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Credibility and Greenwashing in Corporate Energy Transition Communication: Evidence from Manufacturing Firms

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Abstract

The energy transition is reshaping industrial strategy, yet the credibility of corporate environmental communication remains difficult to assess. While many firms refer to decarbonization, energy efficiency, and renewable energy, it is often unclear whether these statements reflect substantive commitments or symbolic alignment with sustainability narratives.

This study analyzes energy transition communication among 19,468 Spanish manufacturing firms in 2023 and 2025 using large-scale web scraping and rule-constrained large language models (LLMs). Corporate website disclosures are evaluated across four credibility dimensions: clarity of language, evidence and substantiation, forward-looking commitments, and external certification.

Results show that the share of firms communicating energy actions increases from 10.3% to 13.2%, yet credibility remains uneven. Clear language is relatively common, while quantifiable evidence, time-bound targets, and verification are substantially less frequent, particularly among smaller firms. The findings highlight persistent gaps between environmental discourse and substantiated commitments.

Keywords: *Energy transition; Greenwashing; Manufacturing firms; Web mining; Large language models; Disclosure credibility.*

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1. Introduction

The energy transition is reshaping industrial production and corporate strategy across Europe. Firms are increasingly expected to reduce emissions, improve energy efficiency, and adopt renewable energy technologies, particularly in the manufacturing sector due to its high energy intensity and significant contribution to industrial emissions. At the same time, companies face growing pressure to communicate their environmental actions and commitments.

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However, assessing the credibility of corporate environmental communication remains challenging. Firms frequently refer to decarbonization or sustainability in their public narratives, yet such claims do not always reflect substantiated actions. Prior research highlights the growing concern about greenwashing, defined as the selective or exaggerated disclosure of environmental performance to create a misleading impression of sustainability (Delmas & Burbano, 2011; Lyon & Montgomery, 2015).

Traditional sources used to study corporate environmental behavior—such as surveys, patent data, or sustainability reports—provide valuable insights but suffer from limited coverage and reporting biases (Gök et al., 2015). Corporate websites offer a complementary source of real-time information with broader firm coverage, but their content is unstructured and partly shaped by strategic communication incentives (Kinne & Axenbeck, 2020).

Recent advances in natural language processing, particularly Large Language Models (LLMs), enable scalable analysis of unstructured corporate text (Hajikhani & Cole, 2024). Building on these advances, this study analyzes the credibility of energy transition communication among 19,468 Spanish manufacturing firms in 2023 and 2025 using web-scraped corporate websites. By combining web mining with rule-constrained LLM classification, the paper provides a scalable framework to assess corporate environmental communication and identify patterns consistent with greenwashing.

2. Literature Review

The transition toward low-carbon production has generated a growing body of research on firm-level adoption of renewable energy, energy efficiency improvements, and decarbonization strategies. These transformations are particularly relevant in the manufacturing sector due to its high energy intensity and central role in industrial emissions. Empirical studies show that environmental innovation is influenced by regulatory pressure, energy prices, and firm capabilities, with larger firms typically adopting green technologies more frequently (Horbach, Rammer, & Rennings, 2012; Woerter et al., 2017; Rammer & Es-Sadki, 2023). At the same time, the economic consequences of these investments remain heterogeneous across sectors and technological contexts (Zhang & Kong, 2022; Block, Lorenzen, & Steinmetz, 2024).

A central concern in the literature is the divergence between symbolic and substantive environmental action. Greenwashing refers to the practice of exaggerating or selectively disclosing environmental performance to create a misleading impression of sustainability (Delmas & Burbano, 2011; Lyon & Montgomery, 2015). Firms may strategically increase environmental disclosure in response to stakeholder pressure even when underlying environmental improvements are limited (Marquis, Toffel, & Zhou, 2016).

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Most empirical analyses of corporate environmental communication rely on structured sources such as surveys, patent records, or sustainability reports. While these datasets provide valuable insights, they often suffer from limited coverage or reporting bias and tend to focus primarily on large listed firms (Gök et al., 2015; Ding, Liu, & Chang, 2023). As a result, important blind spots remain in understanding how small and medium-sized firms communicate environmental initiatives.

Corporate websites have increasingly been used as a complementary source of firm-level information in innovation and strategy research. Web mining approaches have shown that website content can capture signals of technological adoption and strategic orientation beyond traditional datasets (Gök et al., 2015; Kinne & Axenbeck, 2020). However, website communication is inherently unstructured and may also reflect strategic framing, as firms can selectively highlight positive environmental initiatives while omitting less favorable information.

LLMs enable scalable analysis of unstructured corporate text. Unlike traditional keyword-based approaches, LLMs capture semantic context and can identify conceptually similar statements expressed in heterogeneous language (Hajikhani & Cole, 2024). When combined with rule-based evaluation criteria, LLMs can generate transparent and reproducible classifications from large text corpora (Pastor-Merino, Martínez-Barbero, & Domenech, 2025). Nevertheless, most existing applications focus on detecting the presence of technological adoption rather than evaluating the credibility of corporate environmental communication. This study contributes to this emerging literature by analyzing the credibility structure of energy transition communication among manufacturing firms.

3. Methodology

3.1. Data and Text Construction

The empirical analysis combines structured firm-level registry data with unstructured web-based disclosures. Firm-level information was obtained from the Sistema de Análisis de Balances Ibéricos (SABI), which provides standardized metadata including firm identifiers, NACE Rev. 2 industry classification, employment size, and registered web domains. The sample is restricted to firms classified under Section C (Manufacturing), ensuring sectoral homogeneity in terms of energy use and regulatory exposure.

Firm size is defined according to the European Commission SME classification based on the number of employees: micro (<10), small (10–49), medium (50–249), and large (≥250). The final balanced panel includes 19,468 manufacturing firms observed in both 2023 and 2025, resulting in 38,936 firm-year observations. Only firms with an active and accessible website and sufficient textual content in both years were retained in the sample.

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Corporate website content was collected during the first quarter of 2023 and 2025 using an automated crawling procedure applied consistently across firms and years. The crawler retrieved publicly accessible HTML pages and PDF documents from each firm's primary domain, following internal links while excluding external platforms. All retrieved content was converted into plain text. Preprocessing was intentionally limited in order to preserve contextual richness. For each firm-year observation, the collected textual material was consolidated into a single corpus.

To facilitate large-scale analysis, website corpora were segmented into text fragments. Embedding-based semantic similarity was then used to filter and retain fragments related to energy transition concepts. This step reduces noise in the corpus while preserving relevant contextual information for subsequent classification.

3.2. Classification Framework and Empirical Strategy

First, we identify whether firms communicate energy transition actions on their websites. Using a LLM, firms are classified as reporting an action when the website explicitly refers to at least one of the following activities aligned with the objectives of the Spanish Integrated National Energy and Climate Plan (PNIEC): energy efficiency improvements, decarbonization or greenhouse gas reduction initiatives, or renewable energy use or procurement. In 2023, 2,000 firms report at least one such action; in 2025 this number increases to 2,574 firms.

Second, among firms communicating energy transition actions, we evaluate the credibility of their disclosures using a structured rubric aligned with guidelines for credible environmental communication (Ministry of Social Rights, Consumer Affairs and 2030 Agenda, 2023). The rubric captures four binary dimensions: (B1) clarity of language, referring to specific and operational descriptions of actions; (B2) evidence and substantiation, indicating the presence of measurable or technically verifiable information; (B3) forward-looking commitments, referring to time-bound targets or structured transition plans; and (B4) certification or external verification, capturing references to third-party standards or independent validation.

3.3. Methodology Evaluation

Model evaluation was assessed through manual double coding of a stratified subsample of firms. Human coders independently evaluated the presence of energy transition actions and the credibility dimensions using the same rubric applied in the automated classification.

Model validity was evaluated using standard classification metrics, including accuracy, precision, recall, and F1-score. Across the validation runs, the model achieved an average accuracy of 0.696, precision of 0.637, recall of 0.744, and an F1-score of 0.694. These results indicate that the model performs particularly well in identifying relevant cases (high recall), while maintaining a balanced trade-off between precision and overall classification

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performance. To assess the reliability (stability) of the LLM-based classification, the model was executed multiple times using identical prompts. Reproducibility was evaluated using intraclass correlation coefficients (ICC) and Cohen's Kappa statistics.

4. Results

The results reveal three main patterns in manufacturing firms' web-based energy transition communication: an increase in the share of firms reporting energy transition actions, an uneven distribution of credibility across disclosure dimensions, and a strong firm-size gradient in the depth of communication. Overall, the analysis examines the evolution of communication over time, the distribution of credibility dimensions, and differences across firm sizes.

4.1. Expansion in the Scope of Communication

Table 1 reports the evolution in the share of manufacturing firms communicating energy transition actions between 2023 and 2025.

Table 1. Scope of Communication.

Year	Total Firms	Firms Reporting Energy Transition Actions	% of Total
2023	19,468	2,000	10.3%
2025	19,468	2,574	13.2%

Out of a balanced panel of 19,468 firms, 2,000 firms (10.3%) disclosed at least one energy-related action in 2023. By 2025, this number increased to 2,574 firms, representing 13.2% of the total population.

This increase indicates that energy transition communication is expanding within the manufacturing sector. However, even in 2025, nearly 87% of firms do not publicly communicate substantiated energy transition actions on their websites. Thus, while disclosure is growing, it remains minority behavior within the sector.

Importantly, the expansion reflects greater communicative engagement rather than universal adoption. The majority of manufacturing firms either do not engage in energy transition actions or do not publicly communicate them in a way that meets the restrictive classification criteria.

4.2. Composition of Credibility Dimensions in Energy Transition Communication

Among firms that communicate actions, Table 2 presents the distribution of credibility dimensions (B1–B4). A clear hierarchy emerges.

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Table 2: Distribution of Credibility Dimensions in Energy Transition Communication

Year	B1 - Clarity of Language (%)	B2 - Evidence and Substantiation (%)	B3 - Forward-Looking Commitments (%)	B4 - External Certification / Verification (%)
2023	58.6%	40.6%	9.6%	11.4%
2025	60.5%	44.0%	12.3%	15.7%

Clarity of language (B1) is the most prevalent dimension in both years. In 2023, 58.6% of communicating firms use specific and operational language; this increases slightly to 60.5% in 2025. This suggests that most firms that choose to communicate energy transition actions avoid purely generic statements.

However, the share of firms providing quantifiable or technically substantiated evidence (B2) is substantially lower. In 2023, 40.6% of firms provide measurable or verifiable information, increasing to 44.0% in 2025. While this represents progress, a significant proportion of firms rely on descriptive language without quantification.

More demanding dimensions of credibility remain considerably less frequent. Forward-looking commitments (B3)—defined as time-bound targets or structured transition plans—are observed in only 9.6% of communicating firms in 2023 and 12.3% in 2025. Similarly, certification or external verification (B4) appears in 11.4% of firms in 2023 and rises to 15.7% in 2025.

When expressed relative to the full population of manufacturing firms, these proportions become even more restrictive. In 2025, only around 1.6% of all firms disclose forward-looking commitments, and approximately 2.1% reference certification or external validation. This indicates that while discourse is expanding, deeply institutionalized and externally verified commitments remain rare.

Overall, the credibility structure is asymmetric: clarity is relatively common, evidence less so, and structured commitments and verification remain minority features. The architecture of communication is therefore skewed toward descriptive specificity rather than institutionalized accountability.

4.3. Size-Based Credibility Gradient

Figure 1 reveals a pronounced size-based gradient in credibility. Across most dimensions, credibility increases monotonically with firm size.

For clarity of language (B1), 55% of micro firms reporting energy actions use specific language, compared with 61% of small firms, 68% of medium firms, and 89% of large firms. A similar pattern emerges for evidence and substantiation (B2), increasing from 34% among micro firms to 45% for small firms, 55% for medium firms, and 78% for large firms, indicating substantially deeper disclosure practices among larger organizations. Forward-looking commitments (B3)

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exhibit the strongest gradient, rising from 7% among micro firms to 12% for small firms, 22% for medium firms, and 44% for large firms. External certification or verification (B4) also increases with firm size, from 11% among micro firms to 26% among medium firms, while the absence of certification among large firms likely reflects the very small number of observations in this category. Overall, the results show that the credibility of energy transition communication strengthens with firm size, as larger firms are more likely to complement descriptive language with quantifiable evidence, structured commitments, and formal validation mechanisms.

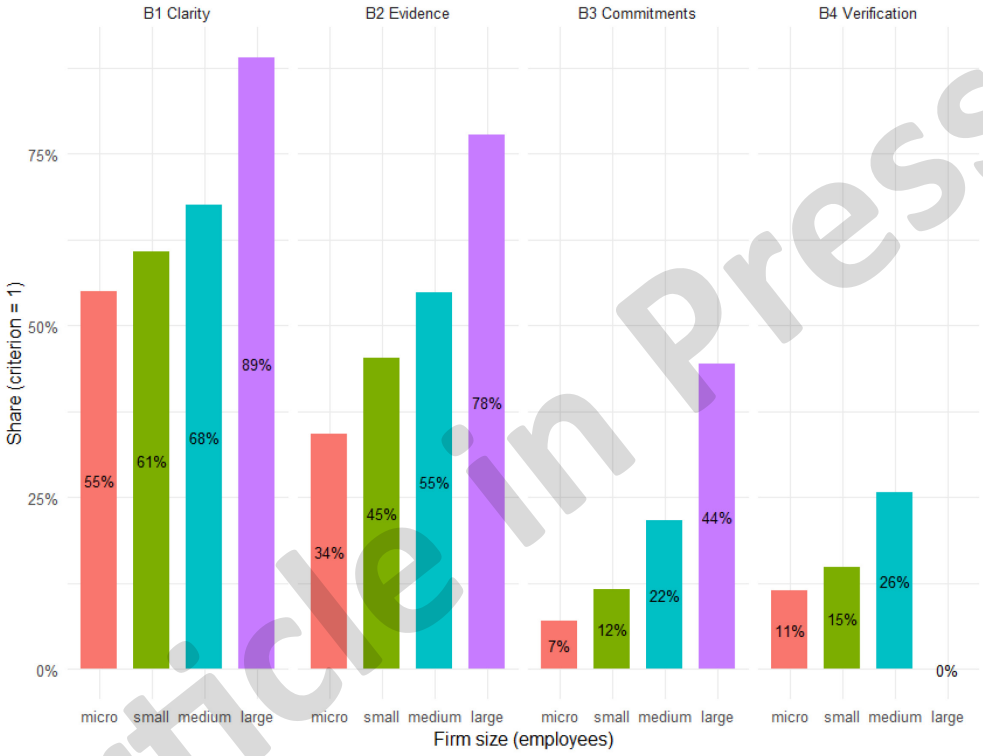


Figure 1: Size-Based Credibility Gradient Among Firms Reporting Actions

5. Conclusions

This study examines how manufacturing firms communicate energy transition actions on their websites. Using large-scale web scraping and a rule-constrained LLM framework, we analyze the credibility of corporate disclosures across a large population of firms.

The results reveal three main patterns. First, although the share of firms communicating energy transition actions increases between 2023 and 2025, most manufacturing firms remain silent.

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Second, among communicating firms, credibility is uneven: clarity of language is relatively common, while quantifiable evidence, forward-looking commitments, and external verification remain substantially less frequent. Third, credibility strongly increases with firm size, suggesting that larger firms have greater capacity or incentives to provide more structured and substantiated disclosures.

These findings contribute to the literature on greenwashing by highlighting that environmental communication reflects a continuum of credibility rather than a simple distinction between truthful and misleading claims. From a policy perspective, the results suggest that monitoring industrial decarbonization should consider not only the presence of environmental claims but also their credibility and substantiation.

Several limitations should be acknowledged. The analysis focuses on disclosed communication rather than actual implementation, and results are limited to manufacturing firms in a single national context. Future research could extend the framework to other sectors and countries and develop more granular measures of disclosure credibility.

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