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Environmental Practices: Lean Production and Sustainable Environmental Performance: A Comprehensive Case Study Based on an Inventory at a Local Paint Manufacturing Plant

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Index Terms

Lean Production Management, Environmental Sustainability Performance, Lean-Green Manufacturing, Paint Manufacturing, Batch-Process Production.

Abstract

This study investigates the association between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing factory operating within a batch-process production environment. The study addresses the need to understand how Lean practices may support environmental sustainability in bounded manufacturing contexts where production flow, material use, waste generation, emissions-related risks, and operational control are closely interconnected. A quantitative descriptive-analytical design was adopted using a census-based case study approach. Data were collected through a structured questionnaire administered to the full accessible production-related workforce, yielding 20 valid responses. Lean Production Management was measured through three dimensions: continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control. Environmental Sustainability Performance was assessed through indicators related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration. The results revealed high perceived levels of both constructs, and reliability analysis confirmed strong internal consistency of the measurement scales. Correlation and supplementary regression analyses indicated positive relationships between Lean practices and Environmental Sustainability Performance; however, these relationships were not statistically significant at the 0.05 level. The findings suggest that Lean practices may provide an operational foundation for environmental sustainability, but their environmental contribution is not automatic and depends on explicit integration with environmental KPIs, waste measurement, resource-efficiency indicators, and sector-specific pollution-control practices. The study contributes context-specific empirical evidence to Lean-Green manufacturing literature and offers practical guidance for strengthening Lean-Green integration in batch-process paint manufacturing.

التطبيقات البيئة الإنتاج الرشيق والأداء البيئي المستدام: دراسة حالة شاملة قائمة على الحصر في مصنع محلي لصناعة الدهانات

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الكلمات المفتاحية

ممارسات إدارة الإنتاج الرشيق والأداء البيئي المستدام :دراسة حالة شاملة قائمة على الحصر في مصنع محلي لصناعة الدهانات

الملخص

تهدف هذه الدراسة إلى فحص العلاقة بين ممارسات إدارة الإنتاج الرشيق والأداء البيئي المستدام في مصنع محلي مختار لصناعة الدهانات يعمل ضمن بيئة إنتاج دفعية .وتستجيب الدراسة للحاجة إلى فهم كيفية دعم ممارسات الإنتاج الرشيق للاستدامة البيئية في سياقات صناعية محدودة تتداخل فيها تدفقات الإنتاج، واستخدام المواد، وتوليد المخلفات، ومخاطر الانبعاثات، والرقابة التشغيلية .اعتمدت الدراسة المنهج الكمي الوصفي التحليلي باستخدام أسلوب دراسة الحالة القائمة على الحصر الشامل .وجُمعت البيانات من خلال استبانة منظمة وُزعت على كامل القوى العاملة الإنتاجية المتاحة، وبلغ عدد الاستجابات الصالحة للتحليل 20استجابة .قيسَت

إدارة الإنتاج الرشيق من خلال ثلاثة أبعاد :التحسين المستمر والعمل المعياري، تقليل الهدر وتحسين تدفق العمليات، وأدوات الرشاقة والرقابة التشغيلية .أما الأداء البيئي المستدام فقيس من خلال مؤشرات تتعلق بتقليل المخلفات، وكفاءة استخدام الموارد، والوعي باستخدام الطاقة، وخفض الانبعاثات، والرقابة على التلوث، وإعادة التدوير، ومراعاة الأداء البيئي .أظهرت النتائج مستويات إدراك مرتفعة لكل من ممارسات إدارة الإنتاج الرشيق والأداء البيئي المستدام، كما أكدت نتائج الثبات اتساقًا داخليًا قويًا لمقاييس الدراسة .وأشارت نتائج الارتباط والانحدار التكميلي إلى علاقات موجبة بين ممارسات الإنتاج الرشيق والأداء البيئي المستدام، إلا أنها لم تكن دالة إحصائيًا عند مستوى .0.05وتخلص الدراسة إلى أن ممارسات الإنتاج الرشيق قد توفر أساسًا تشغيليًا لدعم الاستدامة البيئية، غير أن مساهمتها البيئية ليست تلقائية، بل تتطلب ربطًا صريحًا بمؤشرات أداء بيئية، وقياس المخلفات، ومؤشرات كفاءة الموارد، وممارسات الرقابة على التلوث.

1. INTRODUCTION

Environmental sustainability has become a strategic imperative for manufacturing organizations due to the increasing environmental pressures associated with industrial production activities, including excessive resource consumption, energy use, emissions generation, solid and liquid waste, and process-related pollution. These pressures have intensified the need for production systems that can balance operational efficiency with environmental responsibility. This issue is particularly relevant in process-oriented and batch manufacturing industries, such as paint manufacturing, where material preparation, mixing, dispersion, quality control, filling, packaging, and waste handling are closely connected to both operational performance and environmental outcomes (Yadav et al., 2020; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

Lean Production Management is widely recognized as one of the most influential operational improvement philosophies in industrial engineering and production management. Rooted in the Toyota Production System, Lean focuses on eliminating non-value-added activities, improving workflow, reducing variability, enhancing process discipline, and maximizing customer value through continuous improvement. Although Lean was initially associated with productivity, cost reduction, and quality improvement, recent manufacturing literature increasingly positions Lean as a strategic approach that can support sustainability-oriented operational performance when its practices are aligned with environmental objectives (Abualfaraa et al., 2020; Yadav et al., 2020; Chavez et al., 2022; Ferrazzi et al., 2025).

The relationship between Lean Production and environmental sustainability is grounded in the close connection between operational waste and environmental waste. Overproduction, excessive inventory, waiting time, unnecessary transportation, inefficient motion, defects, rework, and overprocessing do not only reduce operational efficiency; they may also increase material losses, energy consumption, emissions, chemical waste, and pollution risks. Therefore, Lean Production practices may generate dual benefits by improving process efficiency while reducing environmental burdens, particularly when environmental objectives are embedded into operational improvement routines (Abualfaraa et al., 2020; Afum et al., 2021; Teixeira et al., 2021; Ferrazzi et al., 2025).

The integration of Lean and Green Manufacturing has therefore become a major research direction within sustainable operations management. Lean-Green integration suggests that operational excellence and environmental responsibility should not be treated as separate managerial agendas, but as complementary approaches for improving productivity, reducing waste, increasing resource efficiency, and strengthening sustainable manufacturing performance. However, the environmental value of Lean depends on whether Lean practices are intentionally connected to environmental goals rather than being implemented only for cost reduction or productivity improvement (Abualfaraa et al., 2020; Thekkoote, 2022; Elemure et al., 2023; Martinez & Jirsák, 2024).

Several Lean practices are particularly relevant to the improvement of environmental sustainability performance in manufacturing environments. Continuous improvement encourages systematic problem identification and incremental process enhancement; standardized work reduces operational variation; 5S improves workplace organization and reduces unnecessary movement; Value Stream Mapping supports the identification of waste across material and information flows; Total Productive Maintenance reduces equipment breakdowns and production interruptions; Just-In-Time practices contribute to inventory reduction; and visual management supports performance monitoring and operational control. When these practices are effectively implemented and linked to environmental indicators, they may contribute to lower waste generation, improved resource utilization, reduced energy losses, and better environmental process control (Abualfaraa et al., 2020; Kosasih et al., 2023; Hegedić et al., 2024; Ferrazzi et al., 2025).

Recent Lean-Green studies also indicate that the selection and prioritization of Lean tools should not be based only on economic or operational objectives. Hegedić et al. (2024) emphasized that Lean tools may influence both economic and environmental performance indicators, suggesting the need for decision-making approaches that

align Lean tool implementation with environmental priorities. Similarly, Fiorello et al. (2023) argued that the Lean-Green paradigm can support operational performance when improvement practices are connected to sustainability-oriented goals. These studies reinforce the need to examine Lean practices not only as efficiency tools, but also as potential mechanisms for supporting environmental sustainability in real manufacturing contexts.

Environmental Sustainability Performance refers to the extent to which an industrial organization reduces negative environmental impacts through efficient resource utilization, waste reduction, pollution prevention, emissions control, recycling, and environmentally responsible production practices. Within manufacturing systems, environmental performance is often reflected in indicators such as reduced material waste, improved energy efficiency, lower emissions, improved waste management, and consideration of environmental indicators in operational evaluation. These indicators are highly relevant in paint manufacturing, where chemical materials, volatile organic compounds, process residues, and waste management practices may significantly influence environmental outcomes (Afum et al., 2021; Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023).

In paint manufacturing, the environmental implications of production activities are particularly important because the industry is associated with the use of chemical inputs, solvents, pigments, additives, emissions, wastewater, residues, and packaging waste. Recent studies on paint and coating industries emphasize the importance of reducing volatile organic compound emissions, adopting cleaner formulations, improving environmental control, and strengthening eco-friendly manufacturing practices. Accordingly, paint manufacturing provides a meaningful industrial context for examining how Lean Production Management practices may support environmental sustainability through better waste control, process flow improvement, resource efficiency, and operational discipline (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

Despite the growing academic interest in Lean-Green integration, empirical evidence remains fragmented, particularly in developing-economy contexts and in small or locally managed manufacturing organizations. Many previous studies have examined Lean implementation in broad manufacturing sectors, while comparatively less attention has been given to bounded production environments where the entire production-related workforce can be examined through a census-based approach. This limitation is important because small and medium industrial organizations often face specific constraints related to limited resources, informal operational routines, technological readiness, environmental awareness, and managerial integration of sustainability indicators (Yadav et al., 2020; Thekkoote, 2022; Siegel et al., 2024; Kosasih et al., 2023).

Moreover, the environmental contribution of Lean implementation remains context dependent. While several studies suggest that Lean practices can support environmental sustainability, operational efficiency improvements do not automatically lead to environmental performance improvement unless sustainability indicators are deliberately incorporated into operational decision-making. This means that Lean practices may reduce waste and resource consumption, but their environmental contribution depends on managerial commitment, employee involvement, measurement systems, process discipline, and the extent to which environmental objectives are embedded into daily production practices (Afum et al., 2021; Martinez & Jirsák, 2024; Silva & Gomes, 2025; Ferrazzi et al., 2025).

Based on this gap, the present study focuses on a selected local paint manufacturing factory operating as a batch-process industrial environment. Unlike broad survey-based studies that rely on samples drawn from large populations, this research adopts a census-based case study approach because the total number of individuals directly involved in the production-related workforce is limited and clearly identifiable. Therefore, the study examines the perceptions of the full accessible production-related population within the selected factory regarding Lean Production Management practices and Environmental Sustainability Performance. This approach provides context-specific empirical evidence while acknowledging that the findings should be interpreted within the boundaries of the studied organization (Yadav et al., 2020; Kosasih et al., 2023; Sales-Contini et al., 2025).

Accordingly, this study seeks to empirically examine the relationship between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing factory. The study focuses on three dimensions of Lean Production Management: continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control. Environmental Sustainability Performance is examined through indicators related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration. By doing so, the study contributes to the Lean-Green

manufacturing literature by providing census-based empirical evidence from a batch-process paint manufacturing context and by highlighting the need to link Lean practices more explicitly with measurable environmental sustainability indicators (Abualfaraa et al., 2020; Thekkoote, 2022; Ferrazzi et al., 2025; Sales-Contini et al., 2025).

The study's contribution is not to establish a universal or causal Lean-Green effect, but to provide bounded empirical evidence from a batch-process paint manufacturing context. By showing high perceived levels of both Lean Production Management practices and Environmental Sustainability Performance alongside a positive but non-significant association, the study highlights a context-specific Lean-Green gap: Lean routines may create an operational foundation for sustainability, yet they do not automatically translate into measurable environmental outcomes. This contribution is particularly relevant to paint manufacturing, where VOC-related risks, chemical residues, waste generation, and pollution-control requirements require explicit environmental KPIs, waste measurement, and sector-specific monitoring within Lean practices.

2. RESEARCH PROBLEM

In recent years, environmental sustainability has become a strategic concern for manufacturing organizations due to increasing environmental regulations, resource scarcity, climate-related pressures, and growing stakeholder expectations for sustainable industrial practices. Manufacturing firms are increasingly required to improve operational efficiency while simultaneously reducing environmental impacts such as material waste, energy consumption, emissions, chemical residues, and industrial pollution. This challenge is particularly relevant in batch-process industries such as paint manufacturing, where production activities involve material preparation, mixing, dispersion, quality control, filling, packaging, and waste handling, all of which may influence both operational efficiency and environmental sustainability performance.

Lean Production Management has gained considerable attention as an operational philosophy aimed at eliminating non-value-added activities, improving process flow, reducing variability, enhancing resource utilization, and strengthening continuous improvement practices. Although Lean Production was originally developed to improve productivity, quality, and operational efficiency, recent Lean-Green manufacturing literature suggests that Lean practices may also contribute to environmental sustainability by reducing waste, improving energy and material efficiency, minimizing process inefficiencies, and supporting more disciplined production control.

Despite the growing recognition of Lean Production as a potential enabler of environmental sustainability, empirical evidence remains insufficient and context-dependent, particularly in developing-economy settings and in local or bounded batch-process manufacturing organizations. Many previous studies have examined Lean practices in broad manufacturing sectors, while comparatively limited attention has been given to small or bounded industrial settings where the entire production-related workforce can be examined. In paint manufacturing, this gap is especially important because operational inefficiencies may be associated with material losses, rework, excessive energy use, emissions, chemical waste, and environmental pollution risks.

Furthermore, the environmental contribution of Lean Production practices does not occur automatically. Lean tools may improve operational efficiency, but their contribution to environmental sustainability depends on how effectively these practices are connected to waste reduction, resource efficiency, environmental performance indicators, employee involvement, and operational control. Therefore, there is a need for context-specific empirical investigation into how Lean Production Management practices are perceived to support Environmental Sustainability Performance within actual industrial production environments.

Accordingly, the problem of this study lies in examining the relationship between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing factory. Since the total number of individuals directly involved in the production-related workforce is limited and clearly identifiable, the study adopts a census-based case study approach. The research investigates the perceived level of Lean Production Management implementation, the perceived level of Environmental Sustainability Performance, and the extent to which Lean practices are associated with environmental sustainability indicators such as waste reduction, resource efficiency, energy consumption reduction, emissions reduction, pollution control, recycling, and environmental performance consideration.

3. RESEARCH QUESTIONS

- What is the perceived level of Lean Production Management implementation in the selected local paint manufacturing factory?
- What is the perceived level of Environmental Sustainability Performance in the selected local paint manufacturing factory?
- Is there a statistically significant relationship between Lean Production Management practices and

Environmental Sustainability Performance in the selected local paint manufacturing factory?

- How are the three dimensions of Lean Production Management associated with Environmental Sustainability Performance?
- Which Lean Production Management dimension shows the strongest association with Environmental Sustainability Performance in the selected local paint manufacturing factory?

4. RESEARCH HYPOTHESES

- Lean Production Management practices are positively related to Environmental Sustainability Performance.
- A higher level of continuous improvement and standardized work is associated with better Environmental Sustainability Performance.
- Effective waste reduction and process flow improvement are associated with enhanced Environmental Sustainability Performance.
- Lean tools and operational control practices are positively associated with Environmental Sustainability Performance.

5. RESEARCH OBJECTIVES

- In line with the census-based case study conducted in the selected local paint manufacturing factory, this study aims to achieve the following objectives:
- To assess the perceived level of Lean Production Management implementation.
- To assess the perceived level of Environmental Sustainability Performance.
- To examine the relationship between Lean Production Management practices and Environmental Sustainability Performance.
- To examine how the three dimensions of Lean Production Management are associated with Environmental Sustainability Performance.
- To identify the Lean Production Management dimension most strongly associated with Environmental Sustainability Performance and propose practical recommendations for improving sustainable operations in batch-process paint manufacturing.

6. SIGNIFICANCE OF THE STUDY

6.1 Theoretical Significance

This study contributes to the Lean-Green Manufacturing literature by examining the relationship between Lean Production Management practices and Environmental Sustainability Performance within a batch-process paint manufacturing context.

The research provides context-specific empirical evidence from a census-based case study, thereby extending the discussion of Lean and environmental sustainability beyond broad manufacturing settings.

The study enriches sustainable operations management literature by linking three dimensions of Lean Production Management-continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control-with Environmental Sustainability Performance.

The research addresses an empirical gap concerning the environmental implications of Lean Production Management in local or bounded manufacturing organizations operating in developing-economy industrial contexts.

6.2 Practical Significance

The study provides managers in paint manufacturing and similar batch-process industries with practical insights into how Lean Production Management practices may support environmental sustainability performance.

The findings help production and operations managers identify Lean dimensions that are more closely associated with waste reduction, resource efficiency, energy-use awareness, pollution control, and environmental performance consideration.

The research supports decision-makers in aligning operational improvement initiatives with environmental sustainability objectives within production-related activities.

The study offers practical recommendations for strengthening sustainable operations through continuous improvement, standardized work, waste reduction, process flow improvement, Lean tools, and operational control practices.

7. SCOPE OF THE STUDY

This study examines the relationship between Lean Production Management practices and Environmental Sustainability Performance within a selected local paint manufacturing factory operating in a batch-process production environment. The empirical scope is limited to the production-related workforce involved in production, operations, quality, maintenance, and related support activities. Since the total number of individuals directly involved in these functions was limited and clearly identifiable, the study adopted a census-based approach, with 20 valid responses representing the total accessible population. Analytically, the study focuses on the perceived level of Lean Production Management implementation and Environmental Sustainability Performance as measured through a structured questionnaire. Therefore, the findings provide context-

specific evidence from the selected factory and should be interpreted within the boundaries of this census-based case study rather than generalized statistically to all industrial organizations.

8. LITERATURE REVIEW

8.1 Lean Production Management and Sustainable Operational Performance

Lean Production Management has evolved from a traditional operational improvement philosophy into a broader managerial approach that supports sustainable operational performance. Originating from the Toyota Production System, Lean was initially associated with the elimination of non-value-added activities, reduction of waste, improvement of workflow efficiency, inventory control, quality enhancement, and continuous improvement. In contemporary manufacturing research, however, Lean is no longer viewed only as a cost-reduction or productivity-improvement system; rather, it is increasingly discussed as an operational philosophy that may contribute to sustainability-oriented performance when its practices are aligned with environmental and resource-efficiency objectives (Abualfaraa et al., 2020; Yadav et al., 2020; Chavez et al., 2022; Ferrazzi et al., 2025).

The sustainable value of Lean Production is strongly connected to its ability to reduce operational inefficiencies that are also environmentally burdensome. Overproduction, excessive inventory, waiting time, unnecessary transportation, inefficient motion, over processing, defects, and rework may increase material consumption, energy use, emissions, production residues, and pollution risks. Therefore, Lean practices may provide a dual contribution by improving operational efficiency while reducing environmental waste. This relationship is particularly important in process-oriented and batch manufacturing environments, where production inefficiencies can accumulate across sequential stages and generate both operational and environmental losses (Abualfaraa et al., 2020; Afum et al., 2021; Teixeira et al., 2021; Ferrazzi et al., 2025).

Recent empirical studies have strengthened the argument that Lean practices can be associated with broader sustainability outcomes. Chavez et al. (2022) examined the relationship between internal Lean practices and sustainable performance and showed that Lean should be understood through a broader sustainability lens rather than only through operational efficiency. Similarly, Teixeira et al. (2021) connected Lean and Green with sustainability and argued that organizations increasingly need integrated approaches that combine economic, environmental, and operational priorities. These studies support the logic of the present research, which treats Lean Production Management as a potential operational foundation for Environmental Sustainability Performance rather than as a purely productivity-focused system.

Several Lean practices have been identified in the literature as relevant to sustainable operational improvement. Continuous improvement supports systematic problem solving and employee involvement; standardized work reduces process variation; 5S improves workplace organization and reduces unnecessary movement; Value Stream Mapping enables the identification of waste across material and information flows; Total Productive Maintenance reduces equipment failures and production interruptions; Just-In-Time practices support inventory reduction; and visual management strengthens operational monitoring and control. These practices may contribute to more stable production flow, better resource utilization, lower process waste, and improved environmental awareness within manufacturing operations (Abualfaraa et al., 2020; Kosasih et al., 2023; Hegedić et al., 2024; Ferrazzi et al., 2025).

Nevertheless, the literature also shows that the contribution of Lean to sustainability is not automatic. Some studies suggest that Lean implementation may improve environmental performance when organizations integrate environmental objectives into Lean routines, while other studies caution that Lean initiatives may remain narrowly focused on productivity, cost reduction, and efficiency without producing meaningful environmental outcomes. This indicates that the sustainability value of Lean depends on managerial commitment, employee participation, measurement systems, environmental awareness, and the extent to which Lean practices are intentionally connected to sustainability indicators (Afum et al., 2021; Elemure et al., 2023; Martinez & Jirsák, 2024; Ferrazzi et al., 2025).

Environmental Sustainability Performance in Paint Manufacturing

Environmental Sustainability Performance refers to the ability of an organization to reduce negative environmental impacts through waste reduction, efficient resource utilization, energy-use improvement, emissions control, pollution prevention, recycling, and environmentally responsible production practices. In manufacturing organizations, environmental performance is commonly examined through indicators related to material waste, energy consumption, emissions, process residues, wastewater, recycling capability, and environmental performance consideration in operational decisions. These indicators are directly relevant to production systems that depend on material transformation

and process control (Afum et al., 2021; Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023).

Paint manufacturing represents a particularly important context for examining environmental sustainability because it involves chemical inputs, pigments, solvents, additives, mixing operations, dispersion processes, filling, packaging, quality control, and waste handling. The environmental challenges of paint production are often associated with volatile organic compounds, chemical residues, emissions, wastewater, packaging waste, and resource losses during production. Recent studies on paint and coating industries emphasize the need to reduce VOC emissions, improve environmental control practices, adopt cleaner production methods, and strengthen eco-friendly manufacturing approaches (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

From an operational perspective, environmental sustainability in paint manufacturing cannot be separated from process discipline and waste control. Inefficient production flow, poor workplace organization, repeated rework, excessive inventory, equipment downtime, and weak operational monitoring may increase material losses and environmental burdens. Therefore, Environmental Sustainability Performance in this sector is not only a matter of environmental regulation or cleaner materials; it is also closely linked to how production processes are organized, controlled, maintained, and continuously improved. This connection makes Lean Production Management a relevant approach for examining environmental sustainability performance in batch-process paint manufacturing.

Recent paint and coating studies further show that environmental improvement in this industry requires sector-specific attention. Jiménez-López and Hincapié-Llanos (2022) emphasized the importance of identifying factors that affect VOC-emission reduction in the paint industry. Ghobakhloo et al. (2023) highlighted the relevance of exposure risks related to volatile organic compounds in paint production plants. Sales-Contini et al. (2025) also indicated that eco-friendly paint manufacturing requires organizational commitment, cleaner production practices, and systematic attention to sustainability challenges. These studies justify the selection of paint manufacturing as a meaningful empirical setting for studying the relationship between Lean practices and environmental sustainability indicators.

However, despite the environmental relevance of paint manufacturing, limited empirical attention has been given to the way Lean Production Management practices are perceived to support environmental sustainability within this sector. Much of the existing literature discusses Lean-Green integration at the general manufacturing level, while fewer studies focus on bounded production environments such as local paint manufacturing factories. This creates an important research opportunity, especially in developing-economy contexts where environmental performance measurement, technological readiness, and formal sustainability integration may still face practical limitations (Yadav et al., 2020; Kosasih et al., 2023; Sales-Contini et al., 2025).

Lean-Green Integration and the Environmental Role of Lean Practices

Lean-Green integration has emerged as a significant research direction in sustainable operations management. Lean Production traditionally emphasizes the elimination of operational waste, process flow improvement, quality enhancement, and efficiency, whereas Green Manufacturing focuses on reducing environmental impacts through pollution prevention, emissions reduction, cleaner production, resource conservation, and environmental responsibility. The integration of both approaches suggests that operational excellence and environmental sustainability should be treated as complementary objectives rather than separate managerial agendas (Abualfaraa et al., 2020; Thekkoote, 2022; Elemure et al., 2023; Kosasih et al., 2023).

The theoretical logic behind Lean-Green integration is that many operational wastes targeted by Lean are also sources of environmental waste. For example, defects and rework may increase material and energy consumption; unnecessary transportation may increase emissions and handling losses; excessive inventory may increase storage requirements and material deterioration; waiting time may reduce process efficiency; and poor equipment performance may increase energy use and production instability. Accordingly, Lean practices can support environmental sustainability when they reduce these inefficiencies and when environmental indicators are incorporated into operational improvement activities (Afum et al., 2021; Hegedić et al., 2024; Ferrazzi et al., 2025).

Thekkoote (2022) proposed a framework for integrating Lean, Green, and sustainability practices in SMEs and emphasized the need to connect operational improvement with environmental and sustainability-oriented practices. Kosasih et al. (2023) similarly identified gaps in Lean-Green research for manufacturing SMEs and highlighted the need for stronger empirical investigation of integrated Lean-Green practices. These studies are relevant to the present research because the selected local paint manufacturing factory represents a bounded production environment where Lean-Green integration can be

examined through the perceptions of the full accessible production-related workforce.

Recent studies also suggest that Lean tool selection should be linked to environmental priorities. Hegedić et al. (2024) developed a Lean-Green decision model for selecting Lean tools according to economic and environmental performance indicators. This is important for the present study because it supports the idea that Lean tools such as Value Stream Mapping, 5S, Total Productive Maintenance, Just-In-Time, and visual management should not be evaluated only through productivity or cost-related outcomes. Instead, they should also be examined in relation to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, and recycling practices.

Despite this potential, the empirical evidence remains mixed and context-dependent. Some studies report positive links between Lean practices and environmental outcomes, while others argue that Lean implementation does not necessarily lead to sustainability improvement unless environmental goals are explicitly embedded into Lean systems. Martinez and Jirsák (2024) emphasized the need for further research into the Lean-Green relationship, while Silva and Gomes (2025) showed that the connection between Lean, Green practices, and environmental performance may depend on specific configurations of practices rather than the simple presence of Lean tools. This contradiction is important because it prevents the assumption that Lean is automatically green.

In the context of this study, Lean-Green integration is examined through three dimensions of Lean Production Management: continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control. These dimensions reflect the practical mechanisms through which Lean may support Environmental Sustainability Performance. Continuous improvement and standardized work may strengthen discipline and reduce variation; waste reduction and process flow improvement may reduce material and time losses; and Lean tools and operational control may improve equipment reliability, inventory control, process monitoring, and resource efficiency. Therefore, the present study does not treat Lean as a general philosophy only, but as a set of measurable practices linked to perceived environmental sustainability outcomes.

Critical Synthesis and Research Gap

A critical reading of the literature indicates that the relationship between Lean Production Management and Environmental Sustainability Performance has received increasing scholarly attention, yet several gaps remain. First, many studies address Lean-Green integration at a broad manufacturing level without sufficient attention to specific industrial contexts such as paint manufacturing, where environmental risks are closely linked to chemical materials, VOC emissions, residues, process waste, and operational control. Second, previous research often emphasizes operational and economic benefits of Lean, while the environmental dimension is sometimes treated as a secondary outcome rather than a central research focus (Abualfaraa et al., 2020; Ferrazzi et al., 2025; Silva & Gomes, 2025).

Third, the literature shows that Lean practices may contribute to environmental sustainability, but this contribution is not uniform across contexts. The same Lean tools may produce different outcomes depending on organizational readiness, management commitment, employee involvement, production type, measurement practices, and the extent to which sustainability indicators are integrated into daily operations. This is particularly relevant in small, local, or bounded manufacturing environments, where formal sustainability systems may be less developed but operational practices can still influence environmental outcomes (Afum et al., 2021; Thekkoote, 2022; Kosasih et al., 2023; Siegel et al., 2024).

Fourth, limited empirical evidence is available from census-based case studies conducted in bounded production environments. Although broad survey-based studies across multiple firms may provide wider generalizability, they may overlook the internal operational dynamics of specific production systems. Census-based case studies are therefore useful in small and clearly defined industrial settings where the target population is directly involved in the operational processes under investigation. In this sense, the present study does not claim broad statistical generalization, but it provides context-specific evidence from a clearly defined production environment.

Fifth, the paint manufacturing sector requires more focused Lean-Green investigation because its environmental sustainability issues are connected not only to operational waste, but also to chemical materials, VOC emissions, process residues, wastewater, packaging waste, and pollution-control practices. While studies on paint and coating industries have addressed VOC emissions and eco-friendly manufacturing challenges, fewer studies have examined how Lean Production Management practices are perceived to relate to environmental sustainability performance inside a local paint manufacturing factory (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

Accordingly, the present study addresses these gaps by examining the relationship between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing

factory operating in a batch-process environment. The study provides context-specific empirical evidence on how measurable Lean dimensions are perceived to support environmental sustainability indicators, including waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration. This contribution is particularly relevant to Lean-Green manufacturing literature because it links Lean practices with environmental sustainability performance within an actual paint manufacturing context while maintaining a cautious interpretation consistent with the census-based case study design.

9. RESEARCH METHODOLOGY

9.1 Research Design

This study adopted a quantitative descriptive-analytical design based on a census-based case study approach. This design was considered appropriate because the study examined the perceived level of Lean Production Management implementation, the perceived level of Environmental Sustainability Performance, and the relationship between these two constructs within a clearly defined industrial context. The study did not aim to produce broad statistical generalization across all industrial organizations; rather, it provided context-specific empirical evidence from a bounded production environment.

9.2 Study Context and Population

The empirical investigation was conducted in a selected local paint manufacturing factory operating within a batch-process production environment. The production process involved sequential and interrelated activities, including raw material preparation, mixing, dispersion, quality control, filling, packaging, and finished-goods handling. The target population consisted of employees directly involved in production-related activities, including production, operations, quality, maintenance, and related support functions. Since the total number of individuals involved in these functions was limited and clearly identifiable, a census-based approach was adopted. Accordingly, 20 valid responses were obtained, representing the total accessible production-related population within the selected factory.

9.3 Measurement Instrument

Primary data were collected using a structured questionnaire developed from validated constructs in Lean Production Management, Lean-Green integration, and environmental sustainability literature. The instrument was adapted to the context of batch-process paint manufacturing to ensure that the items reflected the operational characteristics of the selected local paint manufacturing factory, including material preparation, mixing, dispersion, quality control, filling, packaging, waste generation, resource use, and environmental control practices.

The questionnaire consisted of two main constructs. Lean Production Management was measured through three dimensions: continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control. Environmental Sustainability Performance was measured through indicators related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration. A five-point Likert scale was used to capture respondents' perceptions.

To ensure construct alignment, the questionnaire items were linked directly to the research problem, research questions, hypotheses, and objectives. Each Lean dimension reflected a specific operational mechanism discussed in the literature, while each environmental sustainability item reflected indicators relevant to batch-process paint manufacturing. Content validity was addressed by reviewing the items for clarity, relevance, and consistency with the study constructs and industrial context before data collection. The reliability of the instrument was subsequently assessed using Cronbach's Alpha.

9.4 Data Collection Procedure

The questionnaire was distributed to all employees included within the production-related population of the selected factory. The data collection process focused on obtaining responses from individuals who were directly familiar with production activities and operational practices. All valid responses were included in the analysis, resulting in a complete census of the accessible production-related workforce.

9.5 Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including means and standard deviations, were used to assess the perceived levels of Lean Production Management implementation and Environmental Sustainability Performance. Cronbach's Alpha was used to evaluate the internal consistency and reliability of the measurement scales. Correlation analysis was conducted to examine the relationship between Lean Production Management practices and Environmental Sustainability Performance. Given the limited size of the bounded study population and the ordinal nature of Likert-scale responses, Spearman correlation was used as the primary association test, while Pearson correlation was reported as a supplementary indicator. Simple linear regression was

applied cautiously to examine the predictive direction between Lean Production Management practices and Environmental Sustainability Performance.

10. RESULTS AND STATISTICAL ANALYSIS

10.1 Respondents' Profile

The final dataset consisted of 20 valid responses, representing the total accessible production-related workforce in the selected local paint manufacturing factory. No missing values were detected in the final dataset. The respondents were drawn from production-related and supporting operational functions, including production, operations, quality management, maintenance, environmental management, and other related areas. This coverage supports the census-based nature of the study, as the responses were collected from individuals directly involved in or familiar with the production process.

The respondents' profile showed that all participants were male. In terms of age, the largest group was between 30 and less than 40 years old, followed by those between 40 and less than 50 years old. Regarding educational level, most respondents held either a bachelor's degree or a diploma/equivalent qualification. The experience profile also indicated that the majority of respondents had more than five years of work experience, with a considerable proportion having between 11 and 15 years of experience. This suggests that the responses were obtained from individuals with practical knowledge of the factory's operational environment.

10.2 Descriptive Statistics of the Study Variables

Descriptive statistics were used to assess the perceived level of Lean Production Management implementation and Environmental Sustainability Performance. The results indicated that all Lean Production Management dimensions recorded high mean scores. Continuous improvement and standardized work recorded the highest mean score, followed by waste reduction and process flow improvement, and then Lean tools and operational control. The overall mean score of Lean Production Management practices was 4.037, indicating a high perceived level of Lean implementation within the selected paint manufacturing factory.

Environmental Sustainability Performance also recorded a high mean score of 3.956. This indicates that respondents perceived the factory as having a relatively high level of environmental sustainability performance in relation to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration.

Table 1. Descriptive statistics of the study constructs

Dimension / Construct	Items	Mean	SD	Level
Continuous improvement and standardized work	4	4.125	0.433	High
Waste reduction and process flow improvement	4	4.013	0.385	High
Lean tools and operational control	4	3.975	0.353	High
Lean Production Management practices	12	4.037	0.358	High
Environmental Sustainability Performance	8	3.956	0.377	High

These results suggest that Lean-related practices were generally perceived as present in the studied factory. The relatively high mean scores also indicate that respondents recognized the role of continuous improvement, standardized work, waste reduction, process flow improvement, and operational control in supporting production performance. However, the interpretation of these results should remain context-specific because the study was conducted within a bounded census-based case study.

10.3 Reliability Analysis

Cronbach's Alpha was used to assess the internal consistency of the measurement scales. The results showed good to excellent reliability across the study dimensions and constructs. Lean Production Management achieved a Cronbach's Alpha of 0.946, while Environmental Sustainability Performance achieved a Cronbach's Alpha of 0.955. The overall questionnaire reliability was 0.944.

Table 2. Reliability analysis

Scale / Dimension	No. of items	Cronbach's Alpha	Interpretation
Continuous improvement and standardized work	4	0.947	Excellent
Waste reduction and process flow improvement	4	0.854	Good
Lean tools and operational control	4	0.843	Good

Lean Production Management practices	12	0.946	Excellent
Environmental Sustainability Performance	8	0.955	Excellent
Overall questionnaire	20	0.944	Excellent

The reliability results indicate that the questionnaire items were internally consistent and suitable for further descriptive and correlational analysis. The high reliability values also suggest that the measurement instrument was coherent in capturing the intended constructs within the selected factory context.

10.4 Correlation Analysis

Correlation analysis was conducted to examine the relationship between Lean Production Management practices and Environmental Sustainability Performance. Given the limited size of the bounded study population and the ordinal nature of Likert-scale responses, Spearman's rho was used as the primary association test. Pearson correlation was also reported as a supplementary indicator of linear association.

Table 3. Correlation between Lean Production Management and Environmental Sustainability Performance

Predictor	Spearman rho	p-value	Pearson r	p-value	Interpretation
Continuous improvement and standardized work	0.283	0.226	0.368	0.110	Positive but not statistically significant
Waste reduction and process flow improvement	0.213	0.368	0.379	0.100	Positive but not statistically significant
Lean tools and operational control	0.219	0.353	0.388	0.091	Positive but not statistically significant
Lean Production Management practices	0.279	0.234	0.411	0.072	Positive but not statistically significant

The results showed positive associations between all Lean Production Management dimensions and Environmental Sustainability Performance. However, none of these relationships reached statistical significance at the 0.05 level. The overall relationship between Lean Production Management practices and Environmental Sustainability Performance was positive according to both Spearman's rho and Pearson correlation. This indicates a positive relational direction, but the evidence was not sufficient to confirm statistical significance within the bounded study population.

10.5 Supplementary Regression Analysis

A simple linear regression analysis was conducted as a supplementary analysis to examine the predictive direction between overall Lean Production Management practices and Environmental Sustainability Performance. The regression coefficient was positive, indicating that higher Lean Production Management scores were associated with higher Environmental Sustainability Performance scores. The model explained 16.9% of the variance in Environmental Sustainability Performance. However, the regression result was not statistically significant at the 0.05 level.

Table 4. Simple regression results

Predictor	B	Std. Error	t	p-value
Constant	2.211	0.916	2.414	0.027
Lean Production Management practices	0.432	0.226	1.913	0.072

Table 5. Model summary

Statistic	Value
R-squared	0.169
Adjusted R-squared	0.123

F-statistic p-value	0.072

The regression result should therefore be interpreted as an exploratory positive trend rather than confirmatory evidence of a causal effect. This interpretation is consistent with the cross-sectional questionnaire-based design and the limited size of the bounded census population.

10.6 Hypotheses Testing

The study hypotheses were evaluated based on the direction and statistical significance of the relationships between Lean Production Management practices and Environmental Sustainability Performance. The results showed positive relationships across all hypotheses; however, these relationships were not statistically significant at the 0.05 level.

Table 6. Summary of hypotheses testing

Hypothesis	Statement	Result
H1	Lean Production Management practices are positively related to Environmental Sustainability Performance.	Positive direction observed, but not statistically supported at 0.05
H2	A higher level of continuous improvement and standardized work is associated with better Environmental Sustainability Performance.	Positive direction observed, but not statistically supported at 0.05
H3	Effective waste reduction and process flow improvement are associated with enhanced Environmental Sustainability Performance.	Positive direction observed, but not statistically supported at 0.05
H4	The implementation of Lean tools and operational control practices is associated with stronger Environmental Sustainability Performance.	Positive direction observed, but not statistically supported at 0.05

Overall, the findings indicate that both Lean Production Management practices and Environmental Sustainability Performance were perceived at high levels in the selected local paint manufacturing factory. The relationships between Lean practices and Environmental Sustainability Performance were consistently positive, but they were not statistically significant at the 0.05 level. Therefore, the findings should be interpreted as exploratory and context-specific evidence from a census-based case study rather than statistically generalizable evidence. The positive direction of the results suggests that Lean practices may support environmental sustainability performance in the studied factory, but stronger validation would require larger multi-site studies or objective operational and environmental performance indicators.

11. DISCUSSION OF FINDINGS

The findings of this study provide context-specific evidence on the relationship between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing factory operating within a batch-process production environment. The results revealed high perceived levels of both Lean Production Management and Environmental Sustainability Performance. However, the associations between Lean practices and environmental sustainability indicators, although consistently positive in direction, were not statistically significant at the 0.05 level. This pattern suggests that Lean practices are perceived as operationally present in the studied factory and may be directionally connected to environmental sustainability, but the current evidence is not strong enough to support confirmatory or generalizable claims within the bounded census-based case study.

The high perceived level of Lean Production Management is consistent with the broader Lean literature, which emphasizes the role of Lean practices in improving process discipline, reducing non-value-added activities, enhancing workflow stability, strengthening standardized work, and supporting continuous improvement. In the present study, continuous improvement and standardized work recorded the highest mean score among the Lean dimensions. This finding suggests that the studied factory may have developed basic Lean-related routines that support operational discipline and process stability. This interpretation is consistent with Yadav et al. (2020), who argued that Lean adoption in manufacturing firms, particularly in developing-economy contexts, depends strongly on structured practices, employee involvement, process discipline, and managerial commitment. It also aligns with Chavez et al. (2022), who emphasized that internal Lean practices should be understood within a broader sustainability-oriented performance perspective rather than only as tools for productivity improvement.

The high perceived level of Environmental Sustainability Performance also reflects an important finding. Respondents perceived the factory as having a relatively high level of practices related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental

performance consideration. This result is consistent with sustainability-oriented manufacturing literature, which links environmental performance to the integration of operational routines with internal green practices and environmental awareness. Afum et al. (2021) showed that Lean production can interact with internal green practices and green product innovation to support sustainability excellence. Similarly, Teixeira et al. (2021) argued that connecting Lean and Green with sustainability requires a broader conceptual integration between operational improvement and environmental responsibility. Accordingly, the present findings suggest that environmental sustainability in the studied factory is perceived not as a separate administrative concern, but as a performance area connected to production-related activities.

The positive direction between Lean Production Management practices and Environmental Sustainability Performance is theoretically consistent with the logic of Lean-Green integration. Lean practices target operational wastes such as waiting, overprocessing, unnecessary movement, excessive inventory, defects, rework, and inefficient resource use. These wastes may also create environmental burdens through increased material consumption, energy losses, emissions, residues, and pollution risks. Abualfaraa et al. (2020) emphasized that Lean-Green manufacturing practices are closely linked to sustainability when operational waste reduction is connected with environmental objectives. Ferrazzi et al. (2025) similarly concluded that Lean manufacturing may support environmental performance when Lean practices are aligned with eco-efficiency and sustainability-oriented improvement. Therefore, the positive direction observed in the present study is theoretically meaningful, even though it did not reach statistical significance.

Nevertheless, the absence of statistical significance provides an important critical insight. The findings do not contradict previous Lean-Green studies that reported positive relationships between Lean practices and environmental outcomes; rather, they show that this relationship is context-dependent and may vary according to organizational maturity, measurement systems, sample structure, production characteristics, and the degree to which environmental indicators are explicitly embedded into Lean routines. Martinez and Jirsák (2024) emphasized that the relationship between Lean and Green still requires further investigation, while Silva and Gomes (2025) showed that environmental performance may depend on specific configurations of Lean and Green practices rather than the simple presence of Lean tools. From this perspective, the non-significant results of the present study are scientifically meaningful because they caution against treating Lean as automatically green.

A methodological explanation for the non-significant results is related to the census-based nature of the study. The study was conducted within a single bounded factory and included 20 valid responses representing the full accessible production-related population. Although this approach is suitable for a census-based case study, it limits statistical power and reduces the likelihood of detecting statistically significant relationships. In addition, the high mean scores for both Lean Production Management and Environmental Sustainability Performance suggest relatively homogeneous responses. When respondents report similarly high perceptions, the level of variability becomes restricted, which may weaken correlation coefficients and reduce statistical significance even when the relationship is positive in direction. Therefore, the findings should be interpreted as context-specific exploratory evidence rather than as statistically generalizable evidence.

The findings also support the argument that Lean-Green integration requires more than the implementation of Lean tools. Thekkoote (2022) emphasized that integrating Lean, Green, and sustainability practices requires a structured framework that connects operational practices with environmental and sustainability objectives. Siegel et al. (2024) similarly argued that the systematic implementation of Green-Lean and sustainability in SMEs depends on organizational readiness, structured implementation, and practical alignment between improvement tools and sustainability priorities. In the present study, the positive but non-significant associations may indicate that Lean practices exist in the factory, but their connection with measurable environmental outcomes may still require clearer environmental indicators, stronger monitoring systems, and more explicit Lean-Green integration.

At the dimension level, all Lean dimensions showed positive associations with Environmental Sustainability Performance, although none reached statistical significance. This indicates that environmental sustainability may be supported through both behavioral and technical Lean mechanisms. Continuous improvement and standardized work may strengthen employee discipline, reduce variation, and improve environmental awareness. Waste reduction and process flow improvement may reduce material losses, waiting time, rework, and unnecessary handling. Lean tools and operational control practices such as Total Productive Maintenance, Just-In-Time, Value Stream Mapping, visual management, and performance monitoring may contribute to equipment reliability, inventory discipline, process

control, and more efficient resource use. This interpretation is supported by Hegedić et al. (2024), who argued that Lean tools should be selected and evaluated not only according to economic indicators, but also according to environmental performance indicators.

The paint manufacturing context provides a further explanation for the findings. Environmental sustainability in paint production is strongly influenced by chemical inputs, pigments, solvents, additives, volatile organic compounds, process residues, wastewater, packaging waste, and pollution-control practices. Jiménez-López and Hincapié-Llanos (2022) emphasized that reducing VOC emissions in the paint industry depends on multiple technical, regulatory, and process-related factors. Ghobakhloo et al. (2023) also highlighted the importance of VOC exposure risks in paint production plants. Therefore, Lean practices alone may not be sufficient to generate clearly measurable environmental improvements unless they are combined with cleaner materials, environmental control systems, VOC monitoring, waste measurement, and explicit environmental performance indicators.

This interpretation is reinforced by recent studies on paint and coating industries. Sales-Contini et al. (2025) showed that eco-friendly paint manufacturing requires organizational commitment, cleaner production strategies, environmental departments, and sustainable production practices. Tang et al. (2025) demonstrated that industrial coating processes can generate significant VOC emissions, which highlights the need for sector-specific monitoring and control. Compared with these studies, the present findings suggest that Lean Production Management may provide an operational foundation for environmental sustainability in paint manufacturing, but this foundation must be strengthened through measurable environmental KPIs, VOC-related indicators, waste tracking, pollution-control practices, and continuous environmental performance review.

The findings also reveal a practical gap in the studied factory. Although Lean Production Management and Environmental Sustainability Performance were both perceived at high levels, the positive but non-significant relationships suggest that Lean practices may not yet be fully translated into measurable environmental outcomes. This supports the critical argument in Lean-Green literature that Lean does not automatically produce environmental sustainability. Environmental benefits require intentional integration between operational improvement routines and environmental performance measurement. Therefore, the factory should strengthen Value Stream Mapping to identify both operational and environmental waste, integrate environmental KPIs into production evaluation, link maintenance practices with energy and emissions awareness, and use visual management to monitor indicators such as waste volume, rework, energy use, VOC-related risks, wastewater, recycling, and packaging waste.

The study also contributes to the literature by showing the value of examining Lean-Green relationships within bounded production environments. Many previous studies have examined Lean-Green integration in broad manufacturing samples or supply chain contexts. Kosasih et al. (2023), for example, emphasized the importance of integrated Lean-Green practices and highlighted research gaps in manufacturing SMEs. However, broad studies may not fully capture the internal operational realities of a single local manufacturing factory. The present study provides a narrower but more context-sensitive perspective by examining the full accessible production-related workforce in one selected local paint manufacturing factory. This design does not allow broad statistical generalization, but it provides useful empirical insight into how Lean and environmental sustainability are perceived within an actual batch-process manufacturing setting.

An important contribution of the present study is that it provides a nuanced interpretation of the Lean-Green relationship in a bounded industrial setting. The positive but non-significant findings suggest that Lean practices may create an operational foundation for environmental sustainability, but this foundation is insufficient unless environmental indicators are formally embedded into Lean routines. This means that the absence of statistical significance should not be interpreted simply as a weak result. Instead, it reveals a practical and theoretical gap between perceived Lean implementation and measurable environmental sustainability outcomes. In this sense, the study contributes to Lean-Green literature by showing that operational discipline, waste reduction, and Lean tools must be connected to explicit environmental measurement systems before their environmental value can be clearly demonstrated.

Overall, the findings partially agree with previous Lean-Green research by showing a positive direction between Lean Production Management practices and Environmental Sustainability Performance. However, they differ from studies that reported stronger or statistically significant relationships because the present research was conducted within a single bounded factory using perceptual questionnaire data and a census-based case study design. This difference is scientifically important because it shows that the Lean-Green relationship should not be treated as universal, automatic, or purely tool-driven. Instead, it should be understood as a context-

dependent relationship shaped by organizational maturity, employee involvement, environmental measurement systems, production characteristics, and the extent to which sustainability indicators are embedded into daily Lean routines.

In conclusion, the discussion of the findings suggests that the selected local paint manufacturing factory has a promising operational foundation for Lean-Green integration, but this foundation remains insufficiently translated into statistically supported environmental sustainability outcomes. Lean practices appear to be present and positively associated with environmental sustainability indicators, yet stronger evidence would require larger multi-site studies, longitudinal designs, and objective environmental data such as material waste, energy consumption per batch, VOC emissions, rework rates, equipment downtime, wastewater, recycling volumes, and packaging waste. Therefore, the main implication of this study is not that Lean directly improves environmental sustainability, but that Lean can become environmentally meaningful when it is deliberately integrated with environmental KPIs, sector-specific pollution-control practices, and systematic sustainability-oriented operational management.

12. CONCLUSIONS

This study examined the relationship between Lean Production Management practices and Environmental Sustainability Performance in a selected local paint manufacturing factory operating within a batch-process production environment. Using a quantitative descriptive-analytical design and a census-based case study approach, the study assessed the perceptions of the full accessible production-related workforce regarding Lean practices and environmental sustainability indicators. Lean Production Management was examined through three dimensions: continuous improvement and standardized work, waste reduction and process flow improvement, and Lean tools and operational control. Environmental Sustainability Performance was examined through indicators related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental performance consideration.

The findings indicate that Lean Production Management practices were perceived at a high level within the studied factory. This suggests that the factory has a relatively strong operational foundation in terms of process discipline, improvement routines, standardized work, waste reduction, and operational control. Among the Lean dimensions, continuous improvement and standardized work recorded the highest mean score, indicating that basic Lean routines were more clearly recognized by respondents than more advanced tool-based practices. This conclusion is consistent with Lean and Lean-Green literature, which emphasizes that Lean practices may support sustainability-oriented operational improvement when they are embedded into daily production routines and aligned with environmental objectives (Abualfaraa et al., 2020; Yadav et al., 2020; Chavez et al., 2022; Ferrazzi et al., 2025).

The study also found a high perceived level of Environmental Sustainability Performance. Respondents recognized practices related to waste reduction, resource efficiency, energy-use awareness, emissions reduction, pollution control, recycling, and environmental consideration in production activities. In the context of paint manufacturing, this finding is particularly important because production processes involve chemical inputs, solvents, pigments, additives, process residues, packaging waste, and potential VOC-related environmental risks. Accordingly, environmental sustainability in this sector cannot be separated from process control, waste management, maintenance practices, and disciplined production flow. This interpretation is consistent with recent studies emphasizing the environmental sensitivity of paint and coating industries and the importance of controlling VOC emissions and production-related environmental risks (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

The correlation and supplementary regression analyses showed positive relationships between Lean Production Management practices and Environmental Sustainability Performance. However, these relationships were not statistically significant at the 0.05 level. Therefore, the study does not provide confirmatory statistical evidence that Lean practices directly enhance Environmental Sustainability Performance in the studied factory. Rather, the results indicate a positive exploratory direction, suggesting that Lean practices may be associated with environmental sustainability outcomes, but this association remains context-dependent and requires stronger empirical validation using larger datasets, multi-site studies, longitudinal designs, or objective environmental performance indicators.

A central conclusion of this study is that Lean is not automatically green. Although Lean practices can reduce operational waste, improve process flow, and support better resource use, their environmental contribution depends on whether environmental objectives are explicitly integrated into Lean routines, performance indicators, employee involvement, and operational decision-making. This conclusion supports the critical view in recent Lean-Green literature that environmental

benefits from Lean implementation require deliberate managerial integration rather than assuming that operational efficiency alone will automatically generate environmental sustainability outcomes (Afum et al., 2021; Teixeira et al., 2021; Thekkoote, 2022; Martinez & Jirsák, 2024; Silva & Gomes, 2025).

The non-significant statistical relationships can be explained by the bounded nature of the study context. Although the 20 valid responses represented the full accessible production-related workforce, the limited population size reduced the statistical power required to detect significant relationships. In addition, the high mean scores for both Lean Production Management and Environmental Sustainability Performance indicate limited variability in respondents' perceptions, which may have weakened the correlation strength. Furthermore, the study relied on perceptual questionnaire data rather than objective measures such as actual waste quantities, energy consumption per batch, VOC emissions, rework rates, wastewater generation, recycling volumes, or packaging waste. Therefore, the findings should be interpreted as exploratory, context-specific evidence from a census-based case study rather than statistically generalizable evidence.

Overall, the study concludes that the selected local paint manufacturing factory has a promising operational foundation for Lean-Green integration, but this foundation is not yet sufficiently translated into statistically supported environmental sustainability outcomes. The main contribution of the study is therefore not the confirmation of a strong or causal relationship, but the identification of a context-specific Lean-Green gap within a batch-process paint manufacturing environment. The findings show that Lean Production Management practices were perceived positively and were directionally associated with Environmental Sustainability Performance, yet this relationship was not automatic, universal, causal, or statistically confirmed within the current bounded setting. This provides a meaningful contribution to sustainable operations and Lean-Green manufacturing literature by demonstrating that Lean becomes environmentally meaningful only when it is deliberately connected to measurable environmental KPIs, VOC-related control, waste tracking, resource-efficiency indicators, employee involvement, and systematic sustainability-oriented operational management.

13. LIMITATIONS AND FUTURE RESEARCH

The study has several limitations that should be acknowledged when interpreting its findings. First, the empirical investigation was limited to one selected local paint manufacturing factory and included 20 valid responses representing the full accessible production-related workforce. Although this census-based approach was appropriate for the bounded study context, it limits the statistical generalizability of the findings to other factories or industrial sectors. Second, the study relied on perceptual questionnaire data, which reflect respondents' assessments of Lean practices and environmental sustainability rather than objective operational or environmental measurements. Third, the cross-sectional design does not allow causal inference or observation of changes over time. Finally, the high mean scores observed for both Lean Production Management and Environmental Sustainability Performance may have reduced response variability, thereby limiting the strength and statistical significance of the observed relationships.

Future research should extend the current study by examining multiple paint manufacturing factories or comparable batch-process industries using larger datasets and broader organizational contexts. Future studies should also incorporate objective environmental and operational indicators, such as material waste, energy consumption per batch, VOC emissions, wastewater, rework rates, equipment downtime, and recycling volumes. Longitudinal research designs would be particularly valuable for assessing whether Lean-Green integration produces measurable improvements over time. In addition, future research may compare different production departments or process stages to identify where Lean practices generate the strongest environmental sustainability contributions.

14. RECOMMENDATIONS

Based on the findings, discussion, and comparison with previous Lean-Green and sustainable manufacturing literature, the study recommends that the selected local paint manufacturing factory should move from general Lean implementation toward more explicit Lean-Green integration. Although the statistical relationships between Lean Production Management practices and Environmental Sustainability Performance were positive but not statistically significant at the 0.05 level, the results indicate that the factory has an operational foundation that can be strengthened through clearer alignment between Lean practices and environmental sustainability objectives. Therefore, Lean practices should not be applied only as tools for productivity, cost reduction, quality improvement, or workflow control; rather, they should be systematically connected to environmental objectives such as waste reduction, resource efficiency, emissions control, pollution prevention, recycling, and environmental performance monitoring (Abualfaraa et al., 2020; Teixeira et al., 2021; Ferrazzi et al., 2025).

First, the factory should strengthen the use of Value Stream Mapping to identify both operational and

environmental waste across the batch-production process. Traditional VSM should be extended beyond time, inventory, and workflow indicators to include environmental indicators such as material losses, energy consumption per batch, rework, waste generation, emissions-related risks, wastewater, packaging waste, and recycling opportunities. This recommendation is consistent with the Lean-Green perspective, which argues that operational waste and environmental waste are closely connected and should be analyzed together within production systems. In the context of paint manufacturing, this is particularly important because waste may arise not only from inefficient flow, but also from chemical residues, defective batches, excessive handling, and poor material utilization (Abualfaraa et al., 2020; Hegedić et al., 2024; Ferrazzi et al., 2025).

Second, the factory should integrate measurable environmental performance indicators into routine production evaluation. Current operational indicators should be expanded to include environmental KPIs such as material waste rate, energy consumption per batch, rework-related losses, VOC-related risks, wastewater generation, recycling volume, packaging waste, and pollution-control performance. This recommendation directly responds to the findings of the study, which showed high perceived Environmental Sustainability Performance but did not provide objective environmental measurements. Therefore, strengthening objective monitoring would help the factory move from perception-based environmental awareness toward evidence-based environmental performance management. This is particularly important in paint and coating industries, where environmental sustainability requires sector-specific monitoring of VOC emissions, chemical residues, resource losses, and production-related environmental risks (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Tang et al., 2025).

Third, Total Productive Maintenance practices should be linked more explicitly with environmental performance. Maintenance activities should not focus only on reducing downtime and improving equipment reliability, but also on reducing energy losses, preventing leakage, minimizing defective batches, improving process stability, reducing rework, and controlling emissions-related risks. In batch-process paint manufacturing, unstable equipment performance may increase material losses, energy consumption, production interruptions, rejected batches, and environmental burdens. Accordingly, TPM should be treated as both an operational and environmental control mechanism. This recommendation is consistent with Lean-Green literature, which emphasizes that Lean tools become more environmentally meaningful when they are linked to sustainability indicators rather than applied only for efficiency improvement (Hegedić et al., 2024; Martinez & Jirsák, 2024; Ferrazzi et al., 2025).

Fourth, visual management should be expanded to include environmental performance indicators. Production areas should display clear, simple, and regularly updated indicators related to waste volume, energy use, recycling, pollution control, rework, VOC-related risks, and environmental improvement targets. This would help employees connect daily Lean routines with sustainability objectives and strengthen environmental awareness within operational decision-making. Since the findings showed high perceived levels of both Lean practices and Environmental Sustainability Performance, visual environmental indicators would help transform this awareness into more systematic monitoring and continuous improvement behavior. This recommendation is consistent with recent Lean-Green research emphasizing that environmental performance depends not only on the presence of Lean tools, but also on the visibility of sustainability objectives within daily operations (Thekkoote, 2022; Siegel et al., 2024; Silva & Gomes, 2025).

Fifth, employee involvement in continuous improvement should be directed toward Lean-Green improvement initiatives. Employees should be encouraged to propose improvement ideas that reduce both operational inefficiencies and environmental burdens. Such initiatives may include reducing material waste, improving workplace organization, minimizing unnecessary movement, improving batch preparation accuracy, reducing rework, preventing material contamination, improving cleaning practices, and strengthening recycling routines. Employee participation is essential because Lean-Green integration depends not only on formal systems and tools, but also on daily operational behavior, improvement culture, and shared responsibility for environmental performance. This recommendation is supported by studies indicating that Lean adoption and sustainability-oriented improvement depend on employee involvement, managerial commitment, and the integration of operational practices with environmental objectives (Yadav et al., 2020; Afum et al., 2021; Chavez et al., 2022).

Sixth, the factory should develop a systematic Lean-Green performance review process. Environmental performance should be reviewed alongside productivity, quality, cost, delivery, and safety indicators. This would support the integration of environmental sustainability into operational excellence and reduce the risk of treating sustainability as a separate or secondary managerial concern. The review process should include regular

assessment of Lean-Green indicators, discussion of environmental improvement opportunities, follow-up of corrective actions, and documentation of measurable progress. This recommendation is aligned with recent studies suggesting that Lean-Green integration requires deliberate managerial alignment, structured implementation, and the incorporation of sustainability indicators into operational routines (Thekkoote, 2022; Siegel et al., 2024; Martinez & Jirsák, 2024).

Seventh, the factory should strengthen sector-specific environmental control practices that are directly relevant to paint manufacturing. General Lean implementation is not sufficient on its own to address the environmental sensitivity of paint production. Therefore, the factory should give particular attention to VOC-related risks, solvent handling, chemical residues, wastewater, packaging waste, cleaner material use, and pollution-control procedures. These practices should be linked with Lean improvement activities so that operational efficiency and environmental responsibility are managed together rather than separately. This recommendation is consistent with recent paint and coating industry studies, which emphasize that eco-friendly paint manufacturing requires cleaner production practices, environmental monitoring, organizational commitment, and systematic attention to sector-specific sustainability challenges (Jiménez-López & Hincapié-Llanos, 2022; Ghobakhloo et al., 2023; Sales-Contini et al., 2025; Tang et al., 2025).

Overall, these recommendations suggest that the selected local paint manufacturing factory should build on its existing Lean foundation by developing a more explicit Lean-Green management approach. The practical value of Lean in this context lies not only in improving production flow, reducing waste, and strengthening process control, but also in creating a structured operational pathway for measurable environmental sustainability improvement. However, consistent with the findings of this study, these recommendations should be interpreted as improvement directions derived from exploratory, context-specific evidence rather than as causal claims. Their successful implementation requires measurable environmental KPIs, employee involvement, management commitment, sector-specific pollution-control practices, and continuous review of Lean-Green performance.

The overall contribution of the study lies in highlighting the need for stronger Lean-Green integration in paint manufacturing through environmental performance measurement, improved Value Stream Mapping, maintenance-energy linkage, visual environmental indicators, and objective sustainability monitoring. The study also provides practical guidance for managers seeking to align operational improvement initiatives with environmental sustainability objectives in batch-process manufacturing environments.

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BIOGRAPHY

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