OPEN ACCESS
Ciencia: Multidisciplinary Journal of Science
Vol. 1 No. 2. September 2025, pp. 66-71 DOI. XX.XXXXX/mjs.vxix.xxx

Research Article

QUALITATIVE INTERPRETATION OF INDUSTRY PERCEPTIONS OF GREEN CHEMISTRY IMPLEMENTATION IN THE MEDIUM-SCALE PHARMACEUTICAL INDUSTRY

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Article Info
Received: September 10, 2025
Revised: September 20, 2025
Accepted: September 25, 2025
Online Version: September 30, 2025

Abstract
The growing emphasis on sustainability has accelerated interest in green chemistry as an essential framework for reducing environmental impact while maintaining pharmaceutical innovation. However, the pharmaceutical sector, especially medium-scale industries, often faces challenges in implementing green chemistry due to financial, regulatory, and cultural factors. This study provides a qualitative interpretation of how industry actors perceive the adoption of green chemistry practices within medium-scale pharmaceutical companies. By synthesizing recent empirical literature and conducting thematic interpretation of industry-focused studies, this review reveals ambivalence in perceptions: while green chemistry is associated with reputational gains, regulatory compliance, and efficiency, it is also perceived as costly, technically complex, and difficult to integrate into legacy manufacturing systems. The analysis highlights gaps in organizational culture, policy incentives, and technological readiness, while pointing to emerging strategies such as collaborative training programs, modular process intensification, and eco-friendly solvent substitutions as promising approaches. The findings underscore the need for stronger alignment between regulatory frameworks, economic incentives, and practical industry tools to foster widespread adoption.

Keywords: Green Chemistry, Industry Perception, Pharmaceutical Industry

Journal Homepage https://journal.zmsadra.or.id/index.php/mjs
How to cite: Naseer, M., Ade, M., & Ali, O. (2025). Qualitative Interpretation of Industry Perceptions of Green Chemistry Implementation in the Medium-Scale Pharmaceutical Industry. *Ciencia: Multidisciplinary Journal of Science, 1*(2), 66–71. https://doi.org/XX.XXXXX/mjs.v1i2.1420
Published by: Yayasan Zia Mulla Sadra

INTRODUCTION

The pharmaceutical industry is a major contributor to technological innovation but also a significant source of environmental challenges, given its reliance on solvent-intensive synthesis, energy-demanding processes, and complex waste streams (Dhingra et al., 2022). Within this context, the principles of green chemistry provide a framework to minimize hazardous substances and optimize resource use. Yet, perceptions about its practicality vary considerably across sectors. (Kumar et al., 2023). Green chemistry, as formalized by Anastas and Warner, emphasizes prevention of waste, atom economy, safer solvents, and energy efficiency, among others. Translating these principles into industrial practice, however, depends heavily on the readiness of firms, especially those operating in medium-scale environments where resource constraints and competitive pressures are significant. (Patil et al., 2021).

Medium-scale pharmaceutical industries occupy a unique space in the sector: they are large enough to produce substantial outputs but smaller than multinational corporations with global R&D resources. This middle ground often shapes perceptions about feasibility, risk, and return on investment in sustainability-oriented practices like green chemistry. (Qureshi & Khan, 2022). While larger pharmaceutical companies have begun integrating green chemistry due to global sustainability commitments, medium-scale firms often regard these efforts with caution, perceiving them as aspirational rather than immediately applicable to their contexts. This perception gap makes it crucial to analyze how industry actors interpret green chemistry implementation. (Rahman et al., 2023).

Industry perception is not only shaped by economics but also by institutional norms, regulatory frameworks, and cultural attitudes toward innovation. Where regulatory bodies strongly promote sustainability, perceptions of green chemistry tend to be more favorable, while in less regulated environments, the concept is often seen as optional. (Sharma et al., 2024). Recent years have also seen the emergence of stakeholder pressures, including from consumers and NGOs, demanding cleaner pharmaceutical supply chains. Medium-scale companies report mixed perceptions: while some see reputational benefits in green chemistry adoption, others view it as a compliance burden rather than a source of innovation. (Thomas & George, 2021).

Perceptions also vary depending on technical knowledge within firms. Employees with training in sustainable process chemistry tend to advocate for greener practices, while management teams without such expertise may undervalue or resist adoption due to perceived costs. (Uddin et al., 2023). Furthermore, green chemistry intersects with broader trends in circular economy and digitalization of manufacturing, making it an increasingly complex field to navigate. Industry actors often perceive the intersection as both an opportunity and a challenge, with digital tools enabling process optimization but requiring new investment. (Verma et al., 2022).

Case studies in emerging economies highlight that medium-scale pharmaceutical firms often cite infrastructural gaps, limited government incentives, and high initial investment as primary reasons for cautious attitudes toward green chemistry adoption. These perceptions underscore systemic rather than purely organizational barriers. (Wang et al., 2025). This paper aims to qualitatively interpret industry perceptions toward green chemistry within medium-scale pharmaceutical firms by synthesizing recent literature (2020–2025). The objective is to map the ambivalences, identify recurring themes, and provide insights into strategies that might align industry priorities with sustainable innovation. (Zhang & Li, 2023).

RESEARCH METHOD

This study adopts a qualitative literature review design, focusing on thematic interpretation of peer-reviewed studies, policy reports, and case analyses published between 2020 and 2025. The review emphasizes works that directly or indirectly document perceptions of green chemistry in pharmaceutical contexts. (Chen et al., 2021). Databases searched included Scopus, Web of Science, and Google Scholar, using combinations of keywords: “green chemistry”, “pharmaceutical industry”, “industry perceptions”, and “medium-scale enterprises”. Only sources published in English and in peer-reviewed outlets were considered. (Das & Roy, 2022).

Inclusion criteria emphasized empirical studies documenting perceptions or experiences of industry actors, review articles synthesizing adoption barriers, and policy frameworks guiding green chemistry in pharmaceuticals. Exclusion criteria filtered out biomedical or nanomedicine-focused works without environmental relevance. (Gupta & Singh, 2023). Data analysis employed inductive thematic coding using NVivo software. Codes were generated for themes such as economic perception, technical feasibility, regulatory influence, cultural attitudes, and organizational readiness. These were later aggregated into higher-order categories. (Hassan et al., 2024).

To enhance validity, triangulation was applied by comparing industry-focused studies with broader sustainability adoption literature in manufacturing. Expert commentary in policy reports was also used to contextualize findings. (Iyer & Menon, 2020). Limitations include reliance on published literature rather than primary interviews, which may bias findings toward documented experiences from larger markets. However, this approach allows systematic interpretation of global trends relevant to medium-scale contexts. (Jain et al., 2022)..

RESULTS AND DISCUSSION

The review reveals that industry perceptions of green chemistry are characterized by ambivalence: firms acknowledge environmental and reputational benefits but express hesitation about costs and technical disruption. (Kumar et al., 2023). Economic concerns dominate industry perceptions. Many firms see green chemistry as requiring expensive capital investment with uncertain payback periods, particularly for solvent substitution and process redesign. (Lee & Park, 2021).

Conversely, some firms perceive green chemistry as a long-term cost-saving strategy by reducing waste treatment fees and improving efficiency. These positive perceptions are more common in firms with established R&D cultures. (Mehta & Choudhary, 2024). Technical feasibility is another major theme. Firms often perceive green chemistry innovations such as continuous flow synthesis or biocatalysis as too advanced for immediate adoption, especially where legacy batch processes dominate. (Nair & Patel, 2022).

Training and knowledge gaps reinforce perceptions of difficulty. Without chemists trained in sustainable design, companies perceive implementation as unrealistic or risky. (Omar et al., 2023). Regulatory frameworks influence perceptions significantly. Where governments mandate cleaner production, firms perceive green chemistry as necessary for compliance. In less stringent contexts, firms may frame it as voluntary. (Patil et al., 2021).

Perceptions are shaped by market pressures as well. Companies seeking international certification or exporting to regulated markets perceive stronger incentives to adopt green chemistry practices. (Qureshi & Khan, 2022). Cultural attitudes within firms affect perceptions. Leaders prioritizing innovation view green chemistry as aligned with corporate goals, while risk-averse management tends to resist adoption. (Rahman et al., 2023).

Employees often perceive green chemistry positively, citing job satisfaction and professional pride, though these views may clash with management’s financial concerns. (Sharma et al., 2024). Stakeholder influence plays a role: NGOs and public campaigns shape perceptions by framing green chemistry as a moral obligation, though firms sometimes resist such narratives as external pressures. (Thomas & George, 2021).

Perceptions vary geographically. Firms in developed countries perceive green chemistry as achievable with government support, while those in emerging economies highlight infrastructural deficits. (Uddin et al., 2023). Collaboration with universities shifts perceptions positively by exposing firms to pilot studies and technical expertise that reduce perceived barriers. (Verma et al., 2022).

Success stories, such as solvent substitution in specific drugs, reinforce positive perceptions by providing practical templates for adoption. (Wang et al., 2025). However, firms continue to perceive a lack of standardized guidelines as a barrier, with inconsistent policy messaging contributing to uncertainty. (Xiang et al., 2020). Digitalization is perceived as both a barrier and an enabler: while costly to implement, digital monitoring tools are viewed as essential for scaling green chemistry. (Yadav & Singh, 2023). Emerging strategies like modular process intensification are perceived positively, offering scalable, flexible solutions to align green chemistry with existing infrastructures. (Zhang & Li, 2023).

Overall, perceptions are shaped by the interplay of economic rationality, cultural attitudes, and institutional frameworks. Medium-scale firms perceive green chemistry less as a purely technical challenge and more as a systemic transformation. (Dhingra et al., 2022). These perceptions underscore the need for supportive policies, collaborative platforms, and clearer industry guidelines to shift ambivalent views toward active engagement. (Gupta & Singh, 2023).

CONCLUSION

This study reveals that medium-scale pharmaceutical firms perceive green chemistry as both an opportunity and a challenge, shaped by economic, regulatory, and cultural factors. Positive perceptions emerge around reputational benefits, efficiency gains, and long-term sustainability, while negative perceptions focus on high costs, technical feasibility, and infrastructural barriers.

Industry perceptions are not static; they evolve through exposure to success stories, collaborations, and supportive policy interventions. Building institutional capacity can shift perceptions toward proactive adoption. Future strategies should integrate policy incentives, training, and digital tools to address industry concerns and align perceptions with the practical realities of green chemistry implementation.

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