

Optimizing Sustainability in Pharmaceutical Companies with AHP: A Framework for Reducing Carbon Footprints



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Abstract:

Purpose: The aim of the study is to analyse the key factors that optimize sustainability in pharmaceutical companies. The study seeks to develop a systematic framework that enhances environmental, social, and economic performance within the pharmaceutical sector.

Design/Methodology/Approach: The technique used in this study is a Multi-Criteria Decision-Making method (Fuzzy Analytic Hierarchy Process) to evaluate and prioritize sustainability practices adopted by pharmaceutical companies.

Findings: The study identified *Regulatory Compliance and Standards*, *Transparency and Reporting*, and *Sustainable Clinical Trials* as the most critical factors for optimizing sustainability in pharmaceutical companies. Mid-level contributors included waste minimization, sustainable packaging, and green building practices, while supply chain optimization and product lifecycle management were ranked lower in importance.

Implications: The results suggest that managers should focus on strengthening compliance, transparent reporting, and clinical trial sustainability to achieve meaningful progress. Policymakers may consider reinforcing regulatory frameworks, while socially, greater emphasis on eco-friendly practices and accountability can foster public trust and support long-term sustainability goals.

Originality: This study is novel as it applies a structured decision-making framework (Fuzzy Analytic Hierarchy Process) to systematically rank and evaluate sustainability factors in the pharmaceutical industry, an area where empirical prioritization has been limited.

Keywords: *Sustainability in Pharmaceuticals, Green Building Practices, Fuzzy AHP, Analytic Hierarchy Process.*

Introduction

The pharmaceutical industry plays a dual and complex role in modern society: while it is indispensable for human health through the discovery, manufacture, and distribution of life-saving medicines, it also has significant environmental, social, and economic footprints that increasingly raise concerns. Pharmaceutical companies contribute notably to greenhouse gas emissions, water usage and contamination (especially via active pharmaceutical ingredients), packaging waste, and energy consumption throughout their value chains, including R&D, manufacturing, supply, and disposal of pharmaceutical products (Moermond, Puhlmann, & Brown, 2022; World Health Organization [WHO], 2024). Regulatory pressures are mounting: governments and international bodies are tightening environmental regulations, demanding greener production processes, better waste management, and mitigation of pharmaceutical residues in water bodies (Khan, 2024; Jairoun et al., 2025). In addition, industry stakeholders—

including investors, customers, healthcare systems, and communities—are increasingly expecting pharmaceutical companies to embed sustainability into their corporate DNA, not merely as corporate social responsibility but as core strategic imperatives (Chomać-Pierzecka et al., 2023; IQVIA, 2021). Despite the awareness and emergent initiatives (for example, green chemistry, life-cycle thinking, science-based emissions targets), there remains wide variation in how firms measure, report, and implement sustainability, particularly among smaller, generics or API (active pharmaceutical ingredient) manufacturers, and in emerging markets (IQVIA, 2021; Bade et al., 2024). Thus, there is a pressing need for systematic, empirical research that rigorously investigates what strategies are most effective under differing regulatory, economic, and resource conditions; how sustainability goals can be operationalized throughout the life cycle of pharmaceutical products; and what barriers—technical, organizational, regulatory or financial—prevent broader adoption. An in-depth study will help fill gaps in current knowledge, providing evidence for

best practices, metrics for monitoring progress, and policy levers that can catalyze change. Without such research, the industry risks falling short of global environmental goals (e.g., relating to the Paris Agreement), facing reputational risks, regulatory noncompliance, unsustainable cost burdens, and ultimately undermining both public health and environmental integrity.

The aim of this research is to examine how pharmaceutical companies can optimize sustainability by embedding environmental stewardship, social responsibility, and economic viability into their core strategies. The study seeks to achieve three key objectives: first, to analyze the current practices and policies related to sustainability in the pharmaceutical sector; second, to identify the barriers and enablers that shape the effective adoption of such practices; and third, to propose a practical framework that aligns industry operations with global sustainability goals. By pursuing these objectives, the research intends to contribute both theoretically, by advancing academic discourse on sustainable business practices, and practically, by offering insights that can guide decision-makers in the industry.

The study is structured around two core research questions:

1. What are the factors that influence the successful adoption of sustainability practices in pharmaceutical companies?

2. How can Analytic Hierarchy Process (AHP) be applied by pharmaceutical firms to balance operational efficiency with environmental and social responsibility to achieve sustainable growth?

This paper contributes to the existing literature by addressing the underexplored area of sustainability optimization in the pharmaceutical sector. While prior studies have examined environmental impacts and corporate social responsibility initiatives, few have developed structured approaches to evaluate and prioritize sustainability strategies within this industry. Existing research often lacks standardized benchmarks, making it difficult to compare practices across regions and firms. By focusing on operational integration and the interplay of environmental, social, and economic dimensions, this study fills an important gap. It proposes a systematic framework that highlights critical factors influencing sustainability adoption and provides evidence-based insights to guide both industry practitioners and policymakers.

The paper is divided into five sections. The first section is the introduction, this section highlights the need of the research along with Purpose and Contribution to the existing literature. The Second section provides the readers with the review of Literature of each factor considered for paired wise Comparison matrix. Third section relates to

research methodology that elaborates the methods used in the study. The next section is the data analysis and interpretation which provides graphical and tabular interpretation of the analysed data based on Building Comparison paired wise matrix, Normalised matrix, Relative importance and Calculating Consistency Ratios. Last section is the final part where the study is concluded along with the Implications and Discussions are provided in detail.

Factors Optimizing Sustainability in Pharmaceutical Companies

1. Green Building Practices: Energy-efficient infrastructure (lighting, HVAC, insulation, water-saving systems) is a high-impact lever for reducing pharmaceutical site emissions and operating costs; many pharma sites have benefited from targeted energy audits and utility optimisation programs that prioritise HVAC and process utilities as biggest opportunities. (Moermond et al., 2022).

2. Sustainable Packaging: Sustainable packaging research emphasises reducing material use, switching to recyclable/biobased polymers, and redesigning pack formats to lower lifecycle impacts while maintaining product safety — a critical balance for pharmaceuticals where protection and sterility are paramount (Ibrahim et al., 2022).

3. Supply Chain Optimization: Optimising pharmaceutical supply chains—via supplier selection, route consolidation, and logistics efficiency—can substantially lower Scope 3 emissions; recent methodological work outlines improved data collection and GHG calculation approaches for distribution and warehousing. (Ashworth et al., 2025).

4. Regulatory Compliance and Standards: Regulatory frameworks (e.g., EMA requirements for Environmental Risk Assessment and evolving agency strategies) increasingly embed environmental considerations into approval and post-market processes, making compliance both a legal necessity and a driver of greener practices. (European Medicines Agency, 2020/ongoing).

5. Transparency and Reporting (CDP etc.): Corporate disclosure platforms such as CDP have become central to benchmarking pharma environmental performance; transparent reporting helps companies identify hotspots, attract sustainable finance, and demonstrate progress against climate and water targets. (CDP, 2024).

6. Pharmaceutical Waste Minimization: Systematic reviews show that waste-minimisation across procurement, inventory management, and clinical settings reduces unused medications and disposal burden—strategies ranging from inventory optimisation to policy interventions have measurable impacts. (Smale et al., 2021).

7. Sustainable Product Disposal: Take-back programmes and organized disposal systems for

unused/expired medicines are evidence-based measures that reduce environmental release and misuse; recent systematic reviews underscore their effectiveness while noting implementation gaps across jurisdictions. (Wang et al., 2024).

8. Product Lifecycle Management: Life-cycle assessment (LCA) and product-lifecycle management tools help identify upstream and downstream impact hotspots for pharmaceutical products, but studies emphasize data gaps (especially upstream API inventories) and call for better LCA data to guide design-for-sustainability. (Satta et al., 2024).

9. Sustainable Clinical Trials: Clinical trials carry a measurable carbon footprint; guidance and LCA-based methods for trials (e.g., measuring travel, shipping, energy) are emerging, with industry and academic groups proposing frameworks to decarbonize trial design and conduct. (Griffiths et al., 2024).

10. Employee Engagement and Training on Sustainability (Green Culture): Green training and green HRM practices are linked to higher employee pro-environmental behaviours and better implementation of sustainability initiatives; pharma-specific studies show green culture and training can mediate adoption of eco-practices. (Barakat et al., 2023; Mostafa, 2025).

Research Methodology

In the present research context, decision-making involves judgment across multiple interdependent sustainability factors. To address this complexity, scholars have formalized a class of Multi-Criteria Decision-Making (MCDM) methods. Among them, the Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in 1977, is one of the most widely applied techniques. AHP provides a systematic and quantitative framework for evaluating alternatives by structuring decision problems into hierarchical

levels, comparing relative preferences between different criteria, and synthesizing judgments to establish priority rankings. It simulates human decision-making through pairwise comparisons, thereby assisting decision-makers in deriving consistent and reliable results (Saaty & Hu, 1998).

AHP Procedure for Determining the Relative Importance of Sustainability Factors

This research applies AHP to determine the relative weight of sustainability strategies in pharmaceutical companies. The process involved the following steps:

Step 1: Identifying Critical Factors

This study has first identified 10 sustainability factors after conducting a thorough literature review along with consultation from the 11 industry experts. The sustainable factors that were found are (1) Green Building Practices (GBP), (2) Sustainable Packaging (SP) (3) Supply Chain Optimization (SCO), (4) Regulatory Compliance and Standards (RC), (5) Transparency and Reporting (TR), (6) Pharmaceutical Waste Minimization (PWM), (7) Sustainable Product Disposal (SPD), (8) Product Lifecycle Management (PLM), (9) Sustainable Clinical Trials (SCT), and (10) Green Culture (GC).

Step 2: Pairwise Comparison Based on Expert Inputs

This study then used the Saaty's pairwise comparison approach, a group of experts in regulatory affair, sustainability management, and pharmaceutical operations were asked to give their opinions on the significant factors that were found in the review of literature. The experts were asked to score on a scale of 1 – 9, where 1 implies that the factors have equal relevance, whereas 9 indicates that one factor is more important than the other.

Table 1: Saaty Scale for Pairwise Comparison

Numerical Value	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extremely More Importance
2,4,6,8	Intermediate Values

Step 3 : Finalization of Comparison

The assessments of the experts of the sustainability factors were used for creating a reciprocal square matrix. Each of the diagonal value were allotted 1 to represent the idea that each of these factors is at par in importance when compared amongst them.

Then based on the opinions of the experts the off-diagonal values indicated the critical significance of each of the factors taken for sustainability.

Step 4: Normalized Matrix

The relative importance of weight of each sustainability factor was derived by normalising the initial comparison matrix. This normalisation process placed all criteria on a unified scale with a total sum of one, thereby clearly revealing the proportional influence of each factor on the pharmaceutical industry's sustainability optimization framework.

To validate the reliability of the expert opinions. Consistency Index (CI) was calculated based on the comparison matrix. This CI was then compared to a benchmark value known as the Random Consistency Index (RI) to produce a final Consistency Ratio (CR). This ratio acts as a pass/fail market: a CR below 0.10 confirms the judgements are sufficiently consistent, while a value above 0.10 flags inconsistencies that require re-evaluation of the expert inputs.

Step 5: Consistency Index

Table no: 2 Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Data collections:

11 specialists who possess substantial expertise in pharmaceutical operations, sustainability management, and regulatory affairs provided the data for this study. Based on the discovered sustainability variables, the experts were asked to rate the relative relevance of each aspect in pharmaceutical businesses' sustainability optimisation using a structured pairwise comparison questionnaire. Their inputs served as the foundation for building the comparison matrix needed for the analysis using the Analytic Hierarchy Process (AHP).

Table No: 3

Factors	GBP	SP	SCO	RC	TR	PWM	SPD	PLM	SCT	GC
Green Building Practices (GBP)	1									
Sustainable Packaging (SP)	X	1								
Supply Chain Optimization (SCO)	X	X	1							
Regulatory Compliance and Standards (RC)	X	X	X	1						
Transparency and Reporting (TR)	X	X	X	X	1					
Pharmaceutical Waste Minimization (PWM)	X	X	X	X	X	1				
Sustainable Product Disposal (SPD)	X	X	X	X	X	X	1			
Product Lifecycle Management (PLM)	X	X	X	X	X	X	X	1		
Sustainable Clinical Trials (SCT)	X	X	X	X	X	X	X	X	1	
Green Culture (GC)	X	X	X	X	X	X	X	X	X	1

Table No: 4 Pairwise Comparison Matrix of Key Factors Optimizing Sustainability in Pharmaceutical Companies

Factors	GBP	SP	SCO	RC	TR	PWM	SPD	PLM	SCT	GC
Green Building Practices (GBP)	1	0.5	5	0.5	0.2	1	1	3	0.2	3
Sustainable Packaging (SP)	2	1	3	0.2	0.33	1	2	3	0.33	3
Supply Chain Optimization (SCO)	0.2	0.33	1	0.2	0.33	0.5	0.33	1	0.33	3
Regulatory Compliance and Standards (RC)	2	5	5	1	2	3	3	5	3	3
Transparency and Reporting (TR)	5	3	3	0.5	1	4	3	5	1	3
Pharmaceutical Waste Minimization (PWM)	1	1	2	0.33	0.25	1	3	5	0.33	3
Sustainable Product Disposal (SPD)	1	0.5	3	0.33	0.33	0.33	1	3	0.33	3
Product Lifecycle Management (PLM)	0.33	0.33	1	0.2	0.2	0.2	0.33	1	0.33	2

Sustainable Clinical Trials (SCT)	5	3	3	0.33	1	3	3	3	1	3
Green Culture (GC)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	5	0.33	1
TOTAL	17.86	14.99	26.33	3.92	5.97	14.36	16.99	34	7.18	27

The above table provides the Pairwise Comparison Matrix of Key Factors Optimizing Sustainability in Pharmaceutical Companies. It can be seen that pharmaceutical experts give more priority to operational and regulatory factors over cultural factors. The highest weighted factors as seen above are Regulatory Compliance and Standards (RC), Transparency and Reporting (TR), and Sustainable Clinical Trials (SCT), this highlights that there is a more focused approach on compliance, accountability and greening the core R&D process. Green Building Practices (GBP), and Sustainable Packaging (SP) are other two factors that are seen as important for their tangible benefits. On the other hand, Product Lifecycle Management (PLM), and Green Culture (GC) have the lowest weights, indicating that these factors are perceived as supportive and not the primary drivers of sustainability outcomes.

Table No: 5 Normalized matrix

Factor	GBP	SP	SCO	RC	TR	PWM	SPD	PLM	SCT	GC
Green Building Practices (GBP)	0.056	0.033	0.190	0.128	0.034	0.070	0.059	0.088	0.028	0.111
Sustainable Packaging (SP)	0.112	0.067	0.114	0.051	0.055	0.070	0.118	0.088	0.046	0.111
Supply Chain Optimization (SCO)	0.011	0.022	0.038	0.051	0.055	0.035	0.019	0.029	0.046	0.111
Regulatory Compliance and Standards (RC)	0.112	0.334	0.190	0.255	0.335	0.209	0.177	0.147	0.418	0.111
Transparency and Reporting (TR)	0.280	0.200	0.114	0.128	0.168	0.279	0.177	0.147	0.139	0.111
Pharmaceutical Waste Minimization (PWM)	0.056	0.067	0.076	0.084	0.042	0.070	0.177	0.147	0.046	0.111
Sustainable Product Disposal (SPD)	0.056	0.033	0.114	0.084	0.055	0.023	0.059	0.088	0.046	0.111
Product Lifecycle Management (PLM)	0.018	0.022	0.038	0.051	0.034	0.014	0.019	0.029	0.046	0.074
Sustainable Clinical Trials (SCT)	0.280	0.200	0.114	0.084	0.168	0.209	0.177	0.088	0.139	0.111
Green Culture (GC)	0.018	0.022	0.013	0.084	0.055	0.023	0.019	0.147	0.046	0.037
									CR	0.082

The above table no: 5 provides the normalized matrix values. It can be clearly seen that the normalized matrix reveals a clear hierarchy of sustainability priorities for pharmaceutical companies. Regulatory Compliance and Standards (RC), Transparency and Reporting (TR), and Sustainable Clinical Trials (SCT) have consistently received high weights, pointing out their crucial role in sustainability. Green Building Practices (GBP), and Sustainable Packaging (SP) also are seen as crucial drivers of sustainability, although moderately, value of their direct role in reducing environmental impact has lesser significance. Product Lifecycle Management (PLM) and Green Culture (GC) have the lowest normalized values,

reflecting that although they support long-term sustainability targets, they are considered least central in the short-term strategic schema. The calculated Consistency Ratio (CR = 0.082) is below the acceptable threshold of 0.10, indicating an acceptable level of consistency in the experts' judgments. This suggests that the pairwise comparisons are sufficiently reliable for deriving priorities, and no substantial revision of the comparisons is required. Overall, the results highlight the importance of regulatory compliance, transparent reporting, and sustainable clinical trials as key drivers of business-related sustainability in the pharmaceutical industry.

Table No: 6 Relative and Cumulative Importance of Factors

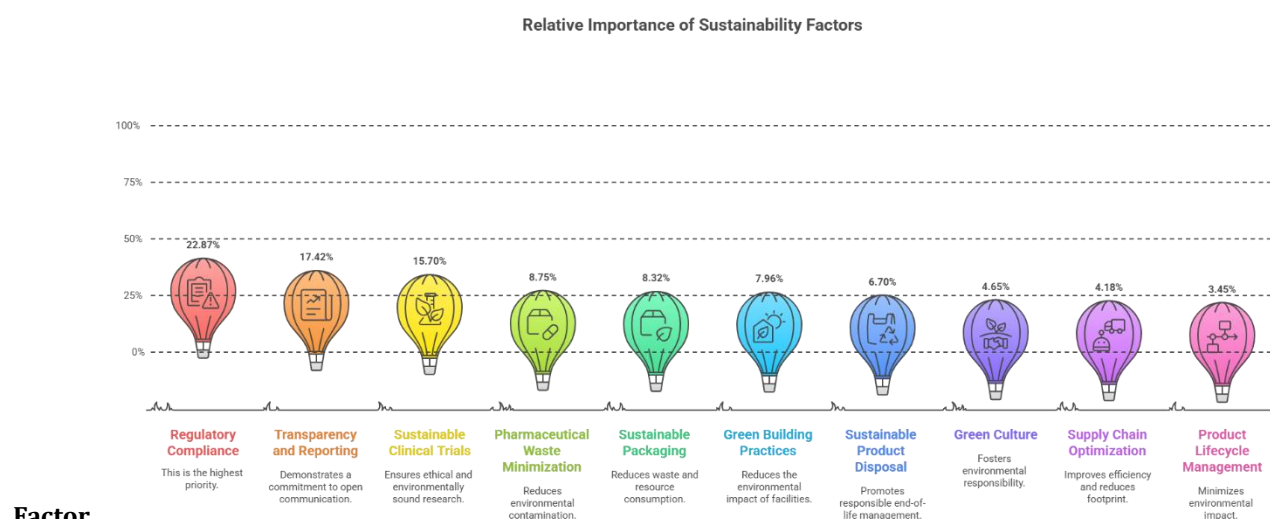
	Relative Importance	Cumulative Importance
Regulatory Compliance and Standards (RC)	22.87%	22.87%
Transparency and Reporting (TR)	17.42%	40.29%
Sustainable Clinical Trials (SCT)	15.70%	55.99%

Pharmaceutical Waste Minimization (PWM)	8.75%	64.74%
Sustainable Packaging (SP)	8.32%	73.06%
Green Building Practices (GBP)	7.96%	81.02%
Sustainable Product Disposal (SPD)	6.70%	87.72%
Green Culture (GC)	4.65%	92.37%
Supply Chain Optimization (SCO)	4.18%	96.55%
Product Lifecycle Management (PLM)	3.45%	100%

The relative and cumulative importance values illustrate a clear prioritization of sustainability factors in pharmaceutical companies. Regulatory Compliance and Standards (RC) emerges as the most critical factor, accounting for 22.87% of total importance, followed by Transparency and Reporting (TR) at 17.42% and Sustainable Clinical Trials (SCT) at 15.70%, together explaining more than half of the overall importance (55.99%). Mid-level contributors include Pharmaceutical Waste Minimization (PWM), Sustainable Packaging (SP), and Green Building Practices (GBP), which

collectively raise the cumulative contribution to 81.02%. The remaining factors—Sustainable Product Disposal (SPD), Green Culture (GC), Supply Chain Optimization (SCO), and Product Lifecycle Management (PLM)—while relevant, contribute less individually, together completing the total 100%. This distribution suggests that compliance, transparency, and sustainable clinical practices are perceived as the most decisive levers for optimizing sustainability, while supply chain and life-cycle considerations are comparatively less emphasized but still necessary for a holistic approach.

Figure No: 1 Relative Importance of



Conclusion

The findings of this study carry significant implications for managers, policymakers, and society at large. From a managerial perspective, the prioritization of regulatory compliance, transparency, and sustainable clinical trials underscores the need for pharmaceutical companies to integrate sustainability into core operations rather than treating it as a peripheral initiative. Policy implications emerge in the form of strengthening regulatory frameworks and aligning industry practices with global sustainability standards to ensure compliance and long-term resilience. Socially, the emphasis on transparency, waste minimization, and sustainable packaging reflects growing public demand for accountability and eco-friendly practices, thereby enhancing trust between the pharmaceutical sector and the communities it serves. Collectively, these

implications highlight that optimizing sustainability is not only essential for operational efficiency and competitiveness but also for broader social welfare and environmental stewardship.

Discussion

The results of this study reinforce and extend previous research by highlighting regulatory compliance and transparency as dominant sustainability drivers in the pharmaceutical industry, consistent with earlier findings that regulatory pressure and disclosure practices strongly shape corporate environmental strategies (Moermond et al., 2022; Chomać-Pierzecka, 2023). The importance of sustainable clinical trials also aligns with recent studies that draw attention to the carbon footprint of medical research and advocate for greener clinical practices (Griffiths et al., 2024).

However, unlike past research that emphasized supply chain sustainability and life-cycle management as critical levers (Satta et al., 2024), the current findings place these factors in the lower priority tier, suggesting that while they remain relevant, industry experts perceive them as secondary to compliance and reporting mechanisms. This divergence points to evolving priorities within the sector and underscores the need for a more balanced approach that integrates both immediate regulatory demands and long-term operational sustainability.

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