award**" from the Lucknow University. Additionally, he has also been recieved **Letter of Appreciation** for his outstanding research work from the **Hon'ble Governor Anandiben Patel, GoUP**. His scholarly contributions include the publication of more than sixteen research papers and four book chapters in peer-reviewed international reputed journals. Currently, he is working as Research Associate at the Directorate of Environment, Gomti Nagar, Lucknow, Uttar Pradesh, India.

Dr. Ravi Prakash Srivastava (Research Associate)
Directorate of Environment, Gomti Nagar, Lucknow, Uttar Pradesh

Sahil Kumar is M.Sc in Environmental Science and Technology from the Institute of Environment and Sustainable Development (IESD), Banaras Hindu University (BHU), Uttar Pradesh. He successfully qualified the National Testing Agency (NTA)-National Eligibility Test (NET) Exam in Environmental Sciences. Currently, he is working as Research Associate at the Directorate of Environment, Gomti Nagar, Lucknow, Uttar Pradesh, India.

Sahil Kumar (Research Associate)
Directorate of Environment, Gomti Nagar, Lucknow, Uttar Pradesh

Mr. Ashish Tiwari is a highly motivated Senior Executive, a member of Indian forest service (IFS), with more than 25 years of proven success spanning across Policy and Planning Level senior positions namely Secretary (Environment, Forest & Climate Change, Government of Uttar Pradesh), Member Secretary (Uttar Pradesh Pollution Control Board), Member Secretary (UP State Climate Change Authority), Member Secretary (Uttar Pradesh Environment Impact Assessment Authority). He possesses a strong professional background with technical, theoretical and practical educational from Indian Institute of Technology (IIT), Delhi and Forest Research Institute (FRI), Deemed University (Indira Gandhi National Forest Institute), Dehradun. His skills include the application of innovative technologies application, online monitoring system & virtual monitoring system for pollution control, pollution abatement planning, environmental compliance & awareness, climate change mitigation and natural resource conservation.

Mr. Ashish Tiwari,
Secretary, Environment, Forest & Climate Change Department, GoUP

Scan to download the study

Uttar Pradesh Climate Change Authority

Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

India T: +91 (0) 0522-2300541 | doelkoup@yahoo.com | upenv.upsdc.gov.in

Uttar Pradesh Climate Change Authority

Directorate of Environment
Vineet Khand-6, Gomti Nagar, Lucknow, Uttar Pradesh 226010

India T: +91 (0) 0522-2300541 | doelkoup@yahoo.com | upenv.upsdc.gov.in