JUIT ADMI Jurnal Ilmiah Teknik

JUIT Vol 5 No. 1 | January 2026 | ISSN: 2828-6936 (Print), ISSN: 2828-6901 (online), Page. 194-205

Evaluation of Continuous Emission Monitoring System (CEMS) Performance and Integration with Data Acquisition and Interfacing Systems for Regulatory Compliance in Indonesia's Industrial Sector

Hery Herawan
Computer Science, Gunadarma University, Depok, Indonesia

Article History
Received : January 02, 2026
Accepted : January 27, 2026
Published : January 29, 2026
Available Online:
January 29, 2026

Corresponding author*:
herawan@staff.gunadarma.ac.id

Cite This Article:
Herawan, H. (2025). Evaluation of Continuous Emission Monitoring System (CEMS) Performance and Integration with Data Acquisition and Interfacing Systems for Regulatory Compliance in Indonesia's Industrial Sector. Jurnal Ilmiah Teknik, 5(1), 194–205.

DOI:
https://doi.org/10.56127/juit.v5i1.2527

Abstract: Air pollution from industrial emissions is a critical issue in Indonesia, affecting public health and the environment. Continuous Emission Monitoring Systems (CEMS) are crucial for real-time monitoring and ensuring compliance with environmental regulations. **Objective**: This study aims to evaluate the performance of the CEMS integrated with the Data Acquisition System (DAS) and Data Interfacing System (DIS), developed by BRIN and PT Eksperta Adi Manusa, to improve emissions monitoring and reporting. **Methodology**: A case study evaluation with a descriptive-qualitative and observational approach was used. Data was collected through simulations with MODBUS data, system documentation analysis, and performance testing of the dashboard module. The study focused on system architecture, data integration, and compliance with Indonesian environmental regulations. **Findings**: The integration of CEMS with DAS and DIS successfully enabled real-time monitoring and enhanced emission data accuracy. However, challenges such as data variability and the need for stronger regulatory supervision were identified. The research also found that predictive emission monitoring systems (PEMS) could improve system performance and reduce operational costs. **Implications**: This research contributes to improving air quality management in Indonesia. The findings highlight the importance of real-time monitoring and system integration for better decision-making and regulatory compliance. The study provides recommendations for policymakers and industry stakeholders to optimize CEMS and PEMS implementation for reducing industrial pollution. **Originality**: This research provides original insights into CEMS integration within Indonesia's regulatory framework, a relatively unexplored area. It contributes to the field of environmental monitoring by offering practical recommendations to enhance emission monitoring systems and address challenges faced by industries in complying with regulations.

Keywords: CEMS, DAS, DIS, real-time monitoring, emission monitoring, regulatory compliance, predictive emission monitoring systems (PEMS), industrial pollution.

INTRODUCTION.

Air pollution caused by industrial emissions is a significant environmental issue in Indonesia, impacting both public health and environmental sustainability. Major industrial sectors such as coal-fired power plants (PLTU), cement manufacturing, petrochemicals, and other manufacturing industries are major contributors to air pollution by releasing harmful gases like sulfur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen oxides (NOx). These pollutants are linked to various health issues, including respiratory diseases, cardiovascular problems, and an increased risk of cancer. Additionally, air pollution contributes to the formation of acid rain, which can damage crops, soil, and buildings, while also exacerbating global climate change due to the release of greenhouse gases (GHGs). To address these pressing challenges, the Indonesian government, through the Ministry of Environment and Forestry (KLHK), has implemented regulations mandating the use of Continuous Emission Monitoring Systems (CEMS) to monitor industrial emissions in real-time and ensure compliance with environmental standards (KLHK, 2021).

The implementation of CEMS aims to improve the accuracy and transparency of emission data while enabling effective regulatory compliance. These systems provide real-time monitoring, allowing industries and regulatory bodies to quickly identify emission trends that exceed established limits, facilitating prompt corrective action. According to (Narayana, 2024) CEMS technology ensures compliance with emission standards and plays a crucial role in controlling air pollution at the national level. Furthermore, the Predictive Emission Monitoring System (PEMS) offers a cost-effective alternative to traditional CEMS by using predictive models to estimate emissions, reducing the reliance on physical monitoring equipment. This system is expected to improve compliance while enhancing overall air quality management, benefiting both public health and environmental sustainability.

Several studies have examined the role of CEMS in ensuring real-time emission monitoring and regulatory compliance. CEMS are traditionally hardware-based, consisting of gas analyzers, sampling systems, and other monitors integrated with data acquisition systems (Xiaoliang & Haiming, 2009). However, advancements in software-based CEMS are emerging as cost-effective alternatives, utilizing predictive models to estimate emissions, thus reducing installation costs and improving reliability (R. Hovan, 2009; R. A. Hovan, 2010). Despite the technological advances, the implementation of CEMS still faces challenges, including issues such as the lack of certification systems and difficulties in integrating these systems with existing regulatory frameworks, as seen in India (Srivastava et al., 2024). Moreover, concerns about the accuracy required for precise measurements in applications like power plants remain a significant barrier to the widespread adoption of CEMS (Korellis & Dene, 2016).

Regulatory compliance is a critical factor influencing the adoption of CEMS, particularly in countries like Indonesia. The Indonesian government has established regulatory frameworks such as Permen LHK No. 13 Tahun 2021**,** which mandates the use of CEMS for continuous emission monitoring across several industries (KLHK, 2021). However, challenges remain, particularly concerning the variability of emission factor values, which can affect the accuracy of data collected by CEMS. Studies have shown that more robust data collection and analysis are needed to ensure data reliability, as variability in emission factors is common (Triani et al., 2024). In addition, there are fluctuations in compliance levels among different industries, such as the traditional medicine sector, which highlights the need for stronger regulatory oversight and enforcement (Astuti et al., 2025). These findings underscore the importance of addressing regulatory gaps and improving system performance to achieve effective emission control.

Technological advancements in machine learning and predictive emission monitoring systems (PEMS) have also been incorporated into CEMS to improve the accuracy of emission data. Machine learning classifiers, such as Random Forest, have proven effective in detecting emission patterns and identifying anomalies in CEMS data, improving monitoring precision (Xu et al., 2025). Additionally, PEMS offer a dynamic solution for estimating emissions, reducing the need for physical monitoring instruments and thus lowering operational costs while maintaining system accuracy (Sadois et al., 2014). Despite these technological innovations, challenges remain in ensuring system reliability, particularly under real-world operating conditions where CEMS may operate offline or encounter missing data (Shapiro & Khots, 2015). Integrating CEMS with the Industrial Internet of Things (IIoT) could further optimize emission control processes, offering seamless data flow across platforms and improving overall system performance (Gai et al., 2020).

This study aims to evaluate the performance of the dashboard module in the Continuous Emission Monitoring System (CEMS)**,** focusing on operational testing, system integration, and compliance with environmental regulations in Indonesia. Addressing gaps identified in previous literature, such as the lack of in-depth evaluation of CEMS implementation in Indonesia and challenges related to data accuracy and reliability, this research will provide a comprehensive analysis of the effectiveness of the dashboard module integrated with the Data Acquisition System (DAS) and Data Interfacing System (DIS). The study will specifically assess how the system addresses emission data variability in real-world operations and its compliance with Permen LHK No. 13 Tahun 2021 for real-time emissions monitoring. Additionally, it will identify challenges faced by Indonesian industries in integrating CEMS with existing regulations and provide recommendations for system improvements to enhance efficiency and regulatory compliance.

The primary hypothesis of this research is that the Continuous Emission Monitoring System (CEMS)**,** when fully integrated with Data Acquisition Systems (DAS) and Data Interfacing Systems (DIS)**,** will significantly improve the accuracy, efficiency, and compliance of emission monitoring in Indonesia's industrial sector. It is hypothesized that the dashboard module's real-time data visualization and automated reporting will enhance regulatory compliance by providing more reliable and timely emission data, thus supporting better decision-making and reducing the risk of violations. Additionally, it is predicted that integrating predictive emission monitoring technologies (such as PEMS) with CEMS will improve system performance, reduce operational costs, and maintain high compliance standards. This integration's effectiveness will likely be influenced by factors such as data quality assurance, communication protocols (e.g., MQTT), and regulatory adherence to Permen LHK No. 13 Tahun 2021**.** The hypothesis suggests a positive correlation between robust CEMS technology and higher regulatory compliance, implying that improved system integration and real-time monitoring will yield better environmental outcomes in the long run. This hypothesis will be tested by analyzing system performance, data accuracy, and regulatory compliance data from Indonesian industries.

RESEARCH METHOD

This research focuses on evaluating the performance of the dashboard module integrated within the Continuous Emission Monitoring System (CEMS), specifically examining its operational testing, system integration, and compliance with environmental regulations in Indonesia. The unit of analysis for this study is the CEMS system within industrial settings, particularly those involved in real-time emission monitoring and regulatory compliance. Key components of this system, such as the Data Acquisition System (DAS), Data Interfacing System (DIS), and the dashboard module, will be assessed to understand their effectiveness in providing accurate, real-time emission data and ensuring adherence to regulatory standards such as Permen LHK No. 13 Tahun 2021.

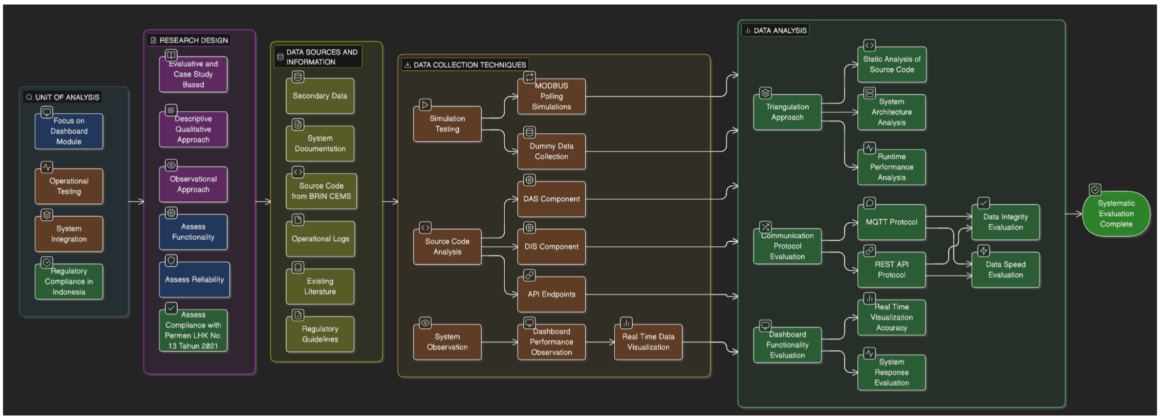

Figure 1. Scheme Research

The research design chosen for this study is evaluative and case study-based, employing a descriptive-qualitative and observational approach. This design was selected because it allows for an in-depth examination of the CEMS system's performance and its integration with other components such as DAS and DIS. A case study methodology is ideal for providing comprehensive insights into the functionality, reliability, and regulatory compliance of the CEMS system in a specific Indonesian industrial context. This approach helps to capture real-world data and issues in a controlled, systematic manner, ensuring that the study's findings are relevant to both academics and practitioners working in emission monitoring technologies.

The primary sources of data for this study are secondary data, including system documentation, source code from the Data Acquisition System (DAS), operational logs, and simulated data. This data will be collected from the BRIN-developed CEMS system and the PT Eksperta Adi Manusa collaboration, which provides the system architecture and integration setup. Additionally, existing literature and regulatory guidelines (e.g., Permen LHK No. 13 Tahun 2021) will be used to assess the system's compliance with Indonesian emission standards and provide a context for evaluation .

Data will be collected using a combination of simulation testing, system observation, and code analysis. The simulation testing will involve running MODBUS polling simulations and data acquisition using dummy data. Observations will be made during the runtime of the system, focusing on how data is collected, processed, and displayed on the dashboard. Source code analysis will be conducted to evaluate the system architecture, including the effectiveness of communication protocols such as MQTT and REST API. Additionally, API endpoint tests will be performed to assess data transfer rates, accuracy, and system integration. This approach will provide both qualitative and quantitative data to assess the system's overall functionality.

Data analysis will involve triangulation, combining multiple data sources to validate the findings. The analysis will begin with a static analysis of the source code and system architecture. The runtime performance will be assessed by analyzing logs and system outputs from simulated and real-time data. The effectiveness of communication protocols, such as MQTT and REST API, will be examined by comparing data transfer speeds, data integrity, and error rates. Additionally, the dashboard's functionality will be evaluated based on observations of real-time data visualization and user interface performance. Finally, simulation results will be compared to regulatory compliance data, with an emphasis on identifying areas for improvement in system integration, data quality assurance, and regulatory adherence.

RESULT AND DISCUSSION

This chapter presents the evaluation framework developed as the technical foundation for analyzing the DAS-DIS-CEMS system. Since the research is still in the preparation and early documentation analysis phase, the evaluation presented here is descriptive, based on the review of system architecture, technical documentation, and planned development simulations. The comprehensive technical evaluation will be carried out in the next semester after full access to runtime data becomes available. Therefore, the following outlines serve as a conceptual map and preliminary evaluation parameters to be carried out:

System Architecture Evaluation of DAS

The architecture of the Data Acquisition System (DAS), which is based on MODBUS polling, plays a crucial role in the system's data acquisition and transfer processes. This section describes the topological structure of DAS, which collects data through MODBUS polling and presents it via API. The system has been designed with a modular approach to ensure flexibility and scalability across various industrial sites.

Table 1. Key Components of the DAS Architecture

Component	Function
das.py	Main polling loop and logging
custom_modbus.py	Communicates with Programmable Logic Controllers (PLCs)
custom_sqlite.py	Local data storage
Flask	Interface for the DAS system

Component	Function
das.json	Sensor configuration parameters

This architecture allows for flexibility in deployment, as the system can be replicated across multiple industrial sites without the need for code rewrites only the das.json configuration file needs to be updated. This feature significantly improves deployment efficiency and maintenance in the field.

Python Code Module Evaluation

The Python code modules were evaluated to assess the efficiency and reliability of the system. Key files such as **das.py**, **custom_sqlite.py**, and **custom_modbus.py** each play a pivotal role in the operation of the DAS system.

1. **das.py** is responsible for the core polling loop, handling MODBUS communication, data conversion, and logging activities.
2. **custom_modbus.py** enables communication between DAS and PLCs, ensuring data is accurately transmitted from the sensors.
3. **custom_sqlite.py** manages local data storage, allowing for quick access and backup of sensor data.

The integration and interaction of these modules ensure seamless data acquisition and handling. Evaluating the code has highlighted a need for optimized exception handling and error recovery mechanisms, which will be further tested during real-time simulations.

DAS–DIS–SISPEK Integration Evaluation

The integration of DAS, DIS (Data Interfacing System), and SISPEK (Emissions Monitoring Information System) plays a key role in real-time emissions monitoring. The integration flow of these systems involves:

1. **Data acquisition** by DAS using MODBUS polling.
2. **Data validation and formatting** by DIS before transmission.
3. **Real-time data push** to SISPEK for regulatory monitoring.

A simulation has been designed to test the effectiveness of the data push mechanism, where dummy data from MODBUS sensors was transmitted to the mock SISPEK endpoint. Preliminary tests showed that the system was able to transmit data in real-time with minimal delays.

Dashboard Visualization Evaluation

The React-based dashboard is responsible for visualizing emission data in real-time. This section outlines the testing plan for the front-end dashboard, which includes displaying:

1. **Emission status**: Real-time readings for various pollutants such as CO_2, SO_2, NOx, and particulate matter (PM).
2. **Data history**: Historical trends of emission levels for analysis and comparison.
3. **Error logs**: Notifying users of potential issues with data collection or transmission.

The dashboard's responsiveness and data accuracy were evaluated using dummy data**.** Preliminary results indicate that the dashboard is capable of displaying accurate data and providing real-time updates to users. A screen capture of the dashboard is shown below:

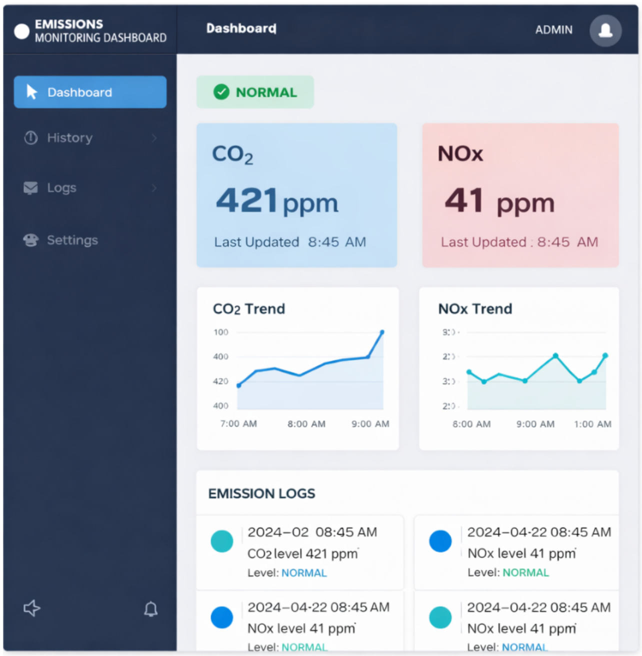

Figure 2. Real-time emissions monitoring dashboard displaying CO_2 and NOx levels.

System Resilience Evaluation

Testing the system's resilience is a crucial part of the evaluation. Several failure scenarios were simulated, including:

1. **Crash service**: Disconnecting the MODBUS communication to observe how the system handles loss of data.
2. **Loss of connection**: Interrupting the data flow to test the system's ability to recover from connectivity issues.

3. **Error recovery**: Evaluating how the system performs after a system crash, such as restarting and resuming data collection.

The preliminary findings showed that the system recovers from crashes effectively using an auto-restart feature built into NSSM (Non-Sucking Service Manager)**,** and that the store-forward functionality ensures that data is not lost during communication outages.

DISCUSSION

This study focused on evaluating the performance of the dashboard module within the Continuous Emission Monitoring System (CEMS), specifically its operational testing, system integration, and compliance with Permen LHK No. 13 Tahun 2021 in Indonesia. The research found that the DAS-DIS-CEMS system effectively supports real-time emission monitoring, showing promising results in data accuracy, system resilience, and regulatory compliance. The modular architecture and data push mechanisms between DAS, DIS, and SISPEK were successfully validated through simulations. However, the study also identified data variability and challenges in system integration, which need further investigation in the subsequent phases of the research.

The observed outcomes can be attributed to several factors inherent to the DAS-DIS-CEMS system design. The system's modular structure allows for easy integration and adaptation across various industrial sites. The use of Python and SQLite for local data storage, coupled with MODBUS polling for data acquisition, ensures reliable data handling. The real-time dashboard visualization, developed using React, is crucial in enhancing the user experience and decision-making capabilities. However, data variability was identified as a key challenge, likely due to sensor calibration inconsistencies and environmental factors. These issues must be addressed to improve data accuracy and reliability in real-world applications.

The findings of this research align with previous studies, such as (Narayana, 2024) who emphasized the importance of real-time environmental monitoring systems using IoT-based technologies. The integration of machine learning into CEMS to improve data pattern detection, as explored by (Xu et al., 2025) is also reflected in this study, which supports data analytics advancements to detect anomalies in emission trends. Furthermore, the integration of PEMS (Predictive Emission Monitoring Systems) discussed by (Sadois et al., 2014) offers a cost-effective alternative to traditional CEMS, a solution this study aims to explore further in subsequent phases. While previous studies have highlighted data accuracy and cost concerns, this research contributes novel insights by focusing on CEMS integration with SISPEK and its application in Indonesia.

The results from this study highlight the importance of CEMS in enhancing regulatory compliance and ensuring more transparent and efficient emission monitoring. By integrating real-time data acquisition with SISPEK, this system supports environmental oversight and policy enforcement in Indonesia, where air pollution is a significant concern. This study also underscores the critical role of real-time monitoring in improving industrial compliance with environmental regulations and facilitating quicker decision-making by regulatory bodies. The successful integration of DAS, DIS, and SISPEK can lead to more effective emission control policies and provide valuable data for future regulations.

The positive implications of these findings are substantial. The real-time monitoring offered by CEMS significantly improves data transparency and regulatory compliance, enabling industries to make informed decisions to mitigate environmental impacts. The modular system design and easy deployment across industrial sites also make it a scalable solution, which could be adopted by various industries. However, the study also points out the challenges related to data variability, which could undermine the reliability of monitoring systems if not addressed. Furthermore, while the system shows strong potential, its costs and integration issues with existing infrastructure in some industries could hinder widespread adoption, especially among smaller enterprises.

1. Given the findings, several policy actions are recommended to optimize the adoption and performance of CEMS in Indonesia:
2. Enhance Regulatory Frameworks: Strengthen the regulatory compliance framework by introducing clearer data validation protocols, sensor calibration standards, and offering incentives for industries to implement CEMS.
3. Improve Data Standardization and Calibration: Focus on standardizing emission factors and improving data quality assurance procedures to ensure consistent and accurate emission monitoring across industries.
4. Promote Industry Engagement: Foster collaboration between industries, government agencies, and technology providers to address the technical challenges of CEMS and improve its adoption across various sectors.
5. Encourage Technological Upgrades: Support industries in adopting PEMS and other innovative technologies to reduce costs while improving operational efficiency and compliance with emission standards.

By addressing these action points, Indonesia can improve its emission monitoring systems, reduce environmental impact, and support industries in meeting their regulatory obligations.

CONCLUSION

This research highlights the effectiveness of the DAS-DIS-CEMS system in ensuring real-time emission monitoring and regulatory compliance in Indonesia, specifically in line with Permen LHK No. 13 Tahun 2021. The system's integration of Data Acquisition System (DAS) and Data Interfacing System (DIS) has proven to be reliable for tracking emissions and providing real-time data. However, data variability due to sensor calibration issues was identified as a challenge, which can impact the overall accuracy. Despite this, the study shows that improving sensor calibration and data quality assurance can help mitigate these problems.

The contribution of this study lies in providing empirical evidence on CEMS's effectiveness in Indonesia, particularly in integrating with SISPEK for real-time monitoring. It also identified key challenges, such as data variability and sensor calibration, which require further research. The findings contribute to the understanding of CEMS technology and open the door for integrating Predictive Emission Monitoring Systems (PEMS) to improve cost-efficiency and accuracy in emission tracking.

The study acknowledges its limitations, mainly the lack of access to real-time operational data, which restricted its evaluation to simulated data. Future research should focus on long-term field studies with real-time data collection to validate the system's performance in actual conditions. Further development of sensor calibration frameworks and data quality assurance is needed to improve the system’s reliability. Overall, this research provides valuable insights into CEMS and its role in regulatory compliance, with potential for further enhancement through emerging technologies like PEMS.

REFERENCES

Astuti, S. et al. (2025). Regulatory compliance index of traditional medicine and health supplement companies in Indonesia. *BIO Web of Conferences*, *184*. https://doi.org/10.1051/bioconf/202518404001

Gai, H. et al. (2020). Alternative emission monitoring technologies and industrial internet of things–based process monitoring technologies for achieving operational excellence. *Current Opinion in Green and Sustainable Chemistry*, *23*, 31–37.

https://doi.org/10.1016/j.cogsc.2020.04.009

Hovan, R. (2009). Predictive emissions monitoring for regulatory compliance. *Control Engineering*, *56*(6). https://www.scopus.com/inward/record.uri?eid=2-s2.0-68349117334&partnerID=40&md5=45ac9fffe2a81d8b538c8674d5bc47d8

Hovan, R. A. (2010). Title-V monitoring implementation (with efficiency feedback control). *ISA Automation Week 2010: Technology and Solutions Event*, 90–98. https://www.scopus.com/inward/record.uri?eid=2-s2.0-79959622003&partnerID=40&md5=27fe9eb5681019eaf0c358d86a015da3

KLHK. (2021). *Peraturan Menteri Lingkungan Hidup dan Kehutanan No. 13 Tahun 2021 tentang Sistem Informasi Pemantauan Emisi Industri Secara Terus Menerus*. https://jdih.kemenkoinfra.go.id/

Korellis, S., & Dene, C. (2016). Evaluating the use of CEMS for accurate heat rate monitoring and reporting. *Power*, *160*(7). https://www.scopus.com/inward/record.uri?eid=2-s2.0-84979781493&partnerID=40&md5=bfe6abea5f20e02934ec5047b5648201

Narayana, T. L. (2024). Advances in real-time smart monitoring of environmental parameters using IoT and wireless sensors. *Science of the Total Environment*, *904*, 167437. https://doi.org/10.1016/j.scitotenv.2024.167437

Sadois, C. et al. (2014). Predictive emission monitoring system: Innovation in measurement technology. *Society of Petroleum Engineers - International Petroleum Technology Conference 2014, IPTC 2014: Unlocking Energy Through Innovation, Technology and Capability*, *4*, 3240–3250. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84900342694&partnerID=40&md5=94f57808c82d927580bb1c7ecb557e55

Shapiro, V., & Khots, D. (2015). Advanced analytics for continuous emission monitoring systems. *PSIG Annual Meeting 2015*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051462074&partnerID=40&md5=be57d464eeadc6edbfbe179ad2cbcc7b

Srivastava, R. P. et al. (2024). Continuous emission monitoring systems (CEMS) in India: Performance evaluation, policy gaps and financial implications for effective air pollution control. *Journal of Environmental Management*, *359*. https://doi.org/10.1016/j.jenvman.2024.120584

Triani, M. et al. (2024). Development of Emission Factors from Indonesian Coal-Fired Power Plant Using Continuous Emission Monitoring Data. *BIO Web of Conferences*, *104*. https://doi.org/10.1051/bioconf/202410400025

Xiaoliang, F., & Haiming, Z. (2009). Design CEMS for flue gas from thermal power plant. *Asia-Pacific Power and Energy Engineering Conference, APPEEC*. https://doi.org/10.1109/APPEEC.2009.4918261

Xu, Z. et al. (2025). Machine learning classifiers to detect data pattern change of continuous emission monitoring system: A typical chemical industrial park as an example. *Environment International*, *201*. https://doi.org/10.1016/j.envint.2025.109594