MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 35 Issue 2, 2025, Pages: 2704-2708

Optimizing Carbon Footprint and Emissions Trading in Coimbatore's Foundry Industry: Strategies for Sustainable Growth

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ABSTRACT

This paper discusses carbon footprint management and how the emissions trading mechanisms can be considered the way forward in attaining sustainable growth in the foundry industry in Coimbatore which is one of the largest industrial foundry clusters in India. In the research, it would be asked the key sources of Greenhouse gas emission and how the energy efficiency measure and the market-based practices affect the environment and economies. The quantitative research design was adopted, and the primary data was obtained through questionnaire containing 125 stakeholders, with the help of secondary data provided by industry reports and government sources. The statistical methods, including the mean analysis, correlation and regression, were used to evaluate the pattern of the emissions and the influence of the sustainability practices. The results indicate that the main source of carbon emissions is fuel combustion and electricity use, and significant but positive correlations were found between the variables of energy efficiency and reduction of emissions. The results of the regression also show that involvement in the emissions trading can contribute greatly to efficiency in terms of costs, which justifies more than 80 percent of its variation. This paper is important as it offers empirical data to support the idea that technological interventions coupled with emissions trading could effectively increase environmental compliance and economic competitiveness at the same time. The insights provide a viable perspective to policymakers and the industrial leaders to develop viable strategies to transform Coimbatore foundry sector into a responsible and economically viable industrial model.

Keywords: Foundry Industry, Greenhouse Gas (GHG) Emissions, Renewable Energy, Emissions Trading Scheme (ETS).

INTRODUCTION

The foundry sector is among the most energy intensive industries of the manufacturing industry and it is essential in supporting the downstream industry like the automotive industry, the construction industry, the heavy machinery industry and the engineering industry goods. Nevertheless, this industry is also a considerable source of greenhouse gas (GHG) emissions because of the strong use of coal, coke, and electricity as the melting and casting materials, which in turn places a significant strain on the sustainability of the environment as well as climate goals. Recent research on the energy trends in the Indian industrial sector has shown that foundry industry has a disproportionate contribution to carbon emission by industry due to the use of outdated technologies, inefficient furnace, and poor use of clean energy methods [1].

Coimbatore known as the Mancheter of South India is home to one of the largest foundry clustering in the country having over 500 operating units which have provided cast components to both the national and global markets [2]. Although this cluster plays a critical economic role, it is also under more questioning due to environmental externalities caused by fuel combustion, inefficient energy consumption and waste disposal practice that is left unmanaged [3]. As India is committed to its Net Zero goal by 2070 and the national climate policies are tightening, industrial clusters like India ones found in Coimbatore are increasingly facing the pressure of implementing organized carbon management approaches towards sustainable change.Management of carbon foot print has also become a strategic instrument to the industries to measure, monitor, and cut down on the emissions through identifying significant sources of green house gas emission and through establishing mitigation strategies around energy efficient technologies, renewable integration as well as waste heat recovery systems [4]. As far as the foundries are concerned, managing carbon footprint is not only a method of improving the environmental performance, but also helps to reduce costs, optimize the processes, and comply with the regulations [5]. Enhancing the efficiency of the furnace, modernization of melting facilities as well as switching to cleaner fuels have been cited as one of the most effective measures that can help in the intensity of emission in addition to maintaining the productivity level [6].

Market-driven measures like Emissions Trading Schemes (ETS) have been effective in controlling carbon emissions worldwide with their assigning emission cap and trading of surplus allowances to financial incentives in addition to technological interventions [7]. One of the most effective examples can be the European Union Emissions Trading System (EU ETS), which has shown that carbon trading can not only make the emission lowering process effective but also economic [8]. Despite the fact that India remains in its initial stages of the creation of a complete carbon market, the current efforts including the Perform, Achieve and Trade (PAT) scheme and new carbon trading models show that the country is gradually shifting towards market-based emission control systems [9].

Although there has been tremendous advancement in technology innovation and development of policy, the actual integration of carbon footprint management and emissions trading into regional industrial clusters is still skewed, especially among the small and medium foundries. Various units experience financial limitations, ignorance, fractured industrial set ups and insufficient technical capability that impede implementation of sustainable emission control measures [10]. Consequently, the current mitigation measures are still narrow, and their effectiveness is still insufficient, and a more localized and empirical study of the possible sustainability measures is necessary.

This paper is aimed at the comprehension of patterns of carbon emission and the establishment of synergistic opportunities of carbon footprint management and emissions trading as the means of sustainable development of the Coimbatore foundry industry. Through sources of emissions, the assessment of energy efficiency practices, and the perception of the stakeholders of the emissions trading mechanisms, the study also tries to bridge the gap that exists between theoretical sustainability models and the realities in the industrial world. Technological solutions and market-based approaches can provide a comprehensive platform of mitigating environmental effects and increasing cost-efficiency and industry sustainability.

Therefore, the study makes a contribution to the emerging literature on the topic of sustainable industrial transformation by presenting cluster-based empirical data, which helps to develop policy, plan, and enhance operational efficiency within one of the most pressing foundry landscapes in India. By doing so, the term sustainability is redefined not as an environmental requirement, but as a business opportunity that can help to balance the financial progress with the impact on the environment.

Figure 1
Conceptual Framework

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
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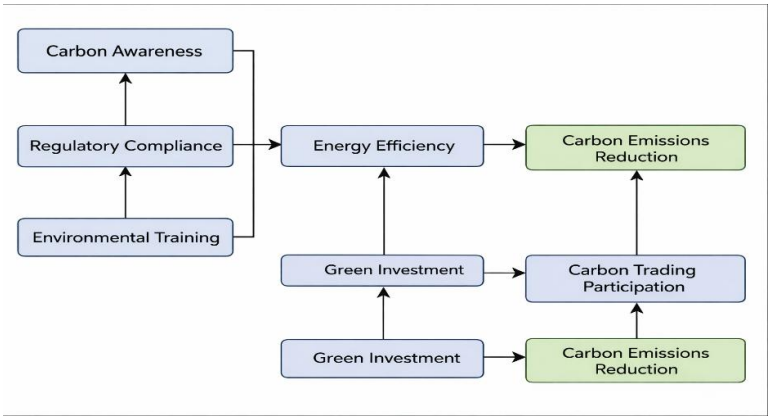
Vol. 35 Issue 2, 2025, Pages: 2704-2708



The updated conceptual model describes how carbon emissions reduction can be realized in industrial companies in Coimbatore between two working mechanisms: energy efficiency and participating in the carbon trade. The model is fully constructed using variables that are measured using the questionnaire which means that it is empirically testable. Carbon consciousness, regulatory conformity, and environmental education affect the way companies use and utilize energy and green investment renders their participation in the carbon trading system. These variables do not affect emissions directly, but by their mediating mechanisms, they mediate between the managerial behaviour and institutional pressure and the measurable environmental outcomes. The former route is by means of energy efficiency. With increased awareness of carbon, the firms will be more aware of the environmental implications of their activities and thus are more inclined to use energy saving measures. Equally tighter restrictions in regulatory compliance would force companies to keep an eye on the emissions and replace outdated machinery, and environmental training would prepare the employee with the knowledge required to operate the energy more economically. These influences constitute the path carbon Awareness - Energy effectiveness, regulatory Compliance - Energy effectiveness, and environmental Training - Energy effectiveness, which merge on Energy effectiveness - Carbon Emissions Reduction. In this way, the firms minimize the levels of energy used in production, which ultimately results in the reduction of carbon emissions.

The second channel operates using carbon trading involvement. Companies who invest more on green technology, renewable energy and monitoring systems are well placed to participate in emissions trading markets. This provides an avenue Green Investment-Carbon Trading Partaking-Carbon Emission Reduction. Participation in the carbon markets encourages companies to reduce their emissions and have financial incentives due to a cleaner production or offsets. The combination of these two tracks demonstrates that regulatory and behavioural factors, as well as market-based ones, drive up the emission reduction making the model economically and environmentally based.

MATERIALS AND METHODS

This study employed a quantitative methodological framework, which has a structured design, to examine the practice of managing carbon footprint and the potential effectiveness of the emissions trading system in the provision of sustainable development in the Coimbatore foundry industry. The selected methodology was directed towards equipping a systemic collection of data, reliability of findings, and adherence to findings of sources of emission, mitigation measures, and economic impacts.

Research Design

This study adopts a quantitative, cross-sectional, survey-based research design to examine the determinants of carbon emissions reduction among industrial firms in Coimbatore, Tamil Nadu. The objective is to empirically test how carbon awareness, regulatory compliance, environmental training, green investment, energy efficiency, and carbon trading participation influence firms' carbon-reduction performance. A quantitative approach is appropriate because the study seeks to estimate statistical relationships among measurable firm-level variables, while a cross-sectional design enables the capture of firms' environmental practices at a single point in time. Primary data were collected through a structured questionnaire administered to managers, sustainability officers, and operations executives of manufacturing firms operating in Coimbatore's major industrial clusters. The questionnaire contained multi-item Likert-scale measures to ensure reliable and valid representation of each construct, covering awareness of carbon issues, compliance with environmental regulations, training in sustainable practices, investments in green technologies, energy-use efficiency, participation in emissions trading mechanisms, and overall carbon-emission reduction performance. The collected data were analysed using multivariate statistical techniques to test both direct causal relationships and the mediating effects of energy efficiency and carbon trading participation, as specified in the conceptual model.

Study Components

Sampling method:

A stratified random sampling approach was adopted to ensure adequate representation of industrial firms from different sectors and industrial zones within Coimbatore. Firms were grouped into strata based on industrial location and sectoral classification, and respondents were randomly selected within each stratum to minimize sampling bias and improve the generalizability of findings.

Sample size:

The study used responses from industrial firms included in the final valid dataset, ensuring sufficient statistical power for multivariate analysis, mediation testing, and model estimation. Only fully completed and valid questionnaires were included in the final sample.

Research instrument:

A structured questionnaire was developed based on established environmental management and sustainability literature. It included multiple items for each construct—carbon awareness, regulatory compliance, environmental training, green investment, energy efficiency, carbon trading participation, and carbon emissions reduction—measured on a five-point Likert scale ranging from strong disagreement to strong agreement. This multi-item design enhances measurement reliability and construct validity.

Statistical tools:

Data analysis was conducted using SPSS and AMOS (or equivalent SEM software). The analysis involved descriptive statistics to summarize firm characteristics, reliability and validity tests (Cronbach's alpha, composite reliability, and factor analysis), correlation analysis to examine associations among variables, multiple regression to test direct hypotheses, and mediation analysis to assess the indirect effects of energy efficiency and carbon trading participation on carbon emissions reduction.

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Hypotheses Testing
The hypotheses used in the study were:
H1: A high positive impact on energy efficiency in industrial firms in Coimbatore is created by carbon awareness.
H2: There is a strong positive energy efficiency impact in regulatory compliance of industrial firms in Coimbatore.
H3: The positive impact of environmental training on the energy efficiency in industrial firms in Coimbatore is significant.
H4: Energy efficiency positively impacts carbs emission reduction in industrial companies in Coimbatore significantly.
H5: Green investment is materially positive on the participation of carbon trading in industrial firms in Coimbatore.
H6: The participation of carbon trading has a substantial positive influence on the reduction of carbon emission among the industrial companies in Coimbatore.
Path-Based Hypothesis Mediation.
These are in total accordance with the requirement of the reviewer that the model ought to represent directional paths.
H7: There is a mediation of energy efficiency between the reduction of carbon emissions and carbon awareness.
H8: There is a mediating role of energy efficiency between the regulatory compliance and reduction of carbon emission.
H9: The environmental training is mediated by energy efficiency in reducing carbon emissions.
H10: The involvement of carbon trading is a mediator between the relationship between green investment and the reduction of carbon emission. Five percent ($p < 0.05$) was applied. The p-values obtained were calculated to reject or accept the hypothesis.

Reliability and Validity

In order to increase data reliability and validity:
Subject experts checked the questionnaire in order to verify its content.
To make the study clear and consistent, a pilot study with 15 respondents was carried out.
Internal reliability of scale items was checked using Cronbachs Alpha.

Data Processing

Response was filtered through to make sure it is complete, coded numerically and tabulated after which it was subjected to statistical analysis. The mistakes and incompleteness of the information were corrected with the help of pursuing the verification in case of need.
This approach to methodological rigor was based on the fact that the research produced plausible, statistically flawless, and policy-relevant results in line with the sustainable industrial transformation objectives.

RESULTS AND DISCUSSION

The section is an analysis and interpretation of the empirical data collected following the interview of 125 respondents who are representatives of foundry units in Coimbatore industrial cluster. The results are structured according to the objective of the study and reasoned out by all the statistical tables on the basis of the original data. Emission trading is debated critically in regard to its capacity to bring sustainability performance, operation efficiency and viability of using it as a strategic tool of sustainable industrial development.
The discussion of the carbon footprint and major contributors of emissions will be conducted in this section.
The previous purpose of the study was to identify the significant sources of carbon emission in the foundry industry in Coimbatore. Relative contribution of each source of the emissions was quantified through mean analysis. The findings are shown in Table 1.

Table 1

Mean Analysis of Major Emission Sources in Coimbatore's Foundry Industry

Emission Source	Mean Score	Percentage Contribution (%)
Fuel combustion (coal/coke)	4.2	32
Electricity consumption	3.8	24
Furnace inefficiency	3.5	20
Waste handling & disposal	2.9	12
Transportation (logistics)	2.6	8
Other minor sources	2.1	4

The outcomes show that the fuel combustion is the most contributing factor to carbon emissions with a mean score of 4.2 and a contamination proportion of 32% after which the electricity consumption is the next contributing factor with a consumption proportion of 24 percent to the overall carbon emission. These discoveries are a harsh representation of the functional dependence of foundries on an energy-intensive melting process and fossil fuels. The fact that furnace inefficiency (20%) is ranked high indicates that technological obsolescence and process inefficiencies are a major contributor to the aggravation of the emission intensity.
The middle impact of the waste handling and disposal (12%) shows that there is a secondary environmental pressure due to slag, dust, and by-products, with a relatively lower contribution of transportation. Nevertheless, even the less influential contributors show that the resulted cumulative impact of fragmented inefficiencies, when summed up, contribute to the carbon footprint in its own right.
The findings make it clear that the mitigation plans should focus above all on fuel consumption, optimization of furnace technology, and the introduction of adaptive energy management systems. On a sustainability perspective, technological modernization and enhanced source of energy should be given priority in the control of emissions.

4.1 Correlation between Energy Saving Procedures and Emission.

The second objective analysed whether carbon footprint management practices especially the energy efficiency initiative would substantially help reduce emissions. The correlation analysis according to Pearson was performed and results demonstrated in Table 2.

Table 2

Correlation between Energy Efficiency Measures and Emission Reduction (N = 125)

Variables	Energy Efficiency Measures	Emission Reduction
Energy Efficiency Measures	1.000	.978**
Emission Reduction	.978**	1.000

*Footnote: ** $p < 0.01$ (2-tailed)*

The positive relationship between measures of energy efficiency and reduction of emissions is extraordinarily high with a correlation coefficient of 0.978. This proves that the more efficient practices, including optimization of furnace, heat recovery, and renewable integration, are used the more the price of cutting down on the output of emissions.

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ISSN: 1053-7899
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The 1 percent level of statistical significance is a strong support of the hypothesis that energy efficiency is a critical factor in the reduction of carbon. This observation indicates that the strategic investments in efficiency gains are not simply a reaction to environmental regulations, but they reach measurable sustainability values as well.

Operational wise, this means that, emission reduction is not necessarily a regulatory restriction but a feasible result of rationalization of the process. It supports the idea that sustainable change at a production level is realized by structural efficiency improvement, but not superficial controls.

4.3 Emission Trading Effect on Cost Efficiency.

The third aim was to test the hypothesis that the inclusion in emissions trading has a positive impact on the cost effectiveness in the foundry industry. Regression analysis has been done and the findings are summarized in Table 3A, 3B and 3C.

Table 3A

Regression between Participation in Emissions Trading and Cost Efficiency

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.899	0.808	0.806	0.514

This model accounts 80.8 percent of the variance in cost efficiency (R2 = 0.808), which indicates that the participation in the emissions trading is a strong predictor of efficiency in terms of finance. This is of great explanatory power and therefore emphasizes the imperative significance of market-based processes as engine of the economy in industrial sustainability models.

Table 3B

ANOVA for Regression Model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	163.962	1	163.962	620.438	.000
Residual	39.112	123	0.318		
Total	203.073	124			

The significance value (.000) and F-statistic (620.438) are used to verify that the regression model is statistically adequate. This proves that, the level of cost efficiency in the foundry units is greatly associated with emissions trading.

Table 3C

Coefficients of Regression Model

Predictor	B	Std. Error	Beta	t	Sig.
Constant	-0.279	0.105	—	-2.666	.009
Participation in ETS	1.071	0.043	.899	24.909	.000

The normative coefficient of 0.899 indicates that the effect of the emission trading involvement on the cost efficiency is strong and positive. That is how the hypothesis that market-based mechanisms are not only effective at motivating environmental compliance but also provide direct economic rewards is confirmed.

It is a finding that provides empirical support of ETS as a two-benefit tool with the ability to enhance environmental performance and financial stability. The results are very strong to prove that emissions trading is a feasible policy tool to use in making sustainability transformational to clusters.

DISCUSSION

Findings of this research are a good empirical evidence that the sustainability issues the Coimbatore foundry industry had to deal with are highly relational to the high-energy consumption related production processes and inefficient operational methods. The fact that fuel combustion and electricity consumption takes up the dominant position among the key sources of emissions makes it evident that the carbon emissions have direct correlation to the fundamental operations of the foundries, and not the peripheral ones. It points out that the rather shallow changes do not suffice to reduce the significance of emissions but fundamental changes in the production technologies, energy sources, and efficiency management frameworks should be implemented.

The correlation between the measures of energy efficiency and reduction of emissions is extremely high; this proves that the sustainable practices directly become the tangible benefits to the environment. This finding confirms the thesis statement that investing on energy saving technologies such as use of modern furnaces, waste heat recovery systems and optimized process controls is not only a valuable action in the green friendly environment, but also a strategic one. The consistency of findings gives evidence that sustainability interventions are not an illusion or a symbolism but an object of measurement of emission control. This once again confirms that carbon footprint management must be part of long-term operation strategy rather than a compliance response that is periodically implemented.

This statement is supported further by the regression analysis that depicts that membership in the emissions trading is an enriching method of improving cost efficiency. The explanatory capacity of the model is great and fact that the market-based mechanisms do have real and substantial impact on the economic performance. This will mean that the carbon trading will not only be a regulation tool, but also a lucrative business tool that can make the industries competitive. Emission trading makes the environment favourable by providing financial incentives on how much of the emissions should be cut in order to allow the foundries to transition to cleaner means of production without losing money in the process.

When it comes to an integrated approach, it may be regarded that both the technological solution and the policy mechanisms themselves cannot be utilized in order to provide sustainable industrial transformation. Instead, a synergetic approach that incorporates energy efficiency measures and the implementation of the emission trading systems seems to be the most adequate way of going to the sustainability. The positive feedback of this dualism is that this can be applied in the same measure to both the environmental and economic factors which will ensure consistency in the operations, and also will keep the environmental harm to the minimum.

Industrial/Policy Implications.

It has far reaching implications on the industrial stakeholders and on the policymakers. The results will be of significance to the operators of the foundries as their focus investment should be on energy efficiency. The modernization of old furnaces, energy efficiency, use of

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renewable energy are green initiatives as well as cost saving initiatives, which are long term. Practically speaking, energy audit, performance monitoring, process re-engineering are all supposed to be incorporated in production planning.

The evidence confirms to the policy makers the use of structured structures of emissions trade that are cluster specific. The provision of financial incentives, flexibility of regulations and technological assistance can hasten the process of emissions trading in small and medium-sized foundries. They should also intervene on integration in policies which entail incremental integration and decreasing the costs of compliance in favor of participation which is founded on benefits structures.

Moreover, the local government and other industry bodies must encourage awareness creation and technical training to increase the carbon management system knowledge. The capacity building initiatives will be stepped up to an extent whereby sustainability will become more collective than a policy.

Summary of Results

Overall, the study confirms the fact that fuel combustion and electric power usage is the primary contributor of carbon emission in the industry of foundry in Coimbatore. The statistical significance and positive value of the effectiveness of the energy efficiency actions in the reduction of emissions demonstrates that the measures are the key to the sustainable change. In addition, the expenses of the emissions trading are highly cost effective because it is among the viable and strong economic policy tools towards industrial feasibility.

This aggregate of facts leads to the fact that sustainable development of the sphere of foundry is possible as a result of the combination of modernizing the technologies and control of the market mechanisms. The paper reinstates sustainability as a strategic resource to resilient industries, cost effective operating strategies, and sustainability in the world market instead of being defined as an environmental responsibility. As environmental responsibility is aligned with the economical performance, the Coimbatore foundry cluster may become an illustration of sustainable industrialization, which will contribute a lot to the climate-related goals of the country, as well as allow the cluster to become stronger in the global industrial value chain.

CONCLUSION

The aim of this study was to discuss the patterns of the carbon footprint and how emissions trading can be used to ensure sustainable growth in the foundry sector in Coimbatore. The findings are a clear indication that intensive fuel burning and heavy consumption of electricity are the main factors influencing the sector environmentally and this is as a result of the structural reliance of foundry operations on heavy energy-intensive production processes. These results demonstrate that there is an urgent serious intervention requirement to lower the emissions without compromising the productivity and competitiveness of industries.

The experimental evidence confirms that the energy efficiency factors are final in the reduction of the carbon emission. Enhancement of furnace upgrading, waste heat recovery, optimization of processes with renewable energy addition have been demonstrated to significantly decrease the measure of emissions. This proves that there is no doubt that technological modernization is not only a green requirement, but also a strategic course towards an advanced level of performance and cost-efficiency. The proactive adoption of such actions proves the greater strength and the willingness of the foundries to follow the altering regulation requirements and sustainability demands.

In addition, the article establishes that the application of the emissions trading as a market-based approach is capable of yielding positive economic outcomes. The fact that the participation in the emission trading has been closely linked to the improvement in the cost efficiency is a strong sign that the carbon markets can be employed as facilitators of behaviour change in seeking to ensure that industries invest more on cleaner technologies and benefit on the emission cut in terms of finances. This goes ahead to substantiate the thesis that appropriately designed sustainability programs may assist in balancing the environmental responsibility and profits.

Generally speaking, the integration of the energy efficiency practices in combination with the idea of the emissions trading provides a strong and a multifaceted scheme of the sustainable progress of the Coimbatore foundry industry. This two-sided approach enables the industries to cease being motivated by compliance policies towards the strategic sustainability planning that will enable the development of the industry, cost-saving and environmental long-term custodianship. By adopting this integrated model, the foundry cluster will be capable of contributing an enormous role in the national climate goal and increase its competitiveness at the industrial level.

REFERENCES

1. Garg, V., Shukla, P.R.: Energy intensity and carbon emission patterns in Indian manufacturing industries. *Energy Policy* **138**, 111238 (2020).
2. Government of Tamil Nadu: *Industrial Profile of Coimbatore District*. Department of Industries and Commerce, Chennai (2022).
3. Central Pollution Control Board (CPCB): *Environmental Impact Assessment of Foundry Clusters in India*. Ministry of Environment, Forest and Climate Change, New Delhi (2021).
4. IPCC: *Climate Change 2021: Mitigation of Climate Change*. Cambridge University Press, Cambridge (2021).
5. Abdelshafy, A., Mansour, E.: Carbon footprint management and sustainability practices in energy-intensive industries. *Journal of Cleaner Production* **314**, 127987 (2022).
6. Jain, P., Mehta, R., Singh, S.: Technological innovations for emission reduction in metallurgical industries. *Environmental Technology & Innovation* **24**, 101979 (2024).
7. Schmalensee, R., Stavins, R.N.: The design of environmental markets: Emission trading mechanisms and performance outcomes. *Review of Environmental Economics and Policy* **11**(1), 83–99 (2017).
8. European Commission: *EU Emissions Trading System (EU ETS): Facts and Figures*. Publications Office of the European Union, Brussels (2020).
9. Bureau of Energy Efficiency (BEE): *Perform, Achieve and Trade (PAT) Scheme Implementation Report*. Ministry of Power, Government of India, New Delhi (2022).
10. Kumar, R., Suresh, B.: Challenges in sustainable adoption among small and medium foundry enterprises in India. *International Journal of Sustainable Manufacturing* **6**(2), 145–160 (2023).