# The Impact of ISO 17025 Implementation on Green Transformation of Laboratories: Laboratory Management Systems as a Mediating Variable

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## Abstract

Background and Objective: This study examines the relationship between ISO 17025 implementation and green transformation in laboratory environments, with laboratory management systems serving as a mediating variable. The research addresses a critical gap in understanding how international quality standards can drive environmental sustainability in laboratory operations.

Methods: A cross-sectional survey was conducted with 346 laboratory staff across various laboratory types and certification stages. The study employed advanced statistical techniques including descriptive statistics, correlation analysis, regression modeling, and structural equation modeling to test the proposed hypotheses. Data collection utilized a validated questionnaire measuring three core constructs: ISO 17025 implementation

(independent variable), laboratory management systems (mediating variable), and green transformation (dependent variable).

Results: The findings revealed significant positive relationships between all study variables. ISO 17025 implementation demonstrated a strong direct effect on laboratory green transformation ($\beta = 0.68$, $p < 0.001$, $R^2 = 83.9\%$). Laboratory management systems emerged as a crucial partial mediator, explaining 90.3% of variance in green transformation outcomes. The combined effect of ISO 17025 implementation and laboratory management systems explained 94% of the variance in green transformation, representing a 10.1 percentage point increase over the direct effect alone.

Conclusions: The study provides strong empirical evidence that ISO 17025 implementation significantly drives green transformation in laboratory environments through both direct pathways and mediated effects via enhanced management systems. Quality management practices inherently support environmental sustainability objectives, with systematic approaches yielding superior outcomes compared to fragmented environmental initiatives.

Keywords: ISO 17025, Green Transformation, Laboratory Management, Environmental Sustainability, Quality Management, Mediation Analysis

الملخص العربي :
تتناول هذه الدراسة العلاقة بين تطبيق معيار ISO 17025 والتحول الأخضر في بيئات المختبرات، مع اعتبار نظم إدارة المختبر كمتغير وسيط. وتُعالج الدراسة فجوة حرجة في الفهم تتعلق بكيفية مساهمة معايير الجودة الدولية في تعزيز الاستدامة البيئية داخل عمليات المختبرات.
المنهجية:
تم إجراء مسح مقطعي شمل ٣٤٦ من العاملين في المختبرات بمختلف أنواعها ودرجات اعتمادها. استخدمت الدراسة تقنيات إحصائية متقدمة شملت الإحصاءات الوصفية، وتحليل الارتباط، ونمذجة الانحدار، ونمذجة المعادلات الهيكلية لاختبار الفرضيات المقترحة. وقد تم جمع البيانات باستخدام استبيان مُعتمد يقيس ثلاثة متغيرات أساسية:
١ .تطبيقISO 17025 (المتغير المستقل)
٢ .نظم إدارة المختبر (المتغير الوسيط)
٣ .التحول الأخضر (المتغير التابع)
النتائج:
كشفت النتائج عن علاقات إيجابية ذات دلالة إحصائية بين جميع متغيرات الدراسة. حيث أظهر تطبيق ISO 17025 تأثيرًا مباشرًا قويًا على التحول الأخضر في المختبرات ($\beta = 0.68$، $p < 0.001$، $R^2 = 83.9\%$). وبرزت نظم إدارة المختبر كوسيط جزئي بالغ الأهمية، حيث فسرت ٩٠.٣% من التباين في نتائج التحول الأخضر. وقد ساهم التأثير المشترك لتطبيق ISO 17025 ونظم إدارة المختبر في تفسير ٩٤% من التباين، أي بزيادة قدرها ١٠.١ نقطة مئوية مقارنةً بالتأثير المباشر وحده.
الاستنتاجات:
توفر الدراسة دليلًا تجريبيًا قويًا على أن تطبيق ISO 17025 يُسهم بشكل كبير في دفع التحول الأخضر في بيئات المختبرات، سواء من خلال المسارات المباشرة أو عبر التأثيرات الوسيطة الناتجة عن تحسين نظم الإدارة. وتدعم ممارسات إدارة

الجودة بطبيعتها أهداف الاستدامة البيئية، إذ تؤدي الأساليب المنهجية إلى نتائج بيئية أفضل مقارنةً بالمبادرات البيئية المجزأة
الكلمات المفتاحية:
ISO 17025، التحول الأخضر، إدارة المختبرات، الاستدامة البيئية، إدارة الجودة، تحليل الوساطة.

## 1. Introduction

The growing emphasis on environmental sustainability has created unprecedented pressure on organizations across all sectors to adopt green practices and reduce their environmental footprint (Hart & Dowell, 2011). Laboratories, as critical components of scientific and industrial infrastructure, face unique challenges in balancing operational excellence with environmental responsibility (Ashford et al., 2012). These facilities consume significant energy, generate hazardous waste, and utilize various chemicals and materials that can impact environmental quality if not properly managed (Blackstone et al., 2018).

International Standard ISO 17025, which specifies general requirements for the competence of testing and calibration laboratories, has emerged as a cornerstone of laboratory quality management worldwide (ISO, 2017). While primarily focused on ensuring technical competence and reliability of test results, ISO 17025 contains inherent elements that may contribute to environmental sustainability when properly implemented (Santos

& Milán, 2013). However, the relationship between quality standard compliance and environmental performance in laboratory settings remains underexplored in the academic literature (Thompson & Martinez, 2021).

Laboratory management systems represent a critical organizational capability that encompasses documentation and monitoring processes, risk management practices, and continuous improvement mechanisms (Hoyle, 2017). These systems serve as the operational infrastructure through which quality standards are translated into daily practices and outcomes (Psomas & Jaca, 2016). The extent to which these management systems mediate the relationship between quality standard implementation and environmental performance constitutes an important research question with significant practical implications (Chen & Wang, 2022).

This study addresses three primary research objectives: (1) to examine the direct relationship between ISO 17025 implementation and green transformation in laboratories, (2) to investigate the mediating role of laboratory management systems in this relationship, and (3) to provide evidence-based recommendations for integrating quality management and environmental sustainability in laboratory operations.

## 2. Literature Review and Theoretical Framework

### 2.1 ISO 17025 and Quality Management in Laboratories

ISO 17025 represents the international standard for laboratory competence, establishing requirements for technical competence,

management systems, and operational procedures (ISO, 2017). The standard encompasses three primary dimensions: organizational structure requirements, resource requirements, and process requirements (Lo et al., 2011). Previous research has demonstrated that ISO 17025 implementation enhances operational efficiency, reduces errors, and improves stakeholder confidence in laboratory results (Sampaio et al., 2009)

Studies have shown that quality management systems provide a structured framework for organizational improvement (Powell, 1995). Specifically, ISO 17025 implementation has been associated with improved process control, enhanced documentation practices, and stronger risk management capabilities (Feng et al., 2008). These systematic approaches to quality management create organizational capabilities that extend beyond technical competence to encompass broader operational improvements (Reed et al., 2000).

**2.2 Green Transformation and Environmental Sustainability**

Green transformation refers to the comprehensive adoption of environmentally sustainable practices across organizational operations (Hart, 1995). In laboratory contexts, this encompasses resource efficiency measures, sustainable practices implementation, and enhanced environmental performance (Christmann, 2000). The literature suggests that systematic approaches to environmental management yield superior outcomes compared to ad-hoc green initiatives (Aragón-Correa, 1998).

Environmental management systems research indicates that organizations benefit from structured approaches to sustainability (Darnall et al., 2008). Studies have identified three key dimensions of environmental performance: resource efficiency, sustainable practices, and environmental outcomes (Clarkson et al., 2011). These dimensions provide a comprehensive framework for assessing organizational environmental transformation (Sharma & Vredenburg, 1998).

**2.3 Laboratory Management Systems**

Laboratory management systems represent the organizational infrastructure that enables effective implementation of quality standards and environmental practices (Dale et al., 2016). These systems typically include documentation and monitoring processes, risk management frameworks, and continuous improvement mechanisms (Deming, 1986). The literature suggests that robust management systems serve as critical enablers of both quality and environmental performance (Anderson et al., 1994).

Research on management systems effectiveness has identified three core components: documentation and monitoring, risk management, and continuous improvement (Feigenbaum, 1991). These components work synergistically to create organizational capabilities that support multiple performance outcomes (Black & Porter, 1996). The mediation literature suggests that management systems can serve as pathways through which

external standards influence organizational outcomes (MacKinnon et al., 2007).

**2.4 Theoretical Framework and Hypotheses**

Based on the literature review and theoretical considerations, this study proposes a mediation model where ISO 17025 implementation influences green transformation both directly and indirectly through laboratory management systems (Preacher & Hayes, 2008). The integration of quality and environmental management has theoretical support in the literature (Rondinelli & Vastag, 2000).

The following hypotheses were formulated based on theoretical foundations and prior empirical evidence:

H1: There is a significant positive relationship between ISO 17025 implementation and green transformation in laboratories.

H2: There is a significant positive relationship between ISO 17025 implementation and laboratory management systems.

H3: There is a significant positive relationship between laboratory management systems and green transformation in laboratories.

H4: Laboratory management systems mediate the relationship between ISO 17025 implementation and green transformation in laboratories.

## 3. Methodology

### 3.1 Research Design and Sample

This study employed a cross-sectional survey design to examine relationships between ISO 17025 implementation, laboratory management systems, and green transformation. The target population consisted of laboratory staff working in ISO 17025 certified laboratories, laboratories undergoing certification processes, and laboratories planning to pursue certification.

Using the Yamane formula with a 5% margin of error and 95% confidence level, the minimum required sample size was calculated as 265 participants from a total population of 785 laboratory professionals. To enhance statistical power and account for potential non-response, the actual sample size was increased to 346 participants, yielding an actual margin of error of 4.0%.

### 3.2 Sampling Strategy

A stratified random sampling approach was employed to ensure representation across different laboratory settings, staff levels, and geographical locations. Stratification was based on three key dimensions: laboratory type (chemical analysis, environmental testing, medical diagnostic, food safety, materials testing, and R&D laboratories), certification status (fully certified, undergoing certification, and planning certification), and geographic distribution (urban and rural locations).

### 3.3 Data Collection Instrument

A structured questionnaire was developed to measure the three core constructs of the study. The instrument consisted of 36 items distributed across three main sections:

- ISO 17025 Implementation (12 items): Measuring organizational structure requirements (4 items), resource requirements (4 items), and process requirements (4 items)
- Laboratory Management Systems (12 items): Measuring documentation and monitoring (4 items), risk management (4 items), and continuous improvement (4 items)
- Green Transformation (12 items): Measuring resource efficiency (4 items), sustainable practices (4 items), and environmental performance (4 items)

All items were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

### 3.4 Validity and Reliability

Content validity was established through expert review by three faculty members with expertise in quality management, environmental sustainability, and laboratory operations. The questionnaire was modified based on their comprehensive review to ensure clarity, appropriate coverage of construct dimensions, and cultural appropriateness.

Reliability was assessed using Cronbach's alpha coefficient. All constructs demonstrated acceptable reliability with alpha values

ranging from 0.849 to 0.972, well above the recommended threshold of 0.70.

### 3.5 Data Analysis

Data analysis was conducted using MINITAB 19 statistical software and employed multiple analytical techniques:

- Descriptive Statistics: Means, standard deviations, and frequency distributions
- Correlation Analysis: Spearman correlation coefficients to examine bivariate relationships
- Regression Analysis: Simple and multiple regression to test direct effects
- Mediation Analysis: Following Baron and Kenny's approach to test mediation effects

## 4. Results

### 4.1 Sample Characteristics

The final sample of 346 participants represented diverse professional roles: quality managers (28.3%), laboratory technicians (24.6%), laboratory supervisors (19.1%), environmental compliance officers (15.3%), and senior laboratory administrators (12.7%). Experience levels were well-distributed, with the largest group having 5-10 years of experience (32.7%), followed by 10-15 years (26.9%), 3-5 years (21.4%), 15-20 years (13.6%), and over 20 years (5.4%).

Educational qualifications showed high levels of professional preparation: bachelor's degree holders (45.1%), master's degree

holders (31.8%), professional certification holders (15.6%), and PhD holders (7.5%). Regarding certification status, 67.3% worked in fully certified laboratories, 22.8% in laboratories undergoing certification, and 9.9% in laboratories planning certification.

**4.2 Descriptive Statistics**

All study variables demonstrated moderate to high mean scores, indicating generally positive perceptions among laboratory staff:

- ISO 17025 Implementation: M = 3.593, SD = 0.720
- Laboratory Management Systems: M = 3.573, SD = 0.959
- Green Transformation: M = 3.558, SD = 0.954

One-sample t-tests confirmed that all means were significantly higher than the neutral midpoint of 3.0 ($p < 0.001$), indicating above-average implementation levels across all constructs.

**4.3 Correlation Analysis**

Correlation analysis revealed strong positive relationships between all study variables:

- ISO 17025 Implementation ↔ Green Transformation: $r = 0.916$, $p < 0.001$
- ISO 17025 Implementation ↔ Laboratory Management Systems: $r = 0.860$, $p < 0.001$
- Laboratory Management Systems ↔ Green Transformation: $r = 0.950$, $p < 0.001$

All correlations were statistically significant and exceeded the threshold for strong relationships ($r > 0.70$).

## 4.4 Hypothesis Testing

Hypothesis 1 Testing: Simple regression analysis confirmed a significant positive relationship between ISO 17025 implementation and green transformation ($F = 1797.20$, $p < 0.001$, $R^2 = 0.839$). This indicates that 83.9% of variance in green transformation is explained by ISO 17025 implementation. H1 is supported.

Hypothesis 2 Testing: Simple regression analysis confirmed a significant positive relationship between ISO 17025 implementation and laboratory management systems ($F = 976.85$, $p < 0.001$, $R^2 = 0.740$). This indicates that 74.0% of variance in laboratory management systems is explained by ISO 17025 implementation. H2 is supported.

Hypothesis 3 Testing: Simple regression analysis confirmed a significant positive relationship between laboratory management systems and green transformation ($F = 3183.76$, $p < 0.001$, $R^2 = 0.903$). This indicates that 90.3% of variance in green transformation is explained by laboratory management systems. H3 is supported.

Hypothesis 4 Testing: Multiple regression analysis including both ISO 17025 implementation and laboratory management systems as predictors of green transformation yielded significant results ($F = 2699.26$, $p < 0.001$, $R^2 = 0.940$). The combined model explained 94.0% of variance in green transformation, representing a 10.1 percentage point increase over the direct

effect alone. Both predictors remained significant in the combined model, indicating partial mediation. H4 is supported.

### 4.5 Mediation Analysis

The mediation analysis confirmed that laboratory management systems partially mediate the relationship between ISO 17025 implementation and green transformation. The indirect effect through the mediator accounts for approximately 58.1% of the total effect, while the direct effect accounts for 41.9%. This partial mediation suggests that ISO 17025 implementation influences green transformation through both direct mechanisms and enhanced management capabilities.

## 5. Discussion

### 5.1 Key Findings and Implications

This study provides strong empirical evidence for the positive relationship between ISO 17025 implementation and green transformation in laboratory environments. The findings demonstrate that quality management practices inherently support environmental sustainability objectives, challenging the traditional view that quality and environmental management represent competing organizational priorities.

The particularly strong relationship between laboratory management systems and green transformation ($R^2$ = 90.3%) suggests that systematic management approaches serve as powerful enablers of environmental sustainability. This finding highlights the importance of robust organizational infrastructure

in translating quality standards into tangible environmental benefits.

### 5.2 Theoretical Contributions

The study makes several important theoretical contributions to the literature:

- Integration Theory Validation: Provides quantitative evidence for theoretical propositions regarding quality-environment integration
- Mediation Mechanism: Elucidates the pathway through which quality standards influence environmental performance
- Systematic Approach Benefits: Demonstrates the superiority of systematic versus fragmented approaches to environmental management

### 5.3 Practical Implications

The findings have significant implications for laboratory administrators, quality managers, and environmental officers:

- Integrated Management: Organizations should adopt unified quality-environment management strategies rather than maintaining separate systems
- Management System Priority: Investment in robust management systems yields the highest returns in environmental performance
- Comprehensive Implementation: Complete rather than selective adoption of ISO 17025 produces superior sustainability outcomes

### 5.4 Limitations and Future Research

Several limitations should be acknowledged. The cross-sectional design limits causal inferences, and the reliance on perceptual measures may introduce response bias. Future research should employ longitudinal designs and incorporate objective performance measures to strengthen causal conclusions.

## 6. Conclusions

This study provides compelling evidence that ISO 17025 implementation significantly drives green transformation in laboratory environments through both direct pathways and mediated effects via enhanced management systems. The findings support an integrated approach to quality and environmental management, demonstrating that these objectives are complementary rather than competing organizational priorities.

Laboratory administrators and quality managers should view ISO 17025 implementation as an opportunity to simultaneously advance quality and environmental objectives. The strong mediating role of laboratory management systems suggests that investment in systematic management approaches yields the highest returns in both quality and environmental performance.

The study contributes to both theoretical understanding and practical guidance for organizations seeking to balance operational excellence with environmental sustainability. As environmental pressures continue to intensify, the integration of

quality and environmental management represents a strategic approach that can deliver superior outcomes across multiple performance dimensions.

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