

HUMAN RESOURCES AS A DETERMINANT OF THE SUCCESSFUL INTEGRATION OF CBAM REQUIREMENTS INTO THE PRODUCT CARBON FOOTPRINT MANAGEMENT SYSTEM

DOI: 10.5937/EMC26144M

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ABSTRACT

The subject of this paper is the consideration of HRM determinants in relation to the quality of Product Carbon Footprint (PCF) data and the success of the integration of CBAM requirements. The framework is based on the Carbon Border Adjustment Mechanism (CBAM), which is implemented as an instrument of the European Union (EU) for equalizing the carbon price in imported products. Calculations, change significantly depending on methodological choices. The transparency of the calculation is often limited, making it difficult to use data in regulatory compliance confirmation processes. Green HRM points out that training, organizational culture and systemic HRM practices contribute to sustainability and performance, emphasizing the role of employee training and intermediary mechanisms through supply chains. The empirical part of the paper is designed as a quantitative-qualitative analysis of the data collected through the survey. The results indicate that organizational readiness and support from top management are key predictors of successful integration of CBAM requirements, while PCF data quality is a critical operational factor, and the impact of HRM practices is significant, but indirect. In conclusion, the integration of CBAM requires a multidimensional approach that goes beyond individual functions and requires the coordinated action of organizational, technological and management capacities.

Key words: Carbon Border Adjustment Mechanism, product carbon footprint, human resource management, data quality, compliance

INTRODUCTION

CBAM is an EU mechanism that introduces a "fair carbon price" for emissions embedded in imports of carbon-intensive goods, with a transitional phase from October 2023 to the end of 2025 and a definitive regime starting in 2026. Although the transitional period focused primarily on reporting, the introduction of the definitive regime, covering authorization, registries, certificates, and annual obligations, raises the issue to the level of systemic compliance (Document 32023R0956, 2023). This requires companies, including exporters outside the EU, to develop the capacity to consistently collect, process, and substantiate data on embedded emissions and PCF. Such a task cannot be reduced to one-off calculations; rather, it requires the management of a comprehensive data system. In parallel with regulatory pressure, methodological literature indicates that PCF results differ significantly depending on the protocol applied (e.g., DEFRA, the GHG Protocol Product Standard, ISO 14067), system boundaries, the treatment of biogenic carbon, cut-off rules, and end-of-life scenarios (Wang et al., 2018). In addition, the transparency and comparability of calculations are often limited. Study (Lange

et al., 2022) presents a 22-item checklist for the transparency of carbon footprint calculations and finds that the average transparency score is low, implying a structural risk for the verifiability of PCF practice (Lange et al., 2022). In practice, CBAM requires the management of precisely those aspects that comparative analyses of PCF protocols identify as challenging: inventory quality, methodological consistency, database selection, and auditability (Wang et al., 2018). Therefore, the central research question of this paper is: Which HRM determinants explain the success of integrating CBAM requirements into the PCF management system through improving PCF data quality and organizational compliance capacities?

LITERATURE REVIEW

CBAM: implications for firms and the need for integration into management systems

Research on CBAM has predominantly applied quantitative and simulation-based approaches to assess effects on trade, investment, carbon leakage, and sectoral vulnerability (Liu et al., 2025; Ren et al., 2025; Siy et al., 2023; Huang et al., 2022). The CBAM mechanism, in fact, serves to counter these risks by imposing a carbon price on imports of certain goods originating outside the EU.

One of the analytical methods used is Difference-in-Differences (DID), a quantitative econometric method applied to estimate the causal effect of a policy or intervention. The method is based on comparing changes in observed variables between an experimental group affected by the policy and a control group not covered by it. Observations are made across two time periods: before and after the implementation of the intervention. In this way, the effect of the policy can be isolated from other factors that may influence the observed change. The DID method is particularly useful in analyses of public policy, labor markets, tax reforms, and environmental regulation. It enables a relatively reliable estimation of causal relationships in situations where controlled experiments are not possible. Using this method, available analysis of Chinese firms finds a positive effect of CBAM on foreign greenfield investment through mechanisms of trade restructuring and innovation incentives (Liu et al., 2025). The Multi-Regional Input-Output (MRIO) model expands traditional input-output models by including multiple regions or countries, thereby enabling analysis of international supply chains and the global distribution of production. Such models are particularly important in research dealing with global trade flows, the analysis of embedded carbon dioxide emissions in products, and the assessment of the environmental effects of international trade. The MRIO approach identifies vulnerable industries and the scenario range of CBAM levies, as well as the buffering role of domestic carbon prices (Ren et al., 2025). Global Trade Analysis Project (GTAP) modeling provides scenario-based estimates of welfare and exports while emphasizing sensitivity to the design of the CBAM mechanism (Siy et al., 2023). Supporting this view, research examining CBAM through evolutionary games—between two key actors, the state and exporting firms and through GTAP-E simulations considers its effects on exports, prices, and trade structure (Huang et al., 2022).

Previous studies systematically indicate that CBAM constitutes a “shock” requiring adaptation in strategies, innovation, and data management (Liu et al., 2025; Ren et al., 2025; Siy et al., 2023; Huang et al., 2022). It is therefore important to emphasize that CBAM is not merely a customs issue but a problem of organizational capability: the capacity to generate and maintain credible PCF data and records throughout the supply chain within the deadlines and formats of the predefined reporting system.

PCF/LCA and data quality as a precondition for compliance

Accurate measurement and management of the product carbon footprint through a verified analysis of its life cycle constitute the basis for ensuring reliable data necessary for regulatory compliance and strategic decision-making. Selected protocols and methodological choices alter PCF results: a comparison of PAS 2050, the GHG Protocol, and ISO 14067 in the MDF case shows significant differences and identifies their causes, including cut-off rules, exclusion rules, and the treatment of carbon storage (Wang et al., 2018). In line with this, a review of LCA simplification approaches

indicates that the LCI phase (inventory) is more data-intensive and that industrial applicability depends on approaches such as parametric models, automation, and screening (Kiemel et al., 2022). A critical review of LCA automation focused on LCI analysis maps automation techniques as a response to the cost and time intensity of data collection (Kock et al., 2023). The quality of results also depends on databases and LCIA implementation: an analysis of packaging shows that database selection (GaBi, ecoinvent 3.6, EF database in openLCA) changes results, especially outside the “climate change” category; and identifies reasons for this, including differences in system boundaries and the regionalization of factors (Pauer et al., 2020). This conclusion is highly important for understanding CBAM, because “embedded emissions” require methodological consistency and verifiable source data. For operational PCF practice, a case study of an Austrian automotive supplier emphasizes the challenges of data collection, the need for structured procedures, and the existence of a large number of PCF calculation and reporting initiatives (Rudele, 2023). Research on parameter uncertainties in carbon footprint calculations shows that such uncertainties affect the magnitude of environmental measures and imply the need for systematic uncertainty management (Rommelfanger et al., 2024). Uncertainty is observed through two components: uncertainty in activity data and uncertainty in the emission factor selected for a given activity. Proper management of uncertainty in these individual components cumulatively results in a better that is, lower overall uncertainty rate in the final calculation.

Green HRM, training, and organizational readiness as determinants of PCF data quality and CBAM integration

Definitions of green human resource management (GHRM) indicate that Green HRM encompasses practices that promote environmentally responsible methods and maps the factors and measurement tools used to assess GHRM (Faisal, 2023). It is a set of good practices aimed at encouraging environmentally responsible employee behavior and integrating sustainability into the everyday functioning of the organization. GHRM is not merely an administrative human resource function; rather, it is an active mechanism through which employee values, competencies, and conscious behavior are shaped for the purpose of environmental protection. Through the long-term cultivation of these principles, firmly embedded in business strategy, organizations achieve ecological maturity, which implies lower risks of errors in the life cycle inventory system, better data quality, and greater confidence in the correct understanding and integration of CBAM reporting through communication patterns directed toward declarants. An evidence-based systematic review further emphasizes the roles of GHRM policies in organizational sustainability, mediated by employees environmental behavior (Benevene, 2020). “Green training” can have both direct effects and indirect effects through supply chain practices, as concluded by a recent scholarly article on environmental training (Barakat et al., 2023). This mechanism is analogous to the focus of the present research: training and HRM policies can influence supplier engagement and the quality of the data required for PCF and CBAM. These insights help organizations align their strategies with environmental sustainability and thereby gain a competitive advantage in the constantly changing business environment of the twenty-first century.

METHODOLOGY

Definitions of key constructs (operationalization of variables)

- Green training intensity (GTI): the degree to which a organization systematically conducts training on LCA/PCF, eco-design, energy efficiency, data management, and CBAM reporting. Knowledge is a fundamental resource of competitive advantage, difficult to obtain through the market but capable of being created through organizational learning (Yu, 2021).
- PCF data quality (PCF-DQ): a multidimensional construct encompassing completeness, consistency and auditability, inspired by transparency and uncertainty issues in PCF studies
- Organizational Green Readiness (OGR): a company readiness to introduce and stabilize sustainability and emissions reporting processes through structures, resources, roles, and culture.

- Top management commitment (TMC): the level of support, investment, strategic priority, and top management involvement in the product carbon management system.
- Supplier engagement (SE): the practice of involving suppliers in providing environmental data, standardizing boundaries, and implementing joint emissions reduction programs.
- ISO 14001 maturity (ISO-M): the degree of institutionalization of the EMS, procedures, internal audits, and continuous improvement as a capacity that may strengthen the implementation of PCF/CBAM processes (Diaz de Junguitu, 2019).
- Success of CBAM requirement integration (CBAM-IS): a producers ability to embed CBAM obligations into operational processes and the PCF system (accuracy and timeliness of reporting, readiness of records for verification, and interoperability with registries and portals).

Research problem and subject matter

The research problem concerns the insufficient understanding of the relationship between human resource management capacities, the quality of carbon footprint data, and the actual readiness of companies in Serbia to respond to the requirements of the European Union's CBAM regulation, particularly in the context of growing regulatory pressures and the need for reliable ESG reporting. Understanding these interdependent elements is exceptionally important because, without adequate human resource management, the competencies required for collecting and processing specific emissions data cannot be developed.

The subject matter of the research encompasses the analysis of the interrelationships among the above-mentioned dimensions at the level of exporting enterprises in Serbia. The study seeks to determine how human resource management capacities in practice affect the quality and reliability of data, and how the quality of those data subsequently shapes an organization's ability to respond effectively to regulatory requirements.

Research objective and Hypotheses

The paper aims to provide companies with a validated organizational-managerial mechanism: HRM - data quality - compliance integration. The research is designed to demonstrate explicitly that, without disciplined management of methodology and data sources, results vary and become difficult to use in regulatory and audit contexts.

The following hypotheses are formulated in the paper:

- H0: Human resource management positively affects the successful integration of CBAM requirements into the product carbon footprint management system.
- H1: (GTI - PCF-DQ) Greater green training intensity positively affects PCF data quality.
- H2: (TMC – OGR) Top management commitment positively affects organizational green readiness.
- H3: (OGR - CBAM-IS) Organizational green readiness positively affects the successful integration of CBAM requirements.
- H4: SE (mediation) Supplier engagement mediates the GTI - PCF-DQ relationship (training improves suppliers data capture capabilities and collaboration).
- H5: (PCF-DQ - CBAM-IS) Higher PCF-DQ positively affects the success of integrating CBAM requirements by reducing non-compliance risk.

Method

The methodological framework of the research is based on a sequential explanatory mixed-method design (QUAN - QUAL), which enables the combination of quantitative and qualitative approaches. The research applies an online survey, the research instrument comprises 30 items distributed across 5 dimensions, including HRM capacities for managing carbon systems, PCF data quality based on standards such as ISO 14067 and the GHG Protocol, CBAM readiness and requirement integration, as well as organizational support and regulatory pressure, along with general company characteristics.

Responses are measured using a five-point Likert scale, enabling the quantification of attitudes. The survey also contains open-ended questions of a qualitative type.

Sample and work plan

The research sample included a total of 10 respondents from companies of different sizes (whose responses represent systems with more than two thousand employees) and industries (iron and steel, aluminum, cement, and others). Most of the companies operate in the European Union market, which further increases the relevance of CBAM regulation for the analyzed context. Linear variables are analyzed by applying a quantitative approach through the analysis of the arithmetic mean of scaled responses within each dimension. Variables examined through the qualitative approach via open-ended questions are based on the analysis of key actors within organizations, such as representatives of HR, ESG, production, procurement, and IT functions, thereby ensuring a deeper interpretation of findings and additional validation of the results.

RESULTS AND DISCUSSION

This chapter presents the results of the empirical research and their interpretation in relation to the defined hypotheses. Figure 1 shows respondents attitudes across the dimensions.

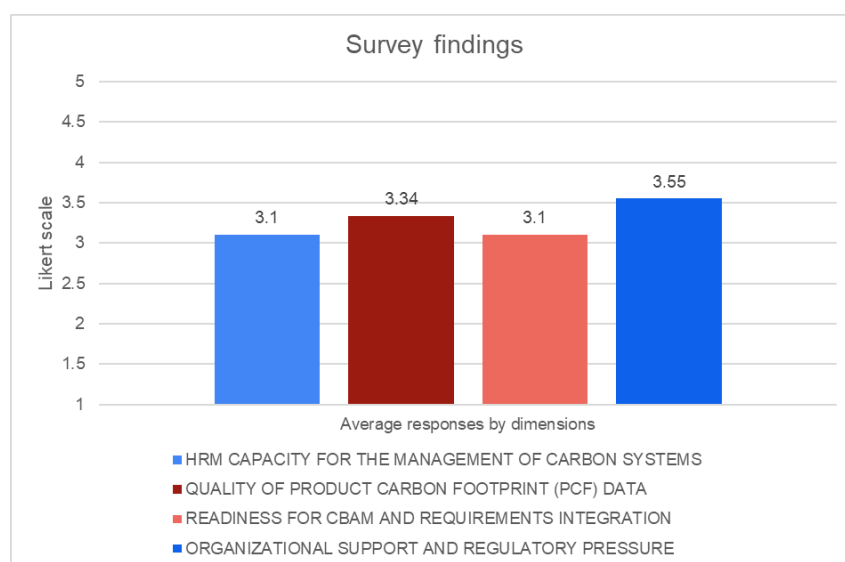


Figure 1: Presentation of respondents attitudes across dimensions

Processing of the collected data showed that all observed research dimensions are positioned within the range between the third and fourth points of the Likert scale (Figure 1). The value 3 on the Likert scale represents the threshold of respondent neutrality. Values above this margin indicate affirmation of the research dimensions, while the intensity of that affirmation is measured by the tendency of the observed dimensions value to approach point 5 on the Likert scale. The results indicate pronounced variability in the implementation of human resource management practices in the field of product carbon footprint (PCF) management. While some companies systematically conduct training and develop internal competencies, a significant number of respondents indicate a low level of institutionalization of these activities. A similar pattern was observed with regard to the quality of carbon footprint data, H1 (PCF-DQ). Large companies show a high level of standardization, reliability, and readiness for external data verification, whereas smaller organizations lag considerably behind, especially in terms of Scope 3 emissions coverage and the development of information technology systems for emissions monitoring. Top management support (TMC) was rated relatively highly in most cases, indicating growing awareness of the importance of decarbonization and regulatory requirements. However, this support is not always accompanied by adequate operational capacities, particularly in the domains of HRM and digital infrastructure. Organizational green readiness (OGR) and the success of CBAM requirement integration (CBAM-IS) show a clear connection with company

size, industry, and exposure to regulatory pressure. Companies exporting to the EU and operating in emission-intensive sectors demonstrate a higher level of readiness and more developed compliance strategies.

The research findings provide insight into the complex nature of integrating CBAM requirements and indicate that this process goes beyond exclusively operational or technical dimensions, simultaneously encompassing strategic, organizational, and human factors. Although the theoretical framework (Faisal, 2023; Benevene, 2020; Barakat et al., 2023) suggests that green training intensity (GTI) has a direct influence on the quality of PCF data, the empirical findings indicate limited strength of this relationship. This suggests that employee competence development, although necessary, is not a sufficient condition for ensuring high data quality. Instead, the results point to the need to integrate HRM practices with technological capacities and standardized methodologies, implying the systemic character of emissions management. Strong confirmation of hypothesis H2 regarding the influence of top management commitment (TMC) on organizational readiness (OGR) confirms the key role of strategic leadership in green transition processes. In addition to directing resources and priorities, management shapes organizational culture and readiness for change, which is further reflected in the company's ability to respond to complex regulatory requirements such as CBAM.

The confirmed relationship between organizational readiness and the successful implementation of CBAM requirements (H3) underscores the importance of a comprehensive approach. Business organizations that possess developed processes, clear responsibilities, and integrated environmental strategies are significantly more successful in adapting to new regulations. A particularly important finding concerns the significance of carbon footprint data quality (H5) as an operational prerequisite for compliance with CBAM regulation. Reliable and verifiable data enable high-quality reporting, as well as strategic emissions management and the reduction of regulatory risk. Unreliable data often lead companies into regulatory non-compliance, which may have serious legal and financial consequences. The role of suppliers (H4) may be described as crucial, particularly in the context of Scope 3 emissions inventories. Qualitative findings indicate that suppliers' limited ability to provide relevant data constitutes a significant barrier, thereby confirming the importance of the systemic integration of the supply chain into decarbonization processes. Finally, the results suggest that external factors, such as regulatory requirements and market pressures, are stronger drivers of change than internal human resource management initiatives. This points to the need to redefine the role of HRM as a condition and mediator of change rather than as the primary driver.

CONCLUSIONS

The analyzed research results confirm that the integration of CBAM requirements into the product carbon footprint management system is conditioned by the interaction of strategic, organizational, and operational factors. Within this framework, human resource management has a significant, though not self-sufficient, role. Empirical findings confirm that green training intensity has a limited direct effect on PCF data quality (H1 partially confirmed), whereas the key significance lies in the strong role of top management in shaping organizational readiness (H2 confirmed) and its indirect influence on the successful integration of CBAM requirements (H3 confirmed). In addition, the direct relationship between PCF data quality and the level of compliance with CBAM regulation is confirmed (H5 confirmed), which underscores the importance of reliable, standardized, and verifiable data as the operational foundation of decarbonization. The role of suppliers is identified as an important mediating mechanism in the relationship between training and data quality (H4 qualitatively confirmed). In this sense, the basic hypothesis (H0) may be considered partially confirmed, with the note that the influence of HRM is effective primarily within a broader, integrated management system.

Results that can be applied in practice indicate that companies should move beyond partial approaches and orient themselves toward the systemic integration of HRM patterns, digital solutions for emissions management, and strategic leadership. Special attention should be devoted to improving data quality, developing capacities for managing indirect emissions, and intensifying cooperation with suppliers, who represent a critical link in the value chain. The findings suggest that regulatory and market

pressures remain the dominant drivers of change. This implies the need for additional institutional support mechanisms, especially for small and medium-sized enterprises. Such an integrated approach enables not only compliance with CBAM regulation but also the long-term improvement of business competitiveness and sustainability.

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