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Luis Miguel Fonseca
José Dinis de Araújo Carvalho
José Carlos Sá
Gilberto Santos[1]

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EFFECT OF LEAN PRACTICES ON THE OPERATIONAL AND ENVIRONMENTAL PERFORMANCE OF PORTUGUESE ORGANIZATIONS

Abstract: *The main objective of this study is to investigate the effect of Lean practices on the operational and environmental performance of Portuguese organisations.*

The study reviewed 70 papers and conducted an online survey of Portuguese industrial professionals, yielding 109 responses, with 72 confirming Lean tool adoption. Results, analysed using descriptive statistics and non-parametric tests via Excel and SPSS v.25, explored Lean practices' impact on operational and environmental performance.

The study found that Portuguese companies primarily use Lean tools like 5S, visual management, Kaizen, Kanban, VSM, SMED, and Poka-Yoke to improve operational and environmental performance. Respondents highlighted synergies between Lean and Green approaches. Longer Lean tool implementation correlated with more significant improvements in customer satisfaction, delivery times, flexibility, waste reduction, and environmental impacts, reflecting a learning curve.

Keywords: *Lean Manufacturing; Green Manufacturing; Lean tools; Operational performance; Environmental performance.*

1. Introduction

Lean manufacturing, introduced through the Toyota Production System (TPS) post-World War II, focuses on waste reduction ("Muda") and achieving operational improvements with minimal resources (Womack et al., 1990; Herron & Hicks, 2008). It has been widely adopted across industries due to its positive impact on inventory reduction, lead times, productivity, and quality (Abdul Wahab et al., 2013; Garza-Reyes, 2015a; Lacerda et al., 2025). Lean is driven by five key principles: specifying product value, identifying value streams, ensuring value flow, allowing customer pull, and pursuing perfection (Womack & Jones, 1996). Additionally, lean practices enhance economic and operational performance, including customer satisfaction and efficiency (Henao et al., 2019; Talapatra et al., 2022; Azzolini Junior et al., 2025; Cimini et al., 2025), and promote environmental performance by reducing waste, lead times, and CO_2 emissions (Garza-Reyes et al., 2016).

The shift toward sustainability in business operations is increasingly important. Companies must integrate sustainability into their strategies to remain competitive, addressing both current and future stakeholder needs. Sustainable practices include circular economy models (Fonseca et

Corresponding author: Gilberto Santos
Email: magilster@gmail.com

al., 2018) and Eco-Innovation (Peralta et al., 2019; Murmura et al., 2021). Lean principles align with green management by focusing on reducing resource consumption, pollution and emissions, while maintaining efficiency (Verrier et al., 2014). Green manufacturing complements Lean by minimizing environmental impacts during manufacturing without sacrificing competitiveness (Azevedo et al., 2019; da Silva & Gouveia, 2020).

Combining lean and green management practices offers mutual benefits, enhancing both operational efficiency and environmental performance. This approach, also known as Lean and Green, enables businesses to reduce waste, cut costs, and improve sustainability (Hines & Rich, 2004; Inman & Green, 2018). Combining lean and green practices positively impacts sustainable development and competitive advantage, particularly in Portuguese organisations. Similarly, Silva and Gomes (2025) identified high environmental performance linked to specific lean-green configurations in Portuguese firms.

In Portugal, lean and quality tools such as checklists and the PDCA cycle are commonly used (Fonseca et al., 2015). Research has emphasized the integration of lean with sustainability approaches (Prakash et al., 2022) and integrating lean with environmental initiatives remains a prominent research theme (Patel & Patel, 2021). The Resource-Based View (RBV) theory supports this integration, as it focuses on creating unique, valuable, and inimitable resources to enhance performance (Barney, 1991; Barney, 2001). Additionally, Institutional Theory explains the spread of green lean adoption, where organizations mimic successful peers to gain legitimacy (DiMaggio & Powell, 2000; Meyer & Rowan, 1977).

Theoretical support contributes to explaining the nature of relationships between phenomena based on a systemised structure and contributes to generalising the research findings (Kenworthy & Verbeke, 2015). From a theoretical point of view, the Resource-Based View (RBV) theory (Barney, 1991; Barney, 2001) can support Green Lean, as its application can generate valuable, rare, inimitable, and non-substitutable resources that explain and ensure the availability of internal capabilities that can successfully improve performance and support the integration with stakeholders (a unique resource) in response to their demands. The RBV theory suggests that an organisation’s resources are essential to superior firm performance, competitive advantage, and strategic success by developing dynamic capabilities and ultimately achieving superior performance. Further, Institutional Theory Adoption, which denotes adopting models from successful organisations, can also explain the spread of green lean. Hence, organisations converge and become similar because of societal influence and the search for organisational legitimacy (DiMaggio & Powell, 2000; Meyer & Rowan, 1977). Therefore, companies are more likely to implement green lean if successful companies in their activity sector or geographical area have done so (Rankin & Matthews, 2020).

Although most literature confirms a positive relationship between lean and environmental performance (Dieste et al., 2019), challenges remain, particularly in areas where lean and green practices are less compatible (Abualfaraa et al., 2020; Carvalho et al., 2011).

In Portuguese industry, engineering is more about production processes than product design. However, we know that what brings wealth to countries is product engineering, more than process engineering. The European Commission (2023) acknowledges the need for Portuguese industry to enhance productivity, innovation, and digitalization while transitioning to greener practices.

Given these challenges, this study investigates the effect of Lean practices on Portuguese organizations’ operational and environmental performance, addressing the following research questions: (1) What are the most used Lean tools? (2) What are the perceived benefits of Lean tools on operational performance? (3) What are the perceived benefits of Lean tools on environmental performance? (4) Do the operational and environmental benefits of Lean improve over time? This manuscript explores these questions in the following sections: literature review, methodology, results, discussion, and conclusions.

2. Literature review

The research was conducted using the literature review method to reflect the state of knowledge in a given subject based on methodical behavior promoted by Tranfield et al. (2003). A literature review supports identifying the field's conceptual content and contributes to theory development, providing a critical overview and revealing gaps and inconsistencies in existing studies (Garza-Reyes, 2015b). The actions performed in this research followed the PRISMA guidelines (Moher et al., 2009), as presented in Figure 1.

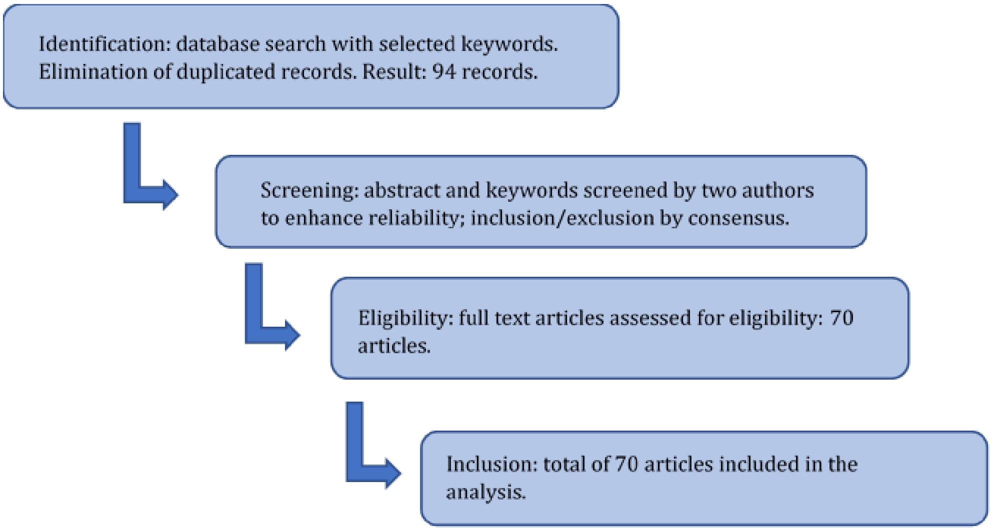

Figure 1. Literature Review Flowchart (adapted from PRISMA)

In the first phase of the review process, potential papers were identified using the keyword "Lean Green" across the Web of Science (WoS) database, covering publications from 1900 to June 2021. WoS includes over 21,100 peer-reviewed journals, ensuring reliable and valid results. From the initial search, 94 publications were selected. After screening, 10 papers were excluded due to inaccessible full texts, and 14 were removed due to theme incompatibility. In cases of ambiguity, two authors reached a consensus on inclusion or exclusion decisions. The selected papers were catalogued in an Excel database, recording details such as the journal name, publication year, research objectives, main contributions, and limitations. The publications were then categorized into three groups: "Lean", "Green", and "Lean Green". The results showed that "Lean Green" attracted the most attention, with 57 publications (81%), followed by 8 papers (12%) on Green Manufacturing and 5 (7%) on Lean Manufacturing.

The Lean Green approach gained significant traction starting in 2013. Among the 33 journals publishing these papers, the Journal of Cleaner Production was the most prominent, contributing 17 of the 57 articles. Other notable journals included Sustainability (3 articles), Business Strategy and the Environment (3 articles), and others like the International Journal of Productivity and Performance Management (2 articles) and Production Planning & Control (2 articles).

The following lean tools were identified as the most frequently adopted (RQ1), contributing to more efficient, standardised, and waste-free processes in manufacturing and other industries:

- 5Ss: The 5S methodology is a systematic approach to workplace organisation that improves safety, ergonomics, and efficiency. It involves five key principles: Seiri (sort, classify), Seiton (straighten, set in order), Seiso (sweep, clean, check), Seiketsu (standardise, stabilise), and Shitsuke (sustain, self-discipline) (Peterson & Smith, 1998).
- Heijunka: This method focuses on production levelling, preventing workload fluctuations. Balancing production sequences, Heijunka enhances productivity, flexibility, and waste reduction (Hüttmeir et al., 2009).
- Jidoka: Jidoka, also known as "quality at the source" or "built-in quality," Jidoka ensures defects are detected and addressed immediately, improving overall quality in manufacturing (Monden, 1995).
- Kanban: The Kanban system facilitates material replenishment only when necessary, using signals (often cards) to manage inventory efficiently (Oliveira et al., 2017).
- Kaizen Events: Kaizen promotes continuous improvement by eliminating waste. Through data collection and analysis, multidisciplinary teams identify and address the root causes of inefficiencies, improving processes, employee engagement, and sustainability (Cherrafi et al., 2019).
- Poka-Yoke: This is a mistake-proofing tool designed to prevent defects by eliminating the causes of errors before they occur (Iranmanesh et al., 2019).
- SMED: Single-minute exchange of Die (SMED) is a methodology for rapid changeovers in manufacturing, reducing downtime, improving flow, and minimising resource consumption (Ohno, 1988).
- Standard Work: This tool standardises work procedures to reduce variability and complexity, minimising defects and rework (Ohno, 1988).
- Visual Management: A system of visual indicators that simplifies communication on the shop floor, helping supervisors track processes, organise workspaces, and enhance efficiency. It is closely related to the 5S methodology (Fonseca & Domingues, 2018).

Concerning the perceived benefits of the applied lean tools in operational performance (RQ2) and environmental performance (RQ3), most scholars identified the benefits of applying lean tools in both operational and environmental performance. Key findings from various studies are as follows:

- Lean tools contribute to reducing air and water pollutants while improving the efficient use of materials, energy, and water (Afum et al., 2021).
- Lean and green practices can complement each other, reducing waste, material and energy consumption and improving supply chain management. However, research on sustainability and lean management often lacks a comprehensive understanding of the three sustainability dimensions (Abualfaraa et al., 2020).
- A case study on an SME implementing lean practices such as 5S, Kanban, SMED, and quality control showed significant environmental benefits. These practices led to more efficient use of resources like water, energy, and raw materials (Belhadi et al., 2018).
- Lean practices applied during the construction phase positively impact sustainability by improving productivity and reducing waste, costs, and time (Carvajal-Arango et al., 2019).

- A matrix analysis linking lean practices to environmental performance identified Just-in-Time (JIT) and Total Quality Management (TQM) as the most widely used tools to improve environmental measures (Dieste et al., 2019).
- The adoption of lean and green practices has positive effects on all performance dimensions.
- Total Productive Maintenance (TPM) and JIT have the most significant impact on environmental performance. Additionally, a Kaizen culture helps reduce material consumption and emissions of polluting gases (Garza-Reyes et al., 2018).
- A study of 182 North American companies found that integrating lean and green practices improves operational performance and significantly enhances environmental performance (Inman & Green, 2018).
- A Brazilian case study demonstrated that combining lean and green led to a 70% reduction in setup times (via SMED), an 81% decrease in carbon footprint, and a 3% improvement in eco-efficiency (Leme et al., 2018).
- Lean practices help eliminate non-value-adding activities (such as excessive resource use and inventory), while green practices focus on minimising the environmental impact of production (Mollenkopf et al., 2010).
- In a metal parts manufacturing company, integrating lean and green led to a 64.7% reduction in lead time, a 36.3% improvement in carbon efficiency, and a 29.9% decrease in carbon footprint (Ng et al., 2015).
- A lean-green model showed that adopting Kaizen could reduce resource use by 30–50% and decrease total costs by 5–10% in terms of mass and energy flow (Pampanelli et al., 2014).
- Lean tools enhance productivity, reduce variability, accelerate production cycles, and simplify processes, leading to a better working environment and fewer customer complaints (Qin & Liu, 2022).
- A case study in a Portuguese company showed that implementing Kaizen, Value Stream Mapping (VSM), Jidoka, and TPM increased production efficiency. Specifically, cycle times were reduced by 33%, energy consumption by 38%, and scrap by 66%, demonstrating that lean tools boost profits while supporting environmental sustainability (da Silva et al., 2020).
- A systematic literature review confirmed that lean-green practices positively impact economic and environmental sustainability, reinforcing their effectiveness in improving sustainability outcomes.
- Research on the role of lean tools in achieving sustainability remains scarce, indicating the need for further studies (Yusup et al., 2015).

While the evidence suggests that lean tools can significantly improve operational efficiency and environmental performance, supporting sustainability initiatives across various industries, it's important to note that some researchers claim that lean and green practices are not always compatible and feasible. There are some areas where combining them can be particularly difficult (Abualfaraa et al., 2020), e.g., small-batch production to meet customer demands increases transport and packaging, resulting in higher emissions and more waste. Successfully combining lean and green requires adapting a company's operations and engaging suppliers, which may require significant investments. Despite the numerous benefits of integrating lean and green practices, academic literature identifies several challenges hindering their implementation. Key obstacles identified in the literature include:

- Emphasising small batch production to meet customer demands increases transportation and packaging use. This results in more frequent replenishment, leading to higher emissions of polluting gases and increased packaging waste (Abualfaraa et al., 2020).

- Achieving positive results from lean and green integration often requires companies to tailor their operational profiles and actively involve suppliers, which can be complex and resource intensive (Galeazzo et al., 2014).
- Some lean and green practices are not fully compatible and treating them as a fully integrated approach has limitations. Certain operational areas may not allow for their seamless combination (Garza-Reyes, 2015b).
- Lean management is negatively associated with reducing atmospheric emissions of volatile organic compounds. While lean practices improve the efficient use of cleaning paints and solvents, they may not be sufficient to meet environmental regulations (Rothenberg et al., 2001).
- Implementing a combined lean and green approach often requires significant financial investment, making it less feasible for companies with resource constraints (Ng et al., 2015).

These challenges highlight the need for careful planning, customisation, and investment to successfully integrate lean and green practices without compromising sustainability goals. Through the analysis of the publications and in conclusion, although many authors posit the existence of a positive relationship between lean and green practices, this view still needs to be consensual in the literature. Hence, it is pertinent to deepen the investigation in this area. Moreover, studies focusing on the effect of Lean practices on Portuguese organisations' operational and environmental performance are lacking in the literature.

Authors such as Patel and Patel (2021) and Fonseca & Domingues (2018) have emphasised the relevance of management support and education and training as critical success factors for Lean, Six Sigma, Kaizen, and Lean Six Sigma implementation. Their work suggests that the longer lean tools are implemented, the more significant the operational and environmental benefits should become (RQ4), and organisations do not need to implement a wide range of lean practices in an initial stage but rather make it sustained. Moreover, it is crucial to consider factors such as company location and profile of the company respondents in research, as these can significantly impact the utilisation of quality tools (Fonseca et al., 2015) and continuous improvement methodologies (Fonseca & Domingues, 2018) within Portuguese companies.

Finally, to ensure the literature review is updated and no relevant works are missed, another literature review with the same keywords was applied for the period between 2021 and 2024. This additional review identified additional works, such as Klein et al. (2022) study of lean management and sustainable practices in higher education institutions of Brazil and Portugal or Kosasih et al. (2023) address of integrated lean-green practices and supply chain sustainability within Indonesian manufacturing SMEs, that further indicate the existence of a positive relationship between lean and green practices, although research gaps remain.

3. Methodology

An online survey was developed based on a bibliographic review to assess the impact of Lean tools on Portuguese organisations' environmental and operational performance. The survey methodology enables standardised and efficient data collection from numerous respondents. The survey was created using Google Forms and distributed to ISO 14001-certified companies from the Portuguese National Accreditation Body (IPAC) and professionals on LinkedIn with relevant knowledge. Other researchers, such as Antony et al. (2023), have used LinkedIn for professional contacts as an updated source of professional networking.

The survey included four key sections: respondent characteristics (e.g., function, qualifications), organisation characteristics (e.g., location, industry sector), Lean tool adoption (e.g., Lean tools implemented, operational impact), and the environmental impact of Lean tools. The impact of Lean on environmental performance was assessed using a 1-5 Likert scale. Likert-type scales are frequently used in research, and scales using 5 or 7 scale points are the most common (Hartley, 2013). The content validity was checked through a pretest by Lean and Green experts. The survey ran from September to December 2020, with a total of 685 questionnaires sent—171 to companies and 514 to LinkedIn contacts. The final response rate was 16% (similar to that of Fonseca & Domingues (2018)), resulting in 109 valid responses, consistent with other studies involving Portuguese companies. A wave analysis (Armstrong & Overton, 1977) confirmed that early and late respondents had similar demographic variables, minimising non-response bias. Statistical analysis was performed using IBM SPSS v. 25 to ensure rigorous and reliable results, and the survey distribution aligned well with the population's demographic profile.

4. Results

Of the 109 valid survey responses, 72 (66%) confirmed the adoption of Lean tools, and these 72 respondents were selected for further statistical analysis. According to Hair et al. (2010), evaluating the quality of the collected data is essential. Cronbach's Alpha was used to assess the reliability of the survey scales, with values above 0.7 indicating reliability (Cronbach, 1951; Saunders et al., 2019).

The operational performance scale showed an alpha of 0.945, and the environmental performance scale had an alpha of 0.920, confirming high internal consistency and the reliability of the data. The respondents' roles varied, with 40.3% holding positions as directors or continuous improvement leaders and 18.1% as directors or quality officers. Most respondents (34.7%) had 1-3 years in their current positions, and 72.2% held higher education qualifications. The respondents were primarily from the North (43.1%), Centro (34.7%), and Lisbon metropolitan areas (19.4%), with the automotive industry (31.9%) being the most represented sector, followed by other industries (27.8%) and metalworking (18.1%).

Most organizations (69.4%) had been operating for over 15 years. Regarding Lean tools, the 5S methodology was most implemented (90.3%), followed by visual management (81.9%). Other tools, such as kaizen, kanban, and VSM, had implementation rates above 50%, while tools like jidoka and heijunka were used by less than 20% of respondents. Most companies (59.7%) introduced Lean practices 1-5 years ago, with 23.6% implementing them 6-10 years ago.

Regarding the impact of Lean tools on operational performance (Table 1), respondents generally agreed on the positive effects, with "improved productivity" being the most significant benefit (average score of 4.0) and "improved product quality" the least significant (average score of 3.6). Overall, Lean tools were perceived to positively impact operational performance across the surveyed companies.

Participants demonstrated their understanding of Lean Green, a key aspect of the study. The majority (80.6%) perceive their companies as environmentally friendly, 52.8% revealed a good grasp of Lean Green, while the remaining 47.2% showed a lack of knowledge.

The effects of implementing lean tools on the environmental performance of organizations were evaluated with a 1 to 5 Likert scale to assess the participants' agreement on a series of possible environmental improvements found in the literature, which may occur with the application of lean practices. The average level of agreement obtained concerning the statements is approximately 3 (neither agree nor disagree), which reveals that the participants need more knowledge regarding this issue.

Table 1 Impact of lean tools on the operational performance

The implementation of lean tools …	Mean	Standard deviation	Minimum	Maximum
Improved productivity	4.0	0.9	1	5
Improved resource efficiency	3.9	0.8	2	5
Improved capacity utilization	3.9	1.0	1	5
Reduced cycle time	3.9	0.9	1	5
Improved the organization image	3.8	1.0	1	5
Reduced costs	3.8	1.0	1	5
Improved delivery time	3.8	1.0	2	5
Improved customer satisfaction	3.7	0.9	2	5
Improved flexibility	3.7	1.0	1	5
Reduced the number of defective products	3.7	1.0	1	5
Reduced stocks	3.7	1.1	1	5
Improved product quality	3.6	1.0	1	5

(1= totally disagree … 5=totally agree)

In Table 2, it is observed that the most significant environmental benefits were "allowed to reduce energy consumption" and "allowed to reduce the consumption of materials", with an average value of 3.7, with the characteristic "allowed to reduce gas emissions" which generated less agreement among the participants, with an average value equal to 3.

To assess RQ4 (Do the operational and environmental benefits of applying Lean tools improve with time?), we evaluated the necessary criteria for parametric tests with the Kolmogorov-Smirnov normality test (whose null hypothesis is that the data are normally distributed). However, as the p-value result was lower than 0.05 for the variables under study, the null hypothesis was rejected, and it was assumed that the sample data did not follow a normal distribution. Therefore, nonparametric tests were performed.

Table 2. Impact of lean tools on the environmental performance

The implementation of lean tools allowed for reduction of …	Mean	Standard deviation	Minimum	Maximum
Energy consumption	3.7	1.0	1	5
Materials consumption	3.7	0.9	1	5
Water consumption	3,5	1.0	1	5
Solid waste generation	3,4	0.9	1	5
Package utilisation	3.4	0.9	1	5
Frequency of environmental accidents	3.3	0.9	1	5
Consumption of hazard materials	3.2	1.0	1	5
Production of effluents	3.1	1.0	1	5
Gases emissions	3.0	0.9	1	5

(1= totally disagree … 5=totally agree)

Thus, to correlate the variables under study, we used the Spearman correlation coefficient (r), which is a measure of nonparametric association between two ordinal variables and can assume any value between +1 and -1 (Table 3) and a value of +1 represents a perfect positive correlation, which means that the two variables are strongly related and that, as the values of one variable increase, the values of the other variable also increase. In contrast, a value of -1 represents a perfect negative correlation, suggesting a strong association between variables. That is, while the values of one variable increase, those of the other decrease. Finally, a value of 0 means that the variables are perfectly independent (Saunders et al., 2019).

Table 3. Correlation coefficient (Spearman) interpretation (adapted from Saunders et al. 2016)

r (+ or -)	**Interpretation**
0,00 - 0,19	Without correlation
0,20 - 0,34	Weak correlation
0,35 - 0,59	Moderate correlation
0,59 - 0,79	Strong Correlation
0,80 – 1,00	Very strong correlation

Hence, to explore the associations between the main variables of this study, it was decided to perform the following hypothesis tests:

a) Educational qualifications of participants versus the impact of the lean tools on organisations' operational performance.

b) Time of existence of organisations versus the impact of lean tools on organisations' operational performance.

c) Time of introduction of the tools versus the impact of the lean tools on organisations' operational performance.

d) Educational qualifications of participants versus the impact of lean tools on the environmental performance of organisations.

e) Uptime of organisations versus the impact of lean tools on the environmental performance of organisations.

f) Time of introduction of the tools versus the impact of the lean tools on the environmental performance of organisations.

To this end, the following research hypotheses were formulated, similar for all tests:

• Hypothesis H0 = The variables are independent.

• Hypothesis H1 = The variables are not independent. That is, they present a degree of association with each other.

It should be noted that the SPSS signals significant correlations, indicating a significance level of 0.05 with an asterisk (*) and a significance level of 0.01 with two asterisks (**). A correlation marked with an asterisk(s) indicates that H0 is rejected at the level of significance referred to, indicating that the correlation under study is significant, which allows verifying more quickly if there is an association.

The results of hypothesis tests to identify potential associations between variables revealed statistically significant positive correlations between the time of the lean tools' introduction and the named impacts (hypotheses e and f). There is no evidence to reject the null hypothesis for the remaining hypotheses (a to d).

Despite the differences between significance levels and correlation intensity, there is sufficient statistical evidence to reject the null hypothesis and state that the implementation time of Lean tools is positively correlated with the impacts identified: Operational performance (see Table 4), with customer satisfaction (r=0.416**), delivery times (r=0.244*) and flexibility (r=0.244*); and environmental performance (see Table 5), namely in the production of solid waste (r=0.336**), in the frequency of environmental accidents (r=0.310**), in gas emissions (r=0.301*), in the production of effluent waste (r=0.294*) and in the consumption of hazardous materials (r=0.291*). These variables tend to increase together (although the correlation is weak to moderate). That is, the longer the implementation time of the tools, the better the performance levels for the dimensions identified above. More specifically, companies that are more familiar with the lean methodology and with progressively improved practices tend to obtain better results than those that are at an early stage.

Table 4. Correlation between the introduction of the tools versus the impact of the lean tools on the operational performance of organizations

Item	For how long your organisation have implemented lean tools
Improved productivity	0.220
Improved resource efficiency	0.132
Improved capacity utilization	0.106
Reduced cycle time	0.099
Improved the organization image	0.078
Reduced costs	0.210
Improved delivery time	0.244**
Improved customer satisfaction	0.416**
Improved flexibility	0.244*
Reduced the number of defective products	0.131
Reduced stocks	0.203
Improved product quality	0.187

**Correlation is significative at 0.01 level (bilateral)
* Correlation is significative at 0.05 level (bilateral)

Table 5. Correlation between the time of introduction of the tools and the degree of agreement with the impacts resulting from the implementation of lean tools on the environmental performance of organizations.

Item	For how long your organisation have implemented lean tools
Energy consumption	0.192
Materials consumption	0.205
Water consumption	0.103
Solid waste generation	0.336**
Package utilisation	0,213
Frequency of environmental accidents	0.310**
Consumption of hazard materials	0.291*
Production of effluents	0.103
Gases emissions	0.301*

**Correlation is significative at 0.01 level (bilateral)
* Correlation is significative at 0.05 level (bilateral)

5. Discussion

Most Portuguese companies (80%) report having implemented lean tools. The 5S methodology, a systematic approach to workplace organization, is the most adopted tool, implemented by 90.3% of companies. This is followed by visual management (81.9%), a tool that uses visual aids to communicate important information. Other tools, including Kaizen (continuous improvement), Kanban (visual scheduling system), Standard Work (documented best practices), VSM (Value Stream Mapping), SMED (Single-Minute Exchange of Die), and Poka-Yoke (error-proofing), also exhibit significant implementation, surpassing 50%. Regarding the lower adoption of tools such as Jidoka, Fonseca and Domingues (2018) researched the adoption of Kaizen, Lean and Six Sigma by Portuguese organisations with certified ISO 9001 Quality Management Systems. They found a mild use (and an increasing trend) of Kaizen, Lean and Six Sigma by those organisations, suggesting that the sampled companies prioritised approaches such as the PDCA, control of defective products and corrective action for defect prevention and control. Considering that Jidoka is about detecting and addressing quality problems on the shop floor in real-time, those companies may adopt the Jidoka principles without being familiar with the terminology.

For RQ2 (What are the perceived benefits of the applied Lean tools in operational performance?), participants generally agreed (average score of 4) on the positive effects of lean tools. Regarding environmental performance (RQ3: What are the perceived benefits of Lean tools in environmental performance?), responses were less unanimous. Most items had a neutral average response, indicating some lack of awareness about the environmental impact of Lean. However, two key environmental impacts stood out, particularly reductions in energy consumption and material use, which were positively associated with Lean tool implementation, corroborating prior research (Fercoq et al., 2016; Garza-Reyes et al., 2018; Dieste et al., 2019).

Spearman's correlation analysis revealed statistically significant positive correlations between the Lean tool implementation duration and operational and environmental benefits (RQ4: Do the operational and environmental benefits improve over time?). For operational performance, longer tool implementation was associated with improvements in customer satisfaction (r=.416**), delivery times (r=.244*), and flexibility (r=.244*). Environmental performance improvements were also linked to longer implementation times, particularly regarding solid waste production, environmental accidents, gas emissions, and the use of hazardous materials.

This study underscores the synergy between Lean and Green methodologies, highlighting the importance of training and experience in Lean adoption. The findings suggest that longer implementation of Lean tools leads to improved operational and environmental outcomes, especially with tools like 5S and visual management. Additionally, the dynamic capabilities theory, an extension of the Resource-Based View (Teece et al., 1997), supports the idea that organizations need dynamic capabilities for successful Lean tool implementation, fostering long-term competitiveness and continuous improvement.

6. Conclusions

This research is significant as it investigates the relationship between Lean practices and operational and environmental performance, focusing on the Portuguese industry. The study explores how Lean tools, particularly 5S and visual management, can enhance both operational efficiency and environmental sustainability, providing valuable insights for local industries. The dual focus on operational and environmental performance is crucial in today's global push for sustainable industrial practices, and the study addresses a gap in the existing literature by examining the adoption of Lean practices in Portugal. The study finds that 5S is Portugal's most widely implemented Lean tool (90.3%), followed by visual management (81.9%). Additionally, the research highlights the potential for Lean tools to improve both operational and environmental outcomes, supporting the synergy between Lean and Green methodologies. This insight is important for companies seeking to enhance sustainability while maintaining or improving operational performance. Furthermore, the research acknowledges the learning curve associated with Lean tool adoption, suggesting that the benefits of Lean practices may increase over time with continued commitment and experience. The significance of these findings underscores the value of this research to academics, industry professionals, and policymakers interested in Lean practices and sustainability.

While this investigation provides valuable insights, it is not without its limitations. The low response rate (15.9%) and small sample size (72 valid responses) may impact the reliability of the findings. Moreover, the study's focus on the Portuguese context may limit the generalizability of the results to other regions or countries. However, these limitations also point to potential areas for future research. For instance, future studies could aim to increase the sample size, expand the study to other countries, and introduce new variables, such as company size, to explore their impact on operational and environmental performance. The rise of Industry 4.0 also presents new challenges, and future studies could investigate how digital transformation influences the application of Lean tools and their effects on performance. Another area for future research is the social dimension of sustainability, as existing studies have focused more on environmental sustainability. Portuguese SME companies could also consider applying large language models, such as ChatGPT, to assist them in developing and applying lean and sustainability roadmaps and methodologies to improve their operational and sustainability performance, engage stakeholders, and identify key sustainability goals, risks, opportunities, and Key Process Indicators (KPIs).These potential avenues for future research underscore the ongoing relevance and applicability of the current study's findings.

This investigation has several practical and social implications that are important for all stakeholders to consider. It demonstrates that Lean tools significantly improve operational efficiency in customer satisfaction, delivery times, and flexibility, offering companies a competitive advantage. Lean practices also contribute to environmental sustainability by reducing energy consumption, waste, and emissions, which can help companies meet stricter regulations and sustainability goals. Socially, Lean can improve the Work Environment by enhancing workplace organization and safety, though improper implementation could lead to stress, which is highly relevant for Lean adoption with digital transformation (Eriksson et al., 2024). Lean's Community and Societal Impact includes contributing to global sustainability efforts through reduced waste and energy consumption. Moreover, Portuguese organisations can improve their proficiency in Lean tools such as Kaizen, Kanban, VSM, Jidoka, or Heinjuka and, in addition to Sustainability, connect Lean with Quality and Service. However, it is critical to ensure a sustained commitment to Lean implementation to significantly impact their organisation performance. Finally, Policy Implications suggest governments can promote Lean adoption by offering incentives and fostering collaborations between industries and academia to integrate Lean with social sustainability goals. These implications underscore the broader impact of lean practices, making all stakeholders more informed and aware of the potential benefits and challenges of Lean adoption.

References:

Abdul Wahab, A. N., Mukhtar, M., & Sulaiman, R. (2013). A conceptual model of lean manufacturing dimensions. *Procedia Technology*, *11*, 1292-1298. doi: 10.1016/j.protcy.2013.12.327

Abualfaraa, W., Salonitis, K., Al-Ashaab, A., & Ala'raj, M. (2020). Lean-green manufacturing practices and their link with sustainability: A critical review. *Sustainability*, *12*(3), 1-21. doi: 10.3390/su12030981

Afum, E., Zhang, R., Agyabeng-Mensah, Y., & Sun, Z. (2021). Sustainability excellence: the interactions of lean production, internal green practices and green product innovation. *International Journal of Lean Six Sigma*, *12*(6), 1089-1114. doi: 10.1108/IJLSS-07-2020-0109

Antony, J., McDermott, O., Sony, M., Toner, A., Bhat, S., Cudney E.A., & Doulatabadi, M., (2023). Benefits, challenges, critical success factors and motivations of Quality 4.0 – A qualitative global study. *Total Quality Management & Business Excellence*, *34*(7-8), 827-846. doi: 10.1080/14783363.2022.2113737.

Armstrong, J. S., & Overton, T. S. (1977). Estimating Nonresponse Bias in Mail Surveys. *Journal of Marketing*, *14*(3), 396-402. doi: 10.2307/3150783.

Azevedo, J., Sá, J. C., Ferreira, L. P., Santos, G., Cruz, F. M., Jimenez, G., & Silva, F. J. G. (2019). Improvement of Production Line in the Automotive Industry Through Lean Philosophy. *Procedia Manufacturing*, *41*, 1023-1030. doi.org/10.1016/j.promfg.2019.10.029

Azzolini Júnior, W., Santos, C. H., Romano, A. L., Salles, H. O., Palma, J. M., & Augusto Filho, R. T. (2025). Integration of simulation and hierarchical approach to support lean implementation. *International Journal of Simulation Modelling*, *24*(1), 111-122. doi: 10.2507IJSIMM24-1-719

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, *17*(1), 99-120, doi: 10.1177/014920639101700108.

Barney, J. B. (2001). Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view. *Journal of Management, 27*(6), 643-650, doi: 10.1016/S0149-2063(01)00115-5

Belhadi, A., Touriki, F. E., & El Fezazi, S. (2018). Benefits of adopting lean production on green performance of SMEs: a case study. *Production Planning and Control*, *29*(11), 873-894. doi: 10.1080/09537287.2018.1490971

Carvajal-Arango, D., Bahamón-Jaramillo, S., Aristizábal-Monsalve, P., Vásquez-Hernández, A., & Botero, L. F. B. (2019). Relationships between lean and sustainable construction: Positive impacts of lean practices over sustainability during construction phase. *Journal of cleaner Production*, *234*, 1322-1337. doi: 10.1016/j.jclepro.2019.05.216

Carvalho, H., Duarte, S. and Cruz Machado, V. (2011). Lean, agile, resilient and green: divergencies and synergies. *International Journal of Lean Six Sigma*, *2*(2), 151-179, doi: 10.1108/20401461111135037

Cherrafi, A., Elfezazi, S., Hurley, B., Garza-Reyes, J. A., Kumar, V., Anosike, A., & Batista, L. (2019). Green and lean: a Gemba–Kaizen model for sustainability enhancement. *Production Planning and Control*, *30*(5–6), 385–399. doi: 10.1080/09537287.2018.1501808

Cimini, C., Lagorio, A., Romero, D., Gaiardelli, P., & Tortorella, G. (2024). On job profiles enlargement and enrichment when lean and industry 4.0 paradigms meet. *International Journal of Industrial Engineering and Management*, *15*(4), 338-347. doi: 10.24867IJIEM-2024-4-367

da Silva, F. J. G., & Gouveia, R. M. (2020). *Cleaner Production*. Springer. doi: 10.1007/978-3-030-23165-1

DiMaggio, P. J., & Powell, W. W. (2000). The iron cage revisited institutional isomorphism and collective rationality in organizational fields. In J.A.C. Baum & F. Dobbin (Eds.) *Economics Meets Sociology in Strategic Management (Advances in Strategic Management*, 17, Emerald Group Publishing Limited, Leeds, pp. 143-166. doi 10.1016/S0742-3322(00)17011-1

Dieste, M., Panizzolo, R., Garza-Reyes, J. A., & Anosike, A. (2019). The relationship between lean and environmental performance: Practices and measures. *Journal of Cleaner Production*, *224*, 120-131. doi: 10.1016/j.jclepro.2019.03.243

Eriksson, K. M., Olsson, A. K., & Carlsson, L. (2024). Beyond lean production practices and Industry 4.0 technologies toward the human-centric Industry 5.0. *Technological Sustainability*, *3*(3), 286-308. doi: 10.1108/TECHS-11-2023-0049

European Commission (2023). Portugal's recovery and resilience plan. Retrieved from https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/portugals-recovery-and-resilience-plan_en

Fercoq, A., Lamouri, S., & Carbone, V. (2016). Lean/Green integration focused on waste reduction techniques. *Journal of Cleaner Production*, *137*, 567-578. doi: 10.1016/j.jclepro.2016.07.107

Fonseca, L. M., Lima, V. M., & Silva, M. M. (2015). Utilization of Quality Tools: does sector and size matter? *International Journal for Quality Research*, *9*(4), 605-620. Retrieved from http://www.ijqr.net/journal/v9-n4/4.pdf

Fonseca, L. M. & Domingues, J. P. (2018). The best of both worlds? Use of Kaizen and other continuous improvement methodologies within Portuguese ISO 9001 certified organizations. *The TQM Journal*, *30*(4), 321-334. doi: 10.1108/TQM-12-2017-0173

Fonseca, L. M., Domingues, J. P., Pereira, M. T., Martins, F. F., & Zimon, D. (2018). Assessment of Circular Economy within Portuguese Organizations. *Sustainability*, *10*, 2521. doi: 10.3390/su10072521

Galeazzo, A., Furlan, A., & Vinelli, A. (2014). Lean and green in action: Interdependencies and performance of pollution prevention projects. *Journal of Cleaner Production*, *85*, 191-200. doi: 10.1016/j.jclepro.2013.10.015

Garza-Reyes, J. A. (2015a). Lean and green-a systematic review of the state of the art literature. *Journal of Cleaner Production*, *102*, 18-29. doi: 10.1016/j.jclepro.2015.04.064

Garza-Reyes, J. A. (2015b). Green lean and the need for Six Sigma. *International Journal of Lean Six Sigma*, *6*(3), 226-248. doi: 10.1108/IJLSS-04-2014-0010

Garza-Reyes, J. A., Villarreal, B., Kumar, V., & Molina Ruiz, P. (2016). Lean and green in the transport and logistics sector – a case study of simultaneous deployment. *Production Planning and Control*, *27*(15), 1221-1232. doi: 10.1080/09537287.2016.1197436

Garza-Reyes, J. A., Kumar, V., Chaikittisilp, S., & Tan, K. H. (2018). The effect of lean methods and tools on the environmental performance of manufacturing organisations. *International Journal of Production Economics*, *200*, 170-180. doi: 10.1016/j.ijpe.2018.03.030

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate Data Analysis* (7th ed.). Pearson.

Hartley, J. (2013). Some thoughts on Likert-type scales. *International Journal of Clinical and Health Psychology*, *14*(1), 83-86. doi: 10.1016/S1697-2600(14)70040-7

Henao, R., Sarache, W., & Gómez, I. (2019). Lean manufacturing and sustainable performance: Trends and future challenges. *Journal of Cleaner Production*, *208*, 99-116, doi: 10.1016/j.jclepro.2018.10.116

Herron, C., & Hicks, C. (2008). The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents. *Robotics Computer-Integrated Manufaturing*, *24*(4), 524-531. doi: 10.1016/j.rcim.2007.07.014

Hines, P., Holweg, M., & Rich, N. (2004). Learning to evolve: a review of contemporary lean thinking. *International Journal of Operations & Production Management*, *24*(10), 994-1011. doi: 10.1108/01443570410558049

Hüttmeir A., Treville S., Ackere A., Monnier L., Prenninger J. (2009). Trading off between heijunka and just-in-sequence. *International Journal of Production Economics*, 118 (2), 501-507, doi: 10.1016/j.ijpe.2008.12.014

Inman, R. A., & Green, K. W. (2018). Lean and green combine to impact environmental and operational performance. *International Journal of Production Research*, *56*(14), 4802–4818. doi: 10.1080/00207543.2018.1447705

Iranmanesh, M., Zailani, S., Hyun, S.S., Ali, M.H., Kim, K. (2019). Impact of lean manufacturing practices on firms' sustainable performance: Lean culture as a moderator. *Sustainability*, *11*, 1112-1132. doi: 10.3390/su11041112

Kenworthy, T. P., & Verbeke, A. (2015). The future of strategic management research: Assessing the quality of theory borrowing. *European Management Journal*, *33*(3), 179-190, doi: 10.1016/j.emj.2015.03.007

Klein, L. L., Alves, A. C., Abreu, M. F., & Feltrin, T. S. (2022). *Lean management and sustainable practices in Higher Education Institutions of Brazil and Portugal: A cross country perspective*. Journal of Cleaner Production, *342*, 130868. doi: 10.1016/j.jclepro.2022.130868

Kosasih, W., Pujawan, I. N., Karningsih, P. D., & Shee, H. (2023). Integrated lean-green practices and supply chain sustainability framework. *Cleaner and Responsible Consumption*, *11*, 100143. doi:10.1016/j.clrc.2023.100143

Lacerda, P., Ramos, M. C. G., de Souza, R. O., Bonamigo, A., & Forcellini, F. A. (2025). Micro downtimes management in the Lean perspective: An empirical research in a production bottleneck. *International Journal of Industrial Engineering and Management*, *16*(2), 189-203. doi:10.24867IJIEM-383

Leme, R. D., Nunes, A. O., Message Costa, L. B., & Silva, D. A. L. (2018). Creating value with less impact: Lean, green and eco-efficiency in a metalworking industry towards a cleaner production. *Journal of Cleaner Production*, *196*, 517-534. doi: 10.1016/j.jclepro.2018.06.064.

Meyer, J. W., & Rowan, B. (1977). Institutionalized organizations: Formal structure as myth and ceremony. *American Journal of Sociology*, *83*(2), 340-363. doi: 10.1086/226550

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*, *6*(7), e1000097, doi: 10.1371/journal.pmed.1000097

Mollenkopf, D., Stolze, H., Tate, W. L., & Ueltschy, M. (2010). Green, lean, and global supply chains. *International Journal of Physical Distribution and Logistics Management*, *40*(1–2), 14-41. doi: 10.1108/09600031011018028

Monden, Y. (1995). *Toyota production system* (3rd ed.). Chapman & Hall. ISBN13: 9780412839306

Murmura, F., Bravi, L., & Santos, G. (2021). Sustainable Process and Product Innovation in the Eyewear Sector: The Role of Industry 4.0 Enabling Technologies. *Sustainability, 13*(1), 365. doi.org/10.3390/su13010365

Ng, R., Low, J. S. C., & Song, B, (2015). Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric. *Journal of Cleaner Production*, *95*, 242–255. doi: 10.1016/j.jclepro.2015.02.043

Ohno, T. (1988). *Toyota production system: Beyond large-scale production* (English translation ed.). Productivity Press. ISBN 0-915299-14-3

Oliveira, J., Sá, C. S., & Fernandes, A. (2017). Continuous improvement through “Lean Tools”: An application in a mechanical company. *Procedia Manufacturing*, *13*, 1082-1089. doi: 10.1016/j.promfg.2017.09.139

Pampanelli, A. B., Found, P., & Bernardes, A.M., (2014). A Lean & Green Model for a production cell. *Journal of Cleaner Production*, *85*, 19-30. doi: 10.1016/j.jclepro.2013.06.014

Patel, A. S., & Patel, K. M. (2021). Critical review of literature on Lean Six Sigma methodology. *International Journal of Lean Six Sigma*, *12*(3) 627-674. doi: 10.1108/IJLSS-04-2020-0043

Peralta, A., Carrillo-Hermosilla, J., & Crecente, F. (2019). Sustainable business model innovation and acceptance of its practices among Spanish entrepreneurs. *Corporate Social Responsibility and Environmental Management*, *26*(5), 1119-1134. doi: 10.1002/CSR.1790

Peterson, J., & Smith, R. (1998). *O Guia de Bolso do 5S*. Productivity Press. ISBN 0-527-76338.

Prakash, S., Kumar, S., Soni, G., Mahto, R. V., & Pandey, N. (2022). A decade of the international journal of lean six sigma: bibliometric overview. *International Journal of Lean Six Sigma*, *13*(2), 295-341. doi: 10.1108/IJLSS-12-2020-0219

Qin, Y., & Liu, H., (2022). Application of Value Stream Mapping in Supply Chain: A Case Study on an Amazon Retail. *Sustainability*, *14*(2), 713. doi: 10.3390/su14020713

Rankin, C. P., & Matthews, T. L. (2020). Patterns of B corps certification: The role of institutional, economic, and political resources. *Societies*, *10*(3), 72. doi: 10.3390/soc10030072

Rothenberg, S., Pil, F. K., & Maxwell, J. (2001). Lean, green, and the quest for superior environmental performance. *Production and Operations Management*, *10*(3), 228–243. doi: 10.1111/j.1937-5956.2001.tb00372.x

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2019). Research Methods for Business Students. Pearson. Retrieved from https://books.google.pt/books?id=LtiQvwEACAAJ

Silva, G. M., & Gomes, P. J. (2025). Lean production, green supply chain management and environmental performance: a configurational perspective based on the Portuguese context. *International Journal of Lean Six Sigma*, *16*(2), 518-541. doi: 10.1108/IJLSS-02-2023-0036

Talapatra, S., Santos, G., & Gaine, A. (2022). Factors Affecting Customer Satisfaction in Eatery Business - an Empirical study from Bangladesh. *International Journal for Quality Research* *16*(1), 163-176. doi.org/10.24874/IJQR16.01-11

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509-533, doi: 10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207-222. doi: 10.1111/1467-8551.00375

Verrier, B., Rose, B., Caillaud, E., & Remita, H. (2014). Combining organizational performance with sustainable development issues: the green and lean project benchmarking repository. *Journal of Cleaner Production*, *85*, 83-93. doi: 10.1016/j.jclepro.2013.12.023

Womack, J., Jones, D. and Roos, D. (1990) *The Machine That Changed the World: The Story of Lean Production, Toyota’s Secret Weapon in the Global Car Wars That Is Now Revolutionizing World Industry.* New York: Free Press.

Womack, J. P., & Jones, D. T. (1996). *Lean Thinking – Banish Waste and Create Wealth in your Corporation.* London: Simon & Schuster.

Yusup, M. Z., Mahmood, W. H. W., Salleh, M. R., & Yusof, A. S. M. (2015). Review the influence of Lean tools and its performance against the index of manufacturing sustainability. *International Journal of Agile Systems and Management*, *8*, 116-131. doi: 10.1504/IJASM.2015.070605

Luís Miguel Ciravegna Martins da Fonseca
Dep. of Mech. Eng., School of Engineering, Polytechnic Institute of Porto,
Porto,
Portugal;
Associate Laboratory for Energy,
Transports and Aerospace (LAETA-INEGI),
Porto,
Portugal
LMF@isep.ipp.pt
ORCID 0000-0001-5668-0656

Gilberto Santos
Associate Laboratory for Energy,
Transports and Aerospace (LAETA-INEGI),
Porto,
Portugal
magilster@gmail.com
ORCID 0000-0001-9268-3272

José Dinis de Araújo Carvalho
University of Minho,
Algoritmi Centre,
University of Minho,
Guimarães,
Portugal
dinis@dps.uminho.pt
ORCID 0000-0002-9724-0312

José Carlos Sá
Dep. of Mech. Eng.,
School of Engineering,
Polytechnic Institute of Porto,
Porto,
Portugal;
Associate Laboratory for Energy,
Transports and Aerospace (LAETA-INEGI),
Porto,
Portugal
cvs@isep.ipp.pt
ORCID 0000-0002-2228-5348