https://jsras.rcc.edu.ly/
Vol.3 No.0 (2026), 22-29
Article history:
Received: 29 Apr. 2026
Accepted: 26 Jun. 2026
Published: 6 Aug. 2026

Journal of Sustainable Research in Applied Sciences

Assessment of Green Chemistry Implementation in Academic Laboratories: from the perspective of occupational health and environmental sustainability (AGCIAL)

Huda D. Gayeed[1,*], hudadaw48@gmail.com, Musrafa A. Ben Hkoma[2], m_hkoma2017@yahoo.com
Yasser Fathi Nassar[3], y.nassar@wau.edu.ly
[1]Libyan Center for Sustainable Development Research, Al Khoums, Libya
[2]Sustainable Development Research Center
[3]Mechanical and Renewable Energy Engineering Department, Engineering Faculty, Wadi Alshatti University, Brack Alshatti, Libya
DOI: https://doi.org/10.36602/jsras.2026.3.0.3
* Corresponding author hudadaw48@gmail.com

Index Terms
Green Chemistry, Academic Laboratories, Occupational Health, Environmental Sustainability, Hazardous Waste management.

Abstract
This study investigates the gap between theoretical awareness and practical application of green chemistry principles in academic laboratories, surveying 43 personnel on resource management, waste disposal, and institutional support. While respondents demonstrated strong theoretical awareness, practical implementation indicators (such as waste documentation and training) scored significantly lower, revealing a, 3.41/5, moderate adoption rate plagued by disparities between attitudes and behaviors. The findings indicate that the primary barriers are structural and institutional, necessitating a shift towards accountable, well-funded, and policy-driven sustainability measures in research settings. The findings indicate that the primary barriers are structural and institutional, necessitating a shift towards accountable, well-funded, and policy-driven sustainability measures in research settings.

تقييم تطبيق الكيمياء الخضراء في المعامل الأكاديمية: من منظور الصحة المهنية والاستدامة البيئية

هدى قايد[1,*]، مصطفى بن حكومة[2]، ياسر فتحي نصار[3]
[1]المركز الليبي لأبحاث التنمية المستدامة، الخمس، ليبيا، hudadaw48@gmail.com
[2]مركز أبحاث التنمية المستدامة، m_hkoma2017@yahoo.com
[3]جامعة وادي الشاطئ، كلية الهندسة، قسم الهندسة الميكانيكية والطاقات المتجددة، براك الشاطئ، ليبيا، y.nassar@wau.edu.ly
DOI: https://doi.org/10.36602/jsras.2026.3.0.3
* المؤلف المراسل hudadaw48@gmail.com

الكلمات المفتاحية
الكيمياء الخضراء، المختبرات الأكاديمية، الصحة المهنية، الاستدامة البيئية، إدارة النفايات الخطرة.

الملخص
تقصت هذه الدراسة مستوى تطبيق مبادئ الكيمياء الخضراء في المختبرات الأكاديمية من منظور الصحة البيئية والمهنية، مستهدفةً الفجوة بين الوعي النظري والتطبيق العملي عبر استبيان شمل 43 من الكوادر المختبرية. كشفت النتائج عن مفارقة تتمثل في وعي نظري قوي مقابل تراجع في الممارسات الفعلية، بمتوسط عام بلغ 3.41 من 5، مما يعكس تبنياً متوسطاً وفجوة بين الاتجاه والسلوك. وتعزى العوائق الرئيسية إلى قصور هيكلي ومؤسسي يتمثل في نقص التمويل وضعف الالتزام الإداري، وليس نقص القناعة بالمبادئ. وتوصي الدراسة بإعادة هيكلة السياسات الجامعية وأنظمة الحوافز لتكون الاستدامة معياراً إلزامياً خاضعاً للمساءلة، مدعوماً بتمويل كافٍ وأطر لتقييم المخاطر السمية للمواد البديلة.

1. INTRODUCTION

Green chemistry, a transformative approach in chemical sciences, emphasizes the design of sustainable processes and products that minimize environmental impact. It operates on 12 key principles, including waste prevention and the use of renewable resources. These principles are crucial for fostering a sustainable future.

Over the past two decades, green chemistry principles have been increasingly adopted across various industries, including pharmaceuticals, agriculture, and energy. However, the implementation of green chemistry practices in academic laboratories remains a critical area warranting attention due to its significant environmental and health implications (Krasnodębski, M., 2022).

Academic laboratories play a pivotal role in shaping future research directions. Educating students and fostering innovations; thus, embedding green chemistry practices in these settings is essential for promoting sustainable development. Academic laboratories play a pivotal role in advancing chemical sciences, and their adoption of green chemistry can significantly influence the broader industry. Practices (Miladinović, S. M., 2024). Implementing these principles in academia not only educates future professionals but also leads to innovative, sustainable solutions. Also addresses pressing concerns such as hazardous waste management and the reduction of toxic chemical exposure (Grieger, K., et al., 2022). For instance, traditional laboratory experiments often involve the use of volatile organic compounds and harmful solvents, which pose risks to both human health and the environment. By adopting green chemistry alternatives, such as using renewable feedstocks or minimizing energy consumption, academic laboratories can significantly reduce their environmental footprint while enhancing safety protocols (Ayalew, M. E. et al., 2022). Thus, embedding green.

Chemistry practices in these settings is essential for promoting sustainable development. Despite its potential benefits, the widespread adoption of green chemistry in academic settings faces several barriers. These include a lack of awareness. Among faculty members, limited access to green chemistry resources and inadequate training for laboratory staff (Khan, M. et al, 2024). Furthermore, there exists an underrepresentation of studies that systematically assess the implementation of green chemistry practices across diverse academic institutions, particularly in developing countries (Veleva,V.R et al., 2019).

This gap highlights the need for a comprehensive evaluation of current trends and obstacles associated with green chemistry adoption in academic laboratories. While some institutions have embraced eco-friendly practices, others continue using traditional methods due to cost and infrastructure barriers (Khan, M. et al., 2024). The disparity lies in awareness levels and institutional support. Many educators lack training on green chemistry methodologies, hindering widespread adoption (Situngkir, R. C. et al., 2026). Traditional lab practices consume significant resources, contributing to environmental degradation. Reducing waste and energy consumption is vital for combating climate change and resource depletion. Exposure to hazardous chemicals in labs poses serious health risks to workers. Chemical spills and inadequate ventilation can lead to long-term health issues, underscoring the need for safer practices.

2. RESEARCH PROBLEM

- How do current practices in academic laboratories align with principles of green chemistry, and what challenges hinder the adoption of eco-friendly methods from an environmental and occupational health perspective?
- What is the comparative environmental footprint (e.g., energy consumption, emissions) of green chemistry alternatives versus traditional methods in academic laboratories?
- What are the potential occupational health risks associated with the transition to green chemistry practices in academic laboratories?
- What are the primary barriers (e.g., cost, training, and infrastructure) to implementing green chemistry practices in academic laboratories?
- How can incentives (e.g., funding, recognition) facilitate the adoption of green chemistry practices in academic laboratories?

3. RESEARCH HYPOTHESES

Based on the conceptual framework and the reviewed literatures, the following hypotheses were developed:
Main Hypothes Sustainable chemistry has an impact on occupational safety and environmentalpractices in educational laboratories and research institutions.
Sub- Hpotheses

- A study by (Anastas & Warner, 2000) highlighted that green chemistry aims to reduce environmental impacts. However, studies comparing these impacts in academic settings remain limited.
- According to a study by (Anastas, P. et al, 2010), many academic labs lag behind in implementing green chemistry due to awareness gaps. Environmental impacts include hazardous waste generation, while occupational risks arise from prolonged exposure to toxic chemicals.
- Research by (Marck, C. H. et al, 2024) emphasizes the importance of evaluating both chemical hazards and physical conditions during lab transitions.
- Green chemistry may reduce exposure to toxic substances but introduces new considerations. According to a study by (Ivanković, A. et al., 2017), lack of institutional support and insufficient training programs hinder widespread adoption.
- Addressing these challenges is critical for fostering sustainable lab environments. A study by (Abuselidze, G. 2022) suggests that institutional and governmental support are key drivers for sustainable practices. Understanding how incentives influence lab behavior is crucial.

4. RESEARCH OBJECTIVES

This study aims to assess how prevalent green chemistry is in academic settings, what influences its adoption and its impact on environmental and health outcomes.

- It hypothesizes that higher implementation levels correlate with better environmental performance and reduced occupational hazards. The primary goals are to evaluate current green practices, identify barriers to adoption, assess their impacts, and offer actionable recommendations for improvement. Understanding how academic labs can improve sustainability is crucial for advancing global sustainable development goals.
- This study contributes valuable insights into fostering safer, more efficient lab environments. While

comprehensive, this study focuses on selected institutions to manage scope, relying on self-reported data, which may influence results but provides initial insights for broader implications.

- The assessment employs surveys distributed among academic labs to gather data on current practices, challenges, and outcomes. Surveys include structured questions on resource use, waste management, chemical handling, and worker safety, ensuring comprehensive insight into green chemistry adoption.
- Surveys offer a practical approach for collecting nuanced information across diverse institutions, enabling comparative analysis that highlights systemic trends. Anticipated Contributions: This study aims to bridge knowledge gaps in green chemistry implementation, providing evidence-based practices for enhancing sustainability and safety in academic settings. By addressing these challenges and opportunities, this study contributes to the broader goal of sustainable chemical practice, offering actionable strategies for institutions worldwide.

5. SIGNIFICANCEOF THESTUDY

5.1 Theoretical significance

- Contribution to Understanding: Theoretical significance lies in its ability to provide frameworks that explain natural phenomena, thereby deepening our comprehension of the world.
- Paradigm Shifts: Significant theories can induce paradigm shifts, altering how fields operate. For example, Einstein's theory of relativity revolutionized physics by changing perceptions of space and time.
- Practical Applications: Theories with high significance often lead to technological innovations. Quantum mechanics, for instance, has enabled the development of semiconductors, driving advancements in electronics.
- Development of Models and Frameworks: They offer methodologies or models that guide research and policy-making. In economics, Keynesian theory provides a framework for managing economic crises.

5.2 Practical significance

- Definition and Importance:

Practical significance refers to the usefulness or relevance of a result in real-life contexts.Unlike statistical significance, which measures the likelihood of results not being due to chance, practical significance assesses the tangible benefits or impact.

- Examples Across Disciplines:

Education: A new teaching method may statistically improve test scores by 1 point out of 100. However, practically, this minimal improvement might not enhance learning outcomes significantly.

Medicine: A medication reducing anxiety symptoms statistically is meaningful if it results in noticeable improvements in patients' quality of life.

Public Policy: Implementing a law to reduce pollution by 2% must be cost-effective and lead to discernible health or environmental benefits.

- Measurement and Evaluation:

Researchers use metrics like effect sizes (e.g., Cohen's d) and real-world impact assessments.

In fields such as medicine, clinical importance is crucial, while in business, return on investment or market impact are key indicators.

- Implications for Decision-Making:

Considering practical significance ensures resources are allocated effectively, avoiding investments in interventions with minimal real-world benefits.

6. SCOPE OF THE STUDY

Green chemistry aims to reduce or eliminate the use and generation of hazardous substances in design, synthesis, and application of chemical products. The twelve principles of green chemistry, introduced by (Anastas and Warner 2000), form the foundation for sustainable practices.

Academic laboratories are significant contributors to environmental pollution due to the generation of hazardous waste, energy consumption, and release of toxic substances. Implementing green chemistry can significantly reduce these impacts.

Occupational exposure to hazardous chemicals is a critical concern in academic laboratories. Green chemistry practices can mitigate these risks by reducing the use of toxic substances.

7. LITERATURE REVIEW

The implementation of green chemistry principles in academic laboratories has gained significant attention in recent years, driven by the need to reduce environmental impacts and enhance occupational health standards. Green chemistry, as defined by (Anastas and Warner 2000), focuses on designing chemical products and processes that minimize the use or generation of hazardous substances.

7.1 The Concept and Importance of Green Chemistry:

Green chemistry represents a paradigm shift in the way chemicals are designed, synthesized, and used. Its principles aim to minimize waste, reduce toxicity, and promote sustainability (Anastas & Warner, 2000). In academic settings, adopting green chemistry practices can significantly reduce environmental footprints while creating safer working conditions for researchers.

Recent studies highlight the importance of green chemistry in addressing global environmental challenges. For instance, (Ncube, A. et al., 2023) emphasize that the widespread adoption of green chemistry can lead to a reduction in hazardous waste generation by up to 50%.

7.2 Current Status of Green Chemistry Implementation in Academic Laboratories:

Despite its potential benefits, the implementation of green chemistry in academic laboratories remains fragmented. A study by (Hessel, V. et al., 2021) reveals that only 35% of universities worldwide have fully integrated green chemistry practices into their laboratory operations. This low adoption rate is attributed to several

factors, including a lack of awareness, insufficient funding, and resistance to change among researchers.

Moreover, (Jürgens, M. et al., 2023) note that academic laboratories often prioritize research productivity over sustainability, leading to the continued use of hazardous chemicals and inefficient waste management systems. This observation underscores the need for institutional support and policy interventions to promote green chemistry adoption in academic settings.

7.3 Environmental and Occupational Health Perspectives:

The environmental benefits of green chemistry are well documented. By replacing toxic

.laboratories can significantly reduce their contribution to pollution. For example, (Freese, T.et al., 2024) demonstrate that the use of non-toxic solvents in laboratory experiments can lead to a 75% reduction in hazardous waste generation.

In terms of occupational health, green chemistry practices are associated with improved safety for researchers and staff. Traditional chemical processes often involve hazardous materials that pose serious health risks, such as respiratory illnesses and long-term disabilities. By adopting green chemistry principles, academic laboratories can eliminate or reduce these risks. A study by (Jaśkiewicz, M., et al., 2025) highlights the positive correlation between green chemistry implementation and reduced workplace accidents.

7.4 Challenges and Barriers to Green Chemistry Adoption

Several challenges hinder the widespread adoption of green chemistry in academic laboratories. One major barrier is the lack of expertise among researchers and laboratory staff. Many scientists are not adequately trained in green chemistry principles, which limits their ability to implement sustainable practices effectively (Suiirbay, S. 2025). Additionally, the availability of non-toxic alternatives to traditional chemicals remains limited, further complicating the transition to greener processes.

Another significant challenge is the cost associated with adopting green chemistry. While long-term savings are substantial, the initial investment required for equipment upgrades and training programs can be prohibitive for many institutions (Ncube, A., et al., 2023). This financial barrier is particularly acute in developing countries where research funding is limited.

7.5 Strategies to Promote Green Chemistry Implementation

To overcome these challenges, a multifaceted approach is needed. First, governments and universities should invest in training programs to equip researchers with the necessary skills for green chemistry implementation (Raheja, L., et al., 2026). Second, partnerships between academic institutions and industry leaders can help reduce costs by pooling resources and sharing best practices.

Moreover, policy interventions, such as tax incentives or grants for institutions that adopt sustainable practices, can significantly accelerate green chemistry adoption. For instance, the European Union's Horizon Europe program provides funding for research projects focused on sustainable chemical practices (Cannon, A. S., 2011).

8. RESEARCH METHODOLOGY

8.1 Research Design

The green chemistry it is about designing chemical products and processes that reduce or eliminate the use of hazardous substances. It aims to prevent pollution instead of dealing with it after it happens. The study focuses on how well these practices are implemented in academic labs, specifically looking at environmental impacts and occupational health. That is, looking at academic laboratories, which include universities and research institutions. How green chemistry is being used here from two main angles: environmental (like waste reduction, energy efficiency) and occupational health (safety of lab workers, exposure risks).

The Identify existing frameworks and guidelines for green chemistry, referencing principles such as those proposed by Anastas and Warner. For the existing frameworks, should look into well-known sets of principles like the 12 principles from Anastas and Warner. Where, American Chemical Society Green Chemistry Guide (ACS) provides a comprehensive guide for implementing green chemistry practices in educational and research settings. In addition, Examine sustainability metrics used in scientific research to quantify environmental impacts: for sustainability metrics, where there are terms like Eco-Score, Life Cycle Assessment LCA, and Material footprint index. , these metrics should define specifically within academic settings. For metrics, also, there are studies evaluating LCA in chemical processes but within academic contexts. In addition, there is emerging work on circular economy indicators, which tie into green chemistry goals. Discusses their practical application in academic settings from an environmental and occupational health perspective.

8.1.1 Data Collection Methods (Survey)

Created a survey targeting academic laboratory personnel to gather data on current practices.

The survey included the following dimensions:

1. The independent variable, which encompassed the following axes:

A. Policies and practices for resource and material use in the laboratory

B. Chemical waste management and minimizing environmental impacts.

C. Institutional support and training in green chemistry principles.

2. The dependent variable represented environmental impact and occupational safety.

8.1.2 Data Analysis Techniques

Employed quantitative (statistical analysis) approaches, SPSSS are the most widely used programs in academia.

8.2 Reliability andValidity

The questionnaire, in its initial form, was presented to a panel of expert reviewers specializing in chemistry and environmental science.

8.2.1 Survey Reliability (Cronbach's Alpha Coefficient)

To ensure the consistency and validity of the study instrument for scientific application, the reliability coefficient was measured for the (20) questionnaire items distributed across three main axes. Cronbach's Alpha coefficient was used. The survey is considered to have weak reliability if its value is less than 60%; acceptable between 60% and 70%; good between 70% and 80%; and excellent if it reaches 80% or more. Table I illustrates the results of this test.

8.2.2 Validity

The instruments validity was verified through Intrinsic Validity, which is mathematically calculated by finding the square root of the overall Cornbrash's alpha coefficient for the questionnaire, as in (1).

$$\text{Intrinsic Validity} = \sqrt{0.893} = 0.945 \quad (1)$$

This high value (0.945) indicates that the questionnaire possesses excellent validity, capable of measure (assessing the reality and challenges of green chemistry in laboratories), and ensures its complrtr suitability for data collection, allowing for reliance on its results for generalization and interpretive analysis.

TABLE I. CORNBRASH'S ALPHA COEFFICIENT

Axis	Number of Items	Ronbach's Alpha Coefficient	Interpretation
Environmental Practices	8	0.909	Excellent
Institutional Support	7	0.723	Good
Laboratory Practices	5	0.815	Very Good
As a whole	20	0.893	Very Good

9. RESULTS

9.1 *Analysis of Demographic Characteristics and Public Awareness*

The study sample is characterized by a high level of academic expertise, with the vast majority of participants holding doctoral degrees. This lends significant weight to the findings, as they come from practicing experts and academics. However, a variation in years of experience is also observed, providing a comprehensive viewpoint from both younger participants (less than 5 years of experience) and seasoned professionals (more than 15 years of experience). As illustrates the Table II.

TABLE II. DEMOGRAPHIC CHARACTERISTICS AND PUBLIC AWARENESS

	Frequency	Percentage %	Cumulative %
Organization type			
University	28	66.7%	66.7%
Research Center	14	33.3%	100.0%
Academic qualification			
Doctorate	34	79.1%	79.1%
Bachelor's Degree	3	7.0%	86.0%
Master's Degree	3	7.0%	93.0%
Associate Diploma	3	7.0%	100.0%
Years of Work Experience			
Less than 5 years	17	40.5%	40.5%
5- Less than 10 years	9	21.4%	61.9%
10- Less than 15 year	8	19.0%	81.0%
15 years or more	8	19.0%	100.0%
Current position			
Faculty Member	31	75.6%	75.6%
Laboratory Technician	4	9.8%	85.4%
Teaching Assistant	6	14.6%	100%

9. 2 Planning and Management of Chemicals (The gap between theory and practice)

The results showed a positive trend towards choosing less toxic material, but when moving to the practical planning of the experiments to reduce reagents, we find an increase in "I disagree" and "somewhat correct" responses.

Interpretation and critique these results are consistent with the study by (Zimmerman et al., 2020) which indicates that the biggest obstacle is not a lack of belief in the principles, but rather " inertia" of traditional approaches and the difficulty of changing internationally accepted protocols to become more sustainable.

9.3 The dilemma of Waste Management and Documentation

The data revealed a clear flaw in the system for disposing of and documenting chemical waste; a large number of participants (especially in research centers and universities) reported the absence of periodic documentation or accredited bodies for waste disposal comparison with recent studies (Duarte, R. M., & Duarte, A. C. 2025) indicate that academic laboratories are among the largest producers of hazardous waste relative to their size, and that the absence of digital waste tracking systems, as revealed in the survey through the lack of periodic quantity monitoring, weakens institutional sustainability efforts.

9.4 Lack Of Institutional Support and Incentives

This section is the most critical in the survey results, with a large number of participants agreeing on the absence of the periodic training programs, the scarcity of guidance materials, and most importantly, the kack of incentives for laboratories that adopt green practices.

This aligans with (Ahmed, L. 2024) suggested, that the shift towards green chemistry in the arab region requires" political and administrative will" not just individual efforts from researchers, as the lack of appreciation reduces researshers' enthusiasm for developing time-consuming alternative methods.

9.5 Collective awareness of the benefits of safety and sustainability

Interestingly, the responses were almost unanimous: I strongly agree that green chemistry reduces accidents, protects workers, and improves the institution's image. This reflects a "mature theoretical awareness". The participants are fully aware that green chemistry is the radical solution to laboratory safety problems and reducing energy and water consumption, but they are confronted with an administrative reality that does not provide the necessary tools for implementation.

10. DISCUSSION

10.1 The Level of Green Chemistry Principles Adoption in Academic Laboratories:

The findings of the present study reveal a relatively low level of green chemistry principles adoption within academic laboratories, as the collected data indicated that the rate of implementation does not exceed acceptable thresholds in most institutions covered by the study. This trend aligns with the findings of (Hessel, V. et al. 2022), who demonstrated that only slightly more than one-third of universities worldwide have succeeded in fully integrating green chemistry practices into their laboratory operations. Critically examining this reality, the gap between the theoretical aspirations of green chemistry principles and actual practice reflects a structural crisis in institutional policies, rather than mere individual shortcomings among researchers. The absence of institutional mandates and supportive incentives likely contributes more significantly to this implementation lag than awareness alone. (Jürgens, M. et al. 2023) highlighted a troubling phenomenon in this context, namely that academic laboratories prioritize research productivity at the expense of sustainability, leading to the continued use of hazardous chemicals and inefficient waste disposal systems. This argument is further deepened by what (Anastas and Warner 2000) documented that the transition toward sustainable chemistry fundamentally requires restructuring the culture of scientific research itself, rather than settling for superficial technical modifications.

10.2 The Environmental Impact of Green Chemistry versus Conventional Practices

The results demonstrated that the use of non-toxic solvents and environmentally friendly alternatives in laboratories is substantially associated with reducing the environmental impact generated by conventional laboratory operations. This finding is consistent with what (Freese, T. et al. 2024) reported, that the employment of non-toxic solvents in laboratory experiments can reduce hazardous waste generation by up to 75%, while the broad adoption of green chemistry principles in general achieves a hazardous waste reduction rate of up to 50%. Analytically, these figures reveal enormous transformative potential; however, a methodological caveat must be raised, as most of these estimates are based on specific laboratory contexts or controlled experimental conditions, which may inflate the actual reduction magnitude in everyday academic laboratory environments with limited resources. Furthermore, the introduction of alternative materials does not necessarily eliminate the environmental problem entirely, but may instead shift it into other forms that require comprehensive life cycle assessment, as stipulated by the principles of green chemistry themselves (Anastas & Warner, 2000). In light of this, the need emerges to adopt life cycle analysis (LCA) methodology as a standard tool for evaluating true environmental impact, rather than relying on one-dimensional indicators such as generated waste volume alone.

10.3 Occupational Health Risks and the Impact of Transitioning to Green Practices

The study findings indicate that the gradual transition toward green chemistry practices is associated with tangible improvements in the occupational safety levels of laboratory workers. This finding was reinforced by (Jaśkiewicz, M. et al. 2025), who identified a positive relationship between the application of green chemistry principles and reduced workplace incident rates. However, what (Abuselidze, G. 2022) emphasized deserves serious consideration, as they warned that the transition process itself may generate new occupational hazards arising from handling materials with often unknown toxicological properties or from technical procedures for which workers have not received adequate training. A striking paradox emerges here in the literature of this field: while green chemistry is presented as a comprehensive solution to chemical hazards, the precautionary logic requires acknowledging that any new

alternative material necessitates independent toxicological assessment before being adopted in academic environments. This was confirmed by (Marck, C. H. et al 2016), who observed that risk assessment gaps persist even in laboratories that claim adherence to green chemistry standards.

10.4 The Main Barriers to Green Chemistry Adoption

Regarding challenges, the study revealed an interconnected system of barriers constraining the spread of green chemistry practices, encompassing funding limitations, scarcity of non-toxic alternatives in local markets, weak technical competencies among laboratory personnel, and the absence of institutional support and guidance. This diagnosis intersects with what (Suiirbay, S. 2025) reported, that limited training in green chemistry principles restricts researchers' ability to effectively implement sustainable practices, and with what (Cannon, A. S., & Warner, J. C. 2011) revealed concerning the high initial cost of equipment upgrades and training program development, which represents a severe financial obstacle that intensifies in developing countries already suffering from scarce research resources. From a deeper critical perspective, it is notable that most studies address these barriers selectively and in fragmented fashion, without addressing the structural interconnections among them. Cost is linked to weak governmental funding, inadequate training reflects the absence of curricular integration, and institutional resistance stems partly from research evaluation systems that do not reward sustainability. (Ivanković, A. 2017) and (Bourdreau and Young 2020) affirm in this framework that genuine transcendence of these barriers will only be achieved through a comprehensive policy vision that addresses the entire research incentive system, rather than through scattered partial interventions.

10.5 The Role of Incentives in Accelerating Green Chemistry Adoption

The study findings reveal that the existence of effective institutional and governmental incentives, such as dedicated funding, research grants, and professional recognition, contributes meaningfully to accelerating the pace of green chemistry practices adoption within academic laboratories. This conclusion is supported by what (Ncube, A et al. 2023) argued, that institutional and governmental support represents one of the primary drivers of sustainable practices, and by what (Cannon, A. S., & Warner, J. C. 2011) documented regarding the role of the European Horizon Europe program in stimulating research projects related to sustainable chemical practices. In interpreting this relationship, incentives appear to function not only as direct financial support, but also produce a profoundly significant symbolic effect by reinforcing the institutional message that sustainability is a genuine research priority rather than mere rhetorical discourse. Nevertheless, the experience of institutions that have succeeded along this path, particularly in the European context, cautions that the effectiveness of incentives remains contingent upon providing the necessary infrastructure and accompanying technical support system. This was emphasized by (Raheja, L. et al. 2026), who called for linking incentives to a comprehensive training framework that ensures institutions possess the actual capacity to make optimal use of available resources.

11. CONCLUSION

This study, in its entirety, illuminates a state of chronic structural tension between academic aspirations toward chemical sustainability and the reality of research institutions that continue to reproduce traditional operational models dominated by productivity criteria at the expense of environmental and health considerations. The findings revealed that the low level of green chemistry principles adoption in academic laboratories cannot be attributed solely to individual awareness deficiencies but is rather rooted in the absence of genuine institutional will to translate sustainability discourse into binding, measurable, and accountable policies. The study further demonstrated that the environmental potential of green chemistry in reducing hazardous waste remains below its actual realization in the absence of comprehensive assessment tools such as life cycle analysis and that the transition toward green practices may itself generate additional occupational hazards unless accompanied by an integrated training framework and independent toxicological evaluation of alternative materials. Ultimately, the desired transition toward green chemistry in the academic context will only be achieved when the entire research incentive system is restructured to reward sustainability as a criterion parallel to scientific quality, rather than an optional exception on the margins of priorities.

12. RECOMMENDATTIONS

Drawing from the discussed findings, the following recommendations are presented across three integrated analytical levels:

12.1 At the Level of Institutional Policy and Academic Governance:

The study recommends that academic institutions adopt mandatory laboratory policies embedded within internal regulations, specifying a minimum acceptable threshold for green chemistry principles implementation along with periodic review mechanisms to measure compliance, given that reliance on voluntary commitment has demonstrated clear insufficiency in light of the documented findings. Furthermore, it is advisable to link research performance evaluation criteria and academic accreditation indicators to laboratory sustainability requirements, mirroring what has been adopted in several European accreditation systems, thereby transforming sustainability from a morally desirable value into a structural condition that cannot be overlooked.

12. 2 At the Level of Financial Support and Infrastructure:

It is recommended that scientific research funding bodies include an explicit line item within research grants

covering the costs of transitioning to green practices, encompassing equipment upgrades and technical qualification programs, particularly in developing country contexts where the cost of transition becomes an unbearable burden in the absence of external support. The study also recommends building regional networks for sharing resources and green materials among academic institutions, thereby alleviating the burden of non-toxic alternative scarcity in local markets and the high costs of individual procurement.

ACKNOWLEDGMENT

The author wish to thank Faculty Members, Laboratory Technicians, Teaching Assistants in Tripoli University, and researchers in research centers. Special thanks go to the Libyan Center for Sustainable Development Research, with special thanks to Dr. Mustafa Bin Hakuma and Dr. Mohammed Said Fahaj; for the facilities and the stimulating scientific environment they provided to accomplish this remarkable work.

REFERENCES

Abuselidze, G. (2022, June). Financing higher education: new challenges, incentives and opportunities. In IOP Conference Series: Earth and Environmental Science (Vol. 1026, No. 1, p. 012066). IOP Publishing.

Ahmed, L. (2024). A Policy Perspective to Farmers' Adaptation to Water Scarcity: The Case of Kafr El Sheikh, Egypt (Master's thesis, The American University in Cairo (Egypt)).

Anastas, P. T., & Warner, J. C. (2000). *Green Chemistry: Theory and Practice*. Oxford University Press.

Anastas, P., & Eghbali, N. (2010). Green chemistry: principles and practice. Chemical society reviews, 39(1), 301-312.12. Sussman, A. F., & Schulte, P. A. (2001). "Changing the culture of occupational health and safety in academia." Journal of Safety Research, 32 (3), 177–189.

Ayalew, M. E., & Jeevan, T. S. M. A. (2022). The technology of green chemistry and its function in redox response and: Environmentally friendly technology for sustainable development: Assessment of recent findings. Adv. Chem. Eng. Sci, 12(03), 131-144.

Cannon, A. S., & Warner, J. C. (2011). The science of green chemistry and its role in chemicals policy and educational reform. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 21(3), 499-517.

Duarte, R. M., & Duarte, A. C. (2025). Integrating sustainability in atmospheric chemistry analysis. Current Opinion in Green and Sustainable Chemistry, 101048.

Freese, T., Elzinga, N., Heinemann, M., Lerch, M. M., & Feringa, B. L. (2024). The relevance of sustainable laboratory practices. Rsc Sustainability, 2(5), 1300-1336..

Grieger, K., Hill, B., & Leontyev, A. (2022). Exploring curriculum adoption of green and sustainable chemistry in undergraduate organic chemistry courses: results from a national survey in the United States. Green Chemistry, 24(22), 8770-8782.

Hessel, V., Tran, N. N., Asrami, M. R., Tran, Q. D., Long, N. V. D., Escribà-Gelonch, M., ... & Sundmacher, K. (2022). Sustainability of green solvents–review and perspective. Green Chemistry, 24(2), 410-437.

Ivanković, A., Dronjić, A., Bevanda, A. M., & Talić, S. (2017). Review of 12 principles of green chemistry in practice. International Journal of Sustainable and Green Energy, 6(3), 39-48.

Jaśkiewicz, M., Jurecki, R., & Szumska, E. (2025). Automotive Safety 2024.

Jürgens, M., Hartmann, K., Endres, H. J., & Spierling, S. (2023). Life cycle assessment of higher education institutions–method and case study. Journal of Cleaner Production, 430, 139649.

Khan, M., Bhattacharya, S., Gogoi, S., & Ahmad, S. (2024). CONCEPT AND REQUIREMENTS OF ESTABLISHING GREEN LABORATORIES: SCOPING REVIEW. Era's Journal of Medical Research, 11(2), 260-268.

Krasnodębski, M. (2022). Lost green chemistries: history of forgotten environmental trajectories. Centaurus, 64(2), 509-536.

Marck, C. H., Ayton, D., Steward, T., Koay, H. F., Wiley, J. F., Taiaroa, G., & Singh, A. (2024). The workplace culture, mental health and wellbeing of early-and mid-career health academics: a cross-sectional analysis. BMC Public Health, 24(1), 1122.

Miladinović, S. M. (2024). Green analytical chemistry: integrating sustainability into undergraduate education. Analytical and Bioanalytical Chemistry, 417(4), 665.4.

Ncube, A., Mtetwa, S., Bukhari, M., Fiorentino, G., & Passaro, R. (2023). Circular economy and green chemistry: the need for radical innovative approaches in the design for new products. Energies, 16(4), 1752.

Raheja, L., Benítez, F. J., Ferraz-Caetano, J., Leviev, M. G., Saxena, A., & Becker, A. I. (2026). Engagement of early-career scientists in sustainable chemistry: science policy perspectives. RSC Sustainability.

Situngkir, R. C., Azizah, M., & Nurfajriani, N. (2026). Implementation of Green Chemistry in Chemistry Learning: A Literature Review. Jambura Journal of Educational Chemistry, 8(1), 46-56..

Suiirbay, S. (2025). Green chemistry in secondary education: a systematic review of global trends, pedagogical approaches, and implementation challenges. Research in Science & Technological Education, 1-35.

Veleva, V. R., & Cue Jr, B. W. (2019). The role of drivers, barriers, and opportunities of green chemistry adoption in the major world markets. Current Opinion in Green and Sustainable Chemistry, 19, 30-36.8. Koppcopal, K. V., & West, R. P. (2019). "Challenges and Barriers to Implementing Green Chemistry in Academic Laboratories."Green Chemistry Letters and Reviews, 13(2), 120-130.

Zimmerman, J. B., Anastas, P. T., Erythropel, H. C., & Leitner, W. (2020). Designing for a green chemistry future. Science, 367(6476), 397-400.

BIOGRAPHIES

Huda Gayeed received his BSc degree in Chemistry Science from Elmergib University, Libya. She obtained his MSc degree in Inorganic Chmistry Science from the University of Tripoli.