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ANÁLISE DO IMPACTO DA IMPLEMENTAÇÃO DE PRÁTICAS *LEAN* E *GREEN* NAS EMPRESAS INDUSTRIAIS: ESTUDO EXPLORATÓRIO

Dissertação no âmbito do Mestrado de Engenharia e Gestão Industrial orientada pelo Professor Doutor Luís Miguel D. F. Ferreira e apresentada ao Departamento de Engenharia Mecânica, da Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

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Analysis of the impact of Lean and Green Practices in manufacturing companies: An exploratory study

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Análise do impacto da implementação de práticas *Lean* e *Green* nas empresas industriais: estudo exploratório

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“You cannot get through a single day without having an impact on the world around you. What you do makes a difference, and you have to decide what kind of difference you want to make.”

Jane Goodall

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I would like to thank my professor, Professor Doutor Luís Ferreira, for all the help in this path, giving me directions and teaching me to ask for them. It has been a long journey.

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ABSTRACT

The world's demand for better and cheaper products created the need for more efficient production systems. In addition, the growing environmental concerns brought legislative constraints and sustainability-driven behavior to the equation. Considering the Blue Planet health, it is crucial to study better approaches regarding the environment for change to happen.

The purpose of this study is the evaluation of the degree of implementation of Lean and Green Practices in the Portuguese manufacturing companies as well as the achieved performance outcomes: operational, environmental and financial. The study's approach led to the design and distribution of an online questionnaire resulting in 158 answers. An Exploratory Factor Analysis confirmed 10 factors that were used to classify the sample through a Cluster Analysis. Three types of companies were identified: 1. *Companies with Low Degree of Implementation of Lean and Green Practices* 2. *Companies with Medium Degree of Implementation of Lean and Green Practices* and 3. *Companies with High Degree of Implementation of Lean and Green Practices*.

Findings show that as the degree of implementation of practices increases, better environmental results are seen but operational and financial performance results are only seen from medium to high degree of implementation, this is consistent with literature that recommends the systematic implementation of practices. The results from this study contribute by providing an image of how Lean and Green practices implementation is occurring at the moment in Portugal and allow companies to be aware of Lean and Green practices and to understand which state they are, conscious that improving practices will transform into favorable outcomes for the company.

Contributions from this study confirm that the wider adoption of practices leads to overall better performance results, therefore it is favorable to invest in the combined implementation. It classifies the Portuguese industry and indicates how companies are performing in terms of Lean and Green and performance measures.

Keywords: Lean manufacturing, Green manufacturing, Portugal, Operational Performance, Environmental Performance, Financial Performance.

RESUMO

A procura mundial de melhores produtos e mais baratos criou a necessidade de sistemas de produção mais eficientes. Para além disso, as preocupações ambientais crescentes conduziram a restrições legislativas e comportamento orientado para a sustentabilidade. Considerando o estado do Planeta Azul, é imperativo estudar melhores abordagens relativas ao ambiente para que mudanças possam ocorrer.

O propósito deste estudo é a avaliação do grau de implementação de práticas *Lean* e *Green* nas indústrias transformadoras portuguesas, bem como os resultados alcançados a nível de performance: operacional, ambiental e financeira. A abordagem tomada levou ao desenvolvimento e distribuição de um questionário online que resultou em 158 respostas. A análise fatorial exploratória confirmou 10 fatores que foram usados para classificar a amostra através de uma análise de clusters. Três tipos de empresas foram identificadas: 1. *Empresas com baixo grau de implementação de práticas Lean e Green*, 2. *Empresas com médio grau de implementação de práticas Lean e Green*, 3. *Empresas com alto grau de implementação de práticas Lean e Green.*

As descobertas mostram que à medida que o grau de implementação de práticas aumenta, são vistos melhores resultados ambientais, mas resultados operacionais e financeiros só surgem a partir de médio para alto grau de implementação, os resultados estão conforme o que consta na literatura sobre implementação sistemática e integral de práticas. Os resultados deste estudo contribuem ao mostrarem uma imagem de como a implementação das práticas *Lean e Green* está a ocorrer em Portugal, sendo que as empresas conseguem entender melhor em que estado se encontram, sabendo que ao investirem terão resultados favoráveis.

Contribuições do estudo confirmam que a adaptação vasta de práticas leva a melhorias nos resultados, sendo assim, favorável investir na implementação conjunta. Classifica a indústria portuguesa e proporciona uma imagem de como as empresas estão em termos de práticas *Lean e Green* e respetivas medidas de avaliação de performance.

Palavras-chave: Lean manufacturing, Green manufacturing, Portugal, Performance Operacional, Performance Ambiental, Performance Financeira.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SIMBOLS AND ACRONYMS

List of Symbols

α - Cronbach alpha

Acronyms/Abbreviations

JIT – Just-It-Time

TQM - Total Quality Management

TPM - Total Preventive/Productive Maintenance

HRM - Human Resource Management

VSM - Visual Stream Mapping

OEE – Overall Equipment Effectiveness

SMED – Single Minute Exchange Of Die

CI – Continuous Improvement

ISO – International Organization For Standardization

KPI – Key Performance Indicators

TPS – Toyota Production System

TBL – Triple Bottom Line

WIP – Work-in-progress

VOC – Volatile Organic Compound

ROA – Return On Assets

CAE – Código De Atividade Económica

OEM – Original Equipment Manufacturer

KMO – Kaiser- Meyer Olkin Measure

EFA – Exploratory Factor Analysis

SD – Standard Deviation

1. INTRODUCTION

The world is reaching its constraints, there is a growing population, shortage in resources and an increasing demand. Addressing these problems means guaranteeing the efficiency of materials and processes while creating sustainable products, as well as complying with legislation and consumer demand. Manufacturing firms are in the spotlight as the major contributor to environmental pollution and environmental sustainability, therefore, is imperative for organizations to do something regarding the subject (Alves et al., (2019); Das & Satao, (2013); Garza-Reyes, (2015b); Martínez-Jurado & Moyano-Fuentes, (2014)). Companies are seeking sustainability which is by The World Commission on Environment and Development (WCED, 1987) definition: "*Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"*. Nevertheless, and, along with these concerns, there is the need for prosperity and performance enhancement since it is vital for the progress and development of mankind. The next steps are the adoption of measures that reduce the humanity burden on the environment and itself which requires putting sustainability as a priority Dhingra et al., (2014).

Lean thinking has been influencing the manufacturing paradigm for a long time, as it seeks efficiency and continuous improvement of products and processes. Lean can be an ally in the sustainability run by guaranteeing that the products are made with fewer resources, less waste and productively. In the meantime, another manufacturing paradigm has emerged, Green, which prioritizes the environmental perspective (Farias et al., (2019); Martínez-Jurado & Moyano-Fuentes, (2014)). Florida, (1996) pioneered in the idea that adopting innovative methodologies such as Lean and Kaizen lead to the adoption of conscious manufacturing, since both improved productivity and reduce environmental costs and risks allowing companies to better perform and create their thriving environment rather than just adjust to new policies. Lean and Green methodologies, although having distinct practices, work similarly, are synergic and catalysts of each other, therefore, have been increasingly associated as an answer to the growing efficiency demand and costumers' environmental concerns (Dieste et al., (2019); Dües et al., (2013)). In the words of Garza-Reyes, (2015b) "it seems natural" to combine them. Bhattacharya et al., (2019) confirmed, through a critical review, that there is a positive outcome of adopting the practices together in comparison to adopting these practices alone. Lean and Green practices follow three main principles: waste reduction, process-centered focus and high levels of people involvement and participation (Martínez-Jurado & Moyano-Fuentes, 2014).

Studies have open up the path, confirmed the favorable relationship between Lean and Green and merging frameworks have been developed. Nevertheless, there is still a lack of knowledge in the relationships between practices of the different concepts and performance impacts. It's essential to research these concepts and prove the favorable relationships and outcomes, in order to put them into practice and achieve urging results.

The combination of the ideas of Chiarini, (2014); Farias et al., (2019); Inman & Green, (2018); Yang et al., (2011) opened up room for the present work. Chiarini, (2014) presented the idea to potentialize Lean tools in order to achieve better environmental outcomes, Farias et al., (2019) provided a framework that categorized Lean practices and Green practices to improve different indicators, Yang et al., (2011) and Inman & Green, (2018) studied the effects of Lean and Green practices on performance. This work explores the relationship between Lean practices, Green practices and operational, environmental and financial performances. The relevance of this study can be seen as Lean and Green being an emerging topic in the words of Farias et al., (2019) and also through the conducted questionnaire where approximately 33% of the respondents expressed their desire to know the study's outcome.

This study aims to extend the knowledge in companies' adoption of Lean and Green practices through survey research. The study objectives are:

- Assessing the most common Lean practices;
- Assessing the most common Green practices;
- Understand the relationship between Lean and Green practices;
- Identify which Lean and Green practices perform better operationally, environmentally and financially.

Sustainability should ensure the Triple Bottom Line, TBL, economic, environmental and social components, but this research will touch only the environmental and economic aspects.

The Lean practices used in this study follow Shah & Ward, (2007), which instigates the suppliers' development, customer involvement, pull production, continuous flow and setup time reduction, total productive and preventive maintenance, statistical process control and employee involvement. Further, the Green practices follow Sarkis et al., (2010) to evaluate the degree of implementation of source reduction practices, eco-design practices and environmental management systems practices. Lastly, the performance indicators follow Negrão et al., (2020); Zhu et al., (2013) which assess the operational, environmental and financial performance.

For this research, a questionnaire was developed and distributed, followed by exploratory factor analysis to understand the relevance of the constructs which were used in a cluster analysis of the practices, culminating in the analysis of the practices that most contribute to the performances. It contributes to the literature with a clear description of three clusters of companies and with the practices that in the Portuguese manufacturing companies contribute for better performance.

This study is divided into 5 chapters, the ongoing present the theme, concepts and proposal. The following chapters are organized: The second chapter is a literature review of the underlying themes. The third chapter describes the methodology of the study as well as the data characteristics. The fourth chapter integrates the results of the Exploratory factor analysis, cluster analysis and others supporting tests intercalated with supporting literature and at last, chapter five, conclusions, study limitations and future suggestions.

2. LITERATURE REVIEW

2.1. Lean Manufacturing

Lean is a methodology known by the manufacturing industry driven by waste reduction and continuous improvement. It derivates from Toyota Production System and has been widely integrated into production systems worldwide since the 1990s. It's based on doing more with fewer resources Womack, James P, (2003) by focusing on value Hines et al., (2004).

> *Value is created if internal waste is reduced, as the wasteful activities and the associated costs are reduced, increasing the overall value proposition for the customer.*

The five principles of Lean are: value, value stream, continuous flow, pull production, and perfection. Value is the worth of a product from the customer's viewpoint and is reflected in the selling price and market demand. Value stream includes all the actions that transform the product. Continuous flow entails the small and consistent batch of items that are processed at the next step rhythm, which should be as continuously as possible. Pull production ensures the communication of needs from downstream to upstream activities. Perfection is the goal and consequence of providing value without waste as defined by the customer (Gorecki & Pautsch, (2013); Womack, James P, (2003)).

The principles can be translated into 4 actions: identify value from the customer standpoint (eliminate waste), center on people who add value, flow value from demand, optimize across organizations Gorecki & Pautsch, (2013). As an implementation strategy, the principles could be decoded as synchronizing supply to the customer, externally; synchronize production, internally; creating flow; establishing pull-demand systems. Wilson, (2010).

Inherent to any production system, three issues need to be tackled: *Muda*, *Muri*, *Mura*. The first stands for waste, while *mura* and *muri* are considered the sources of it

(Gorecki & Pautsch, (2013); Thürer et al., (2017)). Depending on the authors, the translation differs. Thürer et al., (2017) share the definitions from Ohno, (1988) and Harrison, (1992): *Mura* concerns inconsistency or irregularity and *Muri* is unreasonableness or excessiveness. Bergmiller & McCright, (2009) said "*Anything not directly contributing to the creation of value is considered waste in the Lean philosophy*". Waste has such an emphasis on Lean, that there is a need to clarify the 7 *Mudas* that consume resources without adding value: overproduction, waiting, transport, overprocessing, inventory, motion, and defects. Hines, (2012) adds an 8th one being lost people potential (Bergmiller & McCright, (2009); Fercoq et al., (2016); . Hines, (2012); Verrier et al., (2014); Womack, James P, (2003)).

Lean can be perceived in different ways, as Hines et al., (2004) or Hopp & Spearman, (2020). Hines et al., (2004) divides Lean into strategic level and operational level, being the first one concerned with understanding value and the latter related with tools that focus on eliminating waste. Hopp & Spearman, (2020) explains it as the 4 lenses: (1) the process lenses: *Lean is the pursuit of waste elimination*, (2) the flow lenses: *Lean seeks to minimize the cost of excess inventory, capacity or time*, (3) the network lenses: *Lean is a systematic process for reducing the cost of waste*, and (4) the organizational lenses: *Lean is an organizational culture that encourages continual reduction of the cost of waste*.

Successfully implementing Lean is a common challenge in practice and in literature. Companies often try to implement a few tools and practices which accomplish very little because each tool has a role and a purpose that is enhanced when combined with others. The culture shift necessary for Lean to exist is often overlooked and ignored. But implementing Lean requires alignment in socio-technical elements such as people, technology, organization structure and external factors (Yadav et al., (2017)).

Lean bundles emerged to simplify and aggregate the considered tools. Shah & Ward, (2003) initially defined four bundles: Just in Time (JIT), total quality management (TQM), total preventive maintenance (TPM), and human resource management (HRM). Garza-Reyes, Kumar, et al., (2018) re-defines them into five bundles: just-in-time (JIT), total productive maintenance (TPM), autonomation, visual stream mapping (VSM) and Kaizen/Continuous improvement, as shown in Table 1. JIT tools are associated with the timing of the production (one-piece flow, pull system, takt time, leveled production, cellular manufacturing, visual control, Kanban, multifunctional workers, and JIT purchasing). TPM tools are related to maintenance and equipment proficiency (OEE, SMED, 5S, autonomous, planned, quality maintenance, initial control, and safety, hygiene and environment). Autonomation/jidoka ensures integrated quality (mistake proofing/poka-yoke, visual control, full work system). VSM allows the visualization of processes and waste (current state map, future state map, and flow diagrams). Kaizen/CI includes tools that sustain everyday continuous improvement (5S, Brainstorming, Continuous flow, kanbans, data checks, 5whys, Pareto chart, run chart, Gantt chart, VSM, process map, mistake proofing/poka-yoke)(Dieste et al., (2019); Garza-Reyes, Kumar, et al., (2018); Shah & Ward, (2003)).

Studies that used Lean bundles are widely present in literature and associated with Lean implementation. Bevilacqua et al., (2017) studied the Lean practices in relation with product mix variety, product innovation, time effectiveness and company growth performance on Italian manufacturing companies. Belekoukias et al., (2014) defined the best implementation order of significance to maximize performance results in respect to Lean bundles, and Garza-Reyes, Kumar, et al., (2018) following the same study, defined the best implementation order to reduce each different environmental aspect considered between material use, energy consumption, non-product output and pollutant releases. The authors used Lean bundles to assess the Lean implementation. Some limitations of using Lean bundles emerge with the use of them separately. Furlan et al., (2011) study concluded that in order to take full advantage of the synergic effects, JIT and TQM should be complements. Additionally, the authors demonstrated that the implementation of several Lean bundles maximize performance.

The descriptive elements of Lean can be synthesized in 48 items, which identifies 10 elements that are inter-related and complementary, as seen in Table 2. Firms' work should occur in a continuous flow (FLOW) guaranteeing that the shop-floor arrangement makes sense in a flow perspective. To maintain flow, there is a need for regular preventive maintenance (TPM). Equipment is arranged in a way that cross-trained employees and teams can identify and solve problems effectively (HRM). With involved customers (CUSTINV) the demand is accurately predicted, reduced setup times (SMED) are achieved and the quality (SPC) in the output is aligned completely with the demand. The production is controlled by pull production system (PULL) through Kanban, measuring units at the time needed in quantities needed. To match this alignment, the suppliers have to work accordingly through JIT (SUPPJIT), and to ensure harmony there should be feedback

(SUPPFEED) and training for further improvement (SUPPDEVT). This is relevant because the firm should aim for a long-term relationship with the suppliers (Shah & Ward, (2007)). The 10 elements group practices inside that are descriptive. For example, in the pull category the practices are *Production is "pulled" by the shipment of finished goods; Production at stations is "pulled" by the current demand of the next station;* and *We use a kanban, squares, or containers of signals for production control.* Inman & Green, (2018), Negrão et al., (2020) and Nawanir et al., (2013) used the descriptive elements of Lean in their survey research. The first authors were able to assess the combined impact of Lean and Green practices on both environmental and operational performance by structural equation modelling. The second authors understood the S-curve relationship between Lean and business performance. While the later, investigated the relationship between Lean practices, operational performance and business performance in the Indonesian context. The definition of Lean serves as the basis of the present study since it will be used in this dissertation to evaluate the degree of implementation of Lean practices in the Portuguese manufacturing companies.

Table 1. Lean Bundles with tools.
Adapted from (Garza-Reyes, Kumar, et al., 2018).

JIT	TPM	Autonomation	VSM	Kaizen/CI
One piece flow Pull system Takt time Levelled production Visual control Kanban/Pull production Multifunctional employees JIT purchasing	OEE SMED 5S Autonomous maintenance Planned maintenance Quality maintenance Initial control before starting production Safety, hygiene and the environment	Mistake proofing/poka-yoke Andon/Visual control system Full work system	Current state map Future state map Flow diagrams	5S Brainstorming Continuous Flows *Kanbans* Data checks Pareto chart Run Chart Gantt chart VSM Process map Mistake proofing/poka-yoke
Lean tools				

Table 2. The 10 Lean elements.
Adapted from Shah & Ward, (2007)

S U P P F E E D (Supplier Feedback)	Performance feedback with suppliers.
S U P P J I T (Jit Delivery By Suppliers)	Ensuring perfect delivers from suppliers.
S U P P D E V T (Supplier Development)	Engaging and developing the supplier relationship.
C U S T I N V (Customer Involvement)	Production aligned with the customers.
P U L L (Pull)	Pull production as needed.
F L O W (Continuous Flow)	Establishing continuous flow.
S M E D (Set Up Time Reduction)	Minding the times and reduce downtime.
T P M (Total Productive/Preventive Maintenance)	Maintaining equipment and respective availability.
S P C (Statistical Process Control)	Control and ensure supply without defects.
H R M (Employee Involvement)	Involvement of employees in problem solving, and their cross functional character.

2.2. Green Manufacturing

Green is a characterization of the manufacturing philosophy that implies that the production method is aware of its impact on the environment. It impacts planning and control, conceiving an environmentally friendly awareness (Deif, (2011)).

Green manufacturing considers eco-efficiency strategies and tools, that aim to the environment conservation. These tools reflect the ideas of consuming less material, substituting raw materials (because they are toxic or can be renewable) and reducing energy consumption and unwanted outputs, in continuous integration of environmental improvements (Deif, (2011); Jasiulewicz-Kaczmarek, (2014); Van Berkel et al., (1997)).

The environmental waste definition presented by Jasiulewicz-Kaczmarek, (2014) is: *"Environmental waste is an unnecessary or excess use of resources or a released to the air, water, or land that could harm human health or the environment."* Reduction, control, elimination and preventive measures of waste are a crucial part of Green manufacturing as reflected in Figure 1. Waste can only be eliminated if correctly identified. As the 8 Lean *mudas* referred before, there are 8 environmental wastes: Greenhouse gases, eutrophication, excessive water usage, excessive power usage, excessive resource usage, pollution, rubbish, and poor health and safety (Deif, (2011); Hines, (2012)).

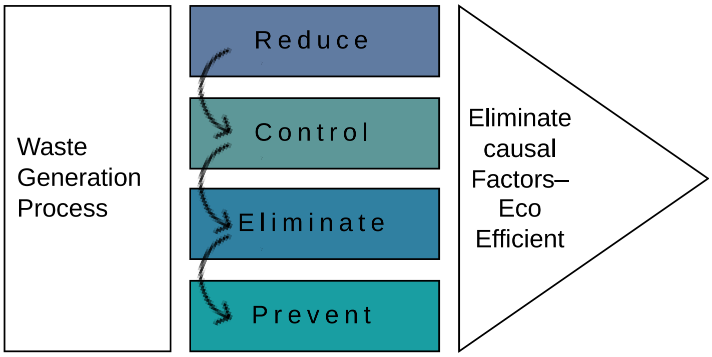


Figure 1. The relationship between Green manufacturing and waste. Adapted from Deif, (2011)

The 3 major categories of corporate environmental practices describing Green management are related to employed material, product design and internal organization, from an environmental management perspective. Employed material is a combination of practices aiming to reduce or find alternatives to the materials used (Sarkis et al., (2010)). Product design can also be called eco-design and Design for the environment (DfE), refers to the practices adopted along the product development phase, considering the product's life cycle. The practices often use indicators to evaluate such impact from use to recycle to dismantling procedures (Dahmani et al., (2021)). Environmental Management Systems (EMS) monitors, tracks, summarizes and reports environmental information to internal and external stakeholders. This way, developing relationships, activities (such as training) and enhancing performance. A standard EMS is the ISO14000 (Sroufe, (2003)). From the literature, eco-design is the most mentioned practice, followed by ISO 14000 Environmental Management norms, Life Cycle Assessment and Reverse logistics (Sarkis et al., (2010); Siegel et al., (2019)).

The Green practices that are going to be used in this study were firstly used in Sarkis et al., (2010) to test hypothesis concerning the relationship between stakeholders pressures and the implementation of eco-design / source reduction / environmental management systems practices is mediated by training programs. The conclusions stated that environmental training does mediate the relationship and is most evident in eco-design practices.

2.3. Lean and Green

King & Lenox, (2001) stated that "Lean is Green" and propose that "Lean production is complementary to environmental performance". A quantitative study from US manufacturing plants that evaluated the adoption of ISO's 9001 (related with quality) and 14001 (related with environmental management), shows that the adoption of the first, generally, lead to the adoption of the second. The synergic relationship between Lean and Green was further confirmed by Dües et al., (2013) adding that Lean facilitates Green in some areas without extra investment, being an easy achievement for companies. Following the idea of Yang et al., (2011), which revealed the importance of implementing both Lean and environmental (Green) practices to benefit from the eco-advantage in environmental performance as well as business performance. Common rewards of implementing both practices are: reduction of waste, which is the most observed, followed by reduction of resources which leads to reduction of costs and lastly the safety of workers (Siegel et al., (2019)).

2.3.1. Overlap in Lean and Green

By studying the advanced Lean system model and the Green system model, Bergmiller & McCright, (2009) concluded the comprehensive Lean and Green systems model. It is comprised by the system (policies and procedures), waste reduction techniques (practices), and business results (unit of measurement). The similarities are exposed indicating that the models are complementary, Figure 2.

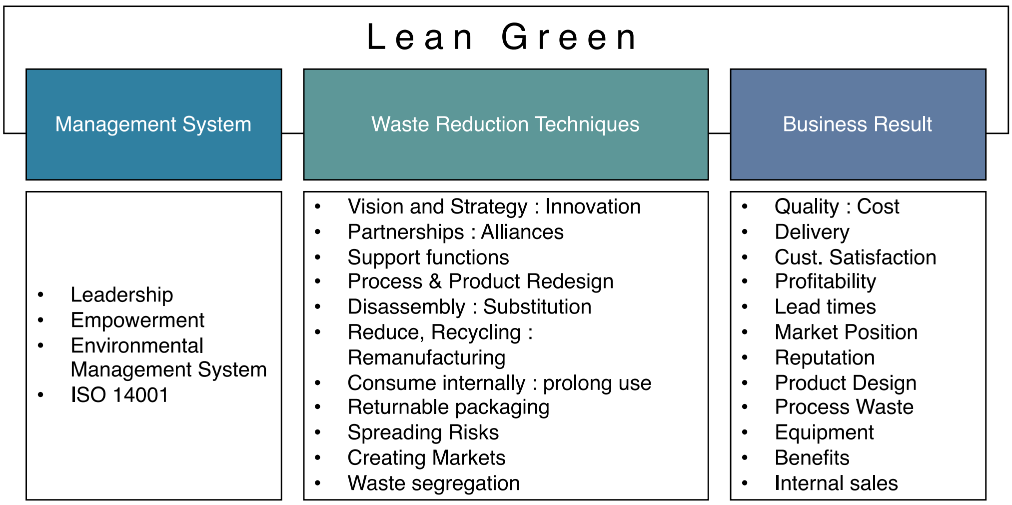


Figure 2. Comprehensive Lean and Green Systems Model.
Adapted from Bergmiller & McCright, (2009)

Lean and Green paradigm overlap in waste and respective reduction techniques, organizational ideas, lead time reduction, supply chain relationship, KPIs of service level, tools and practices. The differences between the two paradigms are: focus, waste definition, the customer, product design and manufacturing strategy, end of product-life concerns, main KPI, and the ultimate dominant cost as presented in Figure 3. Where in Lean view it is the physical value and the Green, the detriment for future generations (Dües et al., (2013)).

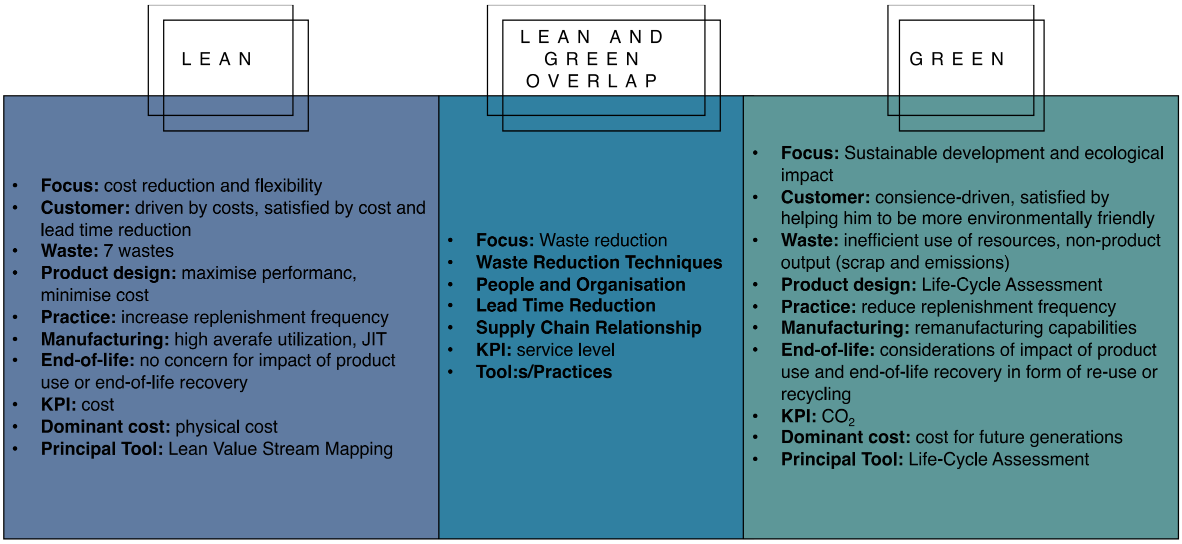


Figure 3. Overlap of Lean and Green Paradigms.
Adapted from Dües et al., (2013).

Concluding, Lean and Green are ruled by three main principles: 1) Principle of Waste Reduction, 2) Process-centered focus and 3) High levels of people involvement and participation (Martínez-Jurado & Moyano-Fuentes, (2014)). The Lean and Green House from Verrier et al., (2016) aims to facilitate the understanding, implementation and message of Lean and Green philosophy. It is inspired by the Lean House from TPS while focusing on strategic sustainability. As show in the Figure 4, the House foundation lays in top-down management for implementation and action, feedback with bottom-up expertise being the base of a continuous improvement culture. The pillars represent the TBL with the concepts of Lean, Green and Human workforce with the principal strategic tools. Inside the House, reflecting the role of the key stakeholders in competitive advantage, there are the suppliers and employee's relationships.

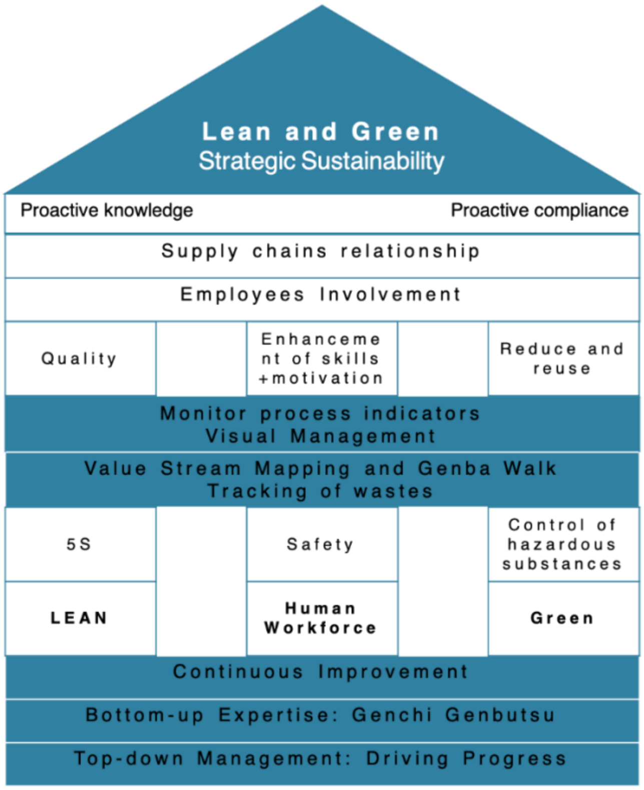


Figure 4. The Lean and Green House.
Adapted from Verrier et al., (2016).

2.3.2. Lean bundles and environmental results

In the quantitative study of Chiarini, (2014), which took in account 5 motorcycle component factories, the effectiveness of Lean tools in reducing environmental impact was evaluated. The evaluated tools were: VSM, 5S, cellular manufacturing, SMED, and TPM. All these tools, except SMED, provided environmental benefits by uplifting environmental aspects, such as reducing emissions and other impacts. Through a questionnaire, Garza-Reyes, Kumar, et al., (2018) assessed the effect of the essential Lean tools concerning different environmental aspects. They found that the bundles of VSM and autonomation have no environmental benefits, as opposed to Kaizen, TPM, and JIT in the aspects of materials use, energy consumption, non-product output, and pollutant releases. Piercy & Rich, (2015) found gains that come with a better production process, concerning Lean and Green, in terms of waste, cost, control, and quality such as better design needing less material, less stock buffer, less rework, more proximity with supplier, and the relationship and improvement of worker safety in process design. Herrmann et al., (2008) developed simulations scenarios considering different Lean strategies, varying energy consumption, lead time and WIP. The authors found that the implementation of continuous flow was critical for lowering the green parameter, however, only the standardization lowered the energy consumption opposed to quality strategy, Andon line and Kanban, that consumed slightly higher energy. On the bright side, quality strategy prevented defects, the stoppage in Andon Line was the reason of higher consumption and Kanban reduced inventory but involved more supply runs.

Trade-offs that have been questioned in the literature are related with the JIT bundles, quality and emissions. In the eyes of Lean bundles and Green results, JIT is classified as the most conflicting, TQM the bundle with the most meaningful effects to diminish the environmental consequences, and HRM as the least impactful (Dieste et al., (2019), (2020)). JIT is conflicting because increases the replenishment frequency leading to more transport and more emissions (Dües et al., (2013)). Quality in the processes that use water and have refinements, for example, in the study of Baumer-Cardoso et al., (2020), found the expected drop in the material consumption and energy when implementing Lean because the amount of products drop but, in the case study, the water consumption increased due to the application of the JIT tool in the injection-molding process, where the water cannot be reused. Which is in line with Rothenberg et al., (2001) findings that say that energy saving opportunities in the plant are easily found but when it comes to water there is a need to redesign the process. Regarding air emissions, Lean philosophy is pro pollution prevention rather than pollution control but, to achieve regulations both are needed and require resources from the company (Rothenberg et al., (2001)).

2.3.3. Lean Practices and Green Practices combined

Through a survey of Canadian manufacturing plants, Hajmohammad et al., (2013) proved that Lean management activities are limited by environmental practices because environmental practices are the force behind the best environmental performance results. Thus, if companies want to address environmental performance, they must reflect it in the implementation, by combining both sets of practices. Dhingra et al., (2014) reiterate that Lean leads to Green but not the reverse and, since these two ways of thinking have been developed independently, the authors advice is that the implementation strategies have to be intentional in integrating both. However it is crucial to remember that the relationship is complex (Dhingra et al., (2014); Rothenberg et al., (2001)). A way to achieve this is by appointing champions which companies can admire and follow, and invest in education about Lean Green thinking's, and instigating it while developing the connection between the two. The implementation stages were explored by Galeazzo et al., (2014) and Piercy & Rich, (2015) that described the best order of the implementation process. Both proved that it is easier to implement either philosophy after the other than implementing one of them for the first time, since the first implementation impulses the development of the other while sharing tools. Galeazzo et al., (2014) goes further and proves that simultaneous implementation is better than sequential, consequently leading to higher operational results. The study of Inman & Green, (2018) supports the implementation of both Lean and Green practices. They evaluated the performance improvement in terms of operational and environmental performance and concluded that the implementation of Lean practices only will result in improved operational performance and slightly improvement on environmental performance. By combining the complementary practices, environmental and operational performance will be boosted.

2.3.4. Lean and Green tools

Kurdve & Bellgran, (2021) classified the operative Lean Green concept "*as the unification of Green and Lean production principles"*, therefore, the Lean Green toolbox aggregates both Lean and Green tools. From Siegel et al., (2019), the literature review related with Lean and Green, as shown in Figure 5, shows Lean and Green tools that are shared as well as emerging Lean Green. The most used tool from Lean is the 5S (Sort, Set, Shine, Standardize and Sustain). On the other hand, for Lean Green the most valued tool is the Green Value Stream Mapping.

Figure 5. Lean and Green tools in consideration with use
Adapted from Siegel et al., (2019)

A Lean and Green assessment framework for manufacturing was proposed by Farias et al., (2019), in it, it is possible to visualize the different needs while comparing practices from each concept to performance. Which means that, to improve the same outcomes it is possible to use both perspectives tools and combine them. As seen in Figure 6 , the operational performance and the environmental performances are presented as hubs, with respective needs. Inside the needs there are the practices (tools) to improve the domains. The operational performance hub has the domains of inventory, profitability, and productivity while the environmental performance has the environmental impacts and energy consumption. The overlap between the two hubs has cost reduction, quality, and waste reduction.

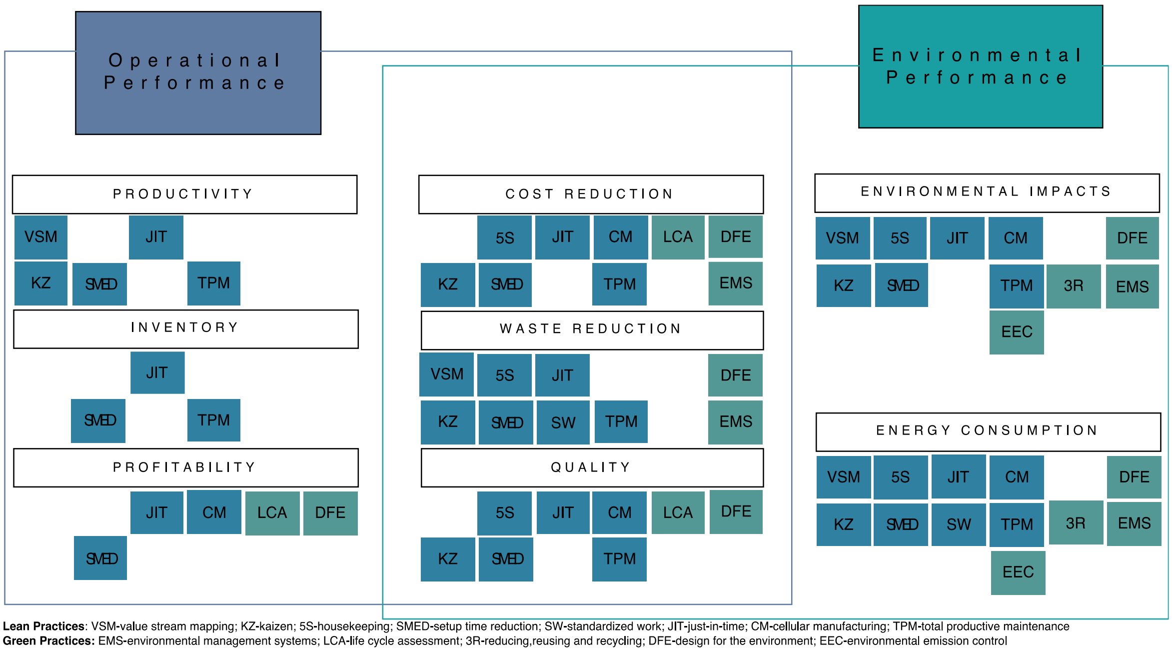


Figure 6. Lean and Green assessment framework.
Adapted from Farias et al., (2019)

Lean and Green tools retrieved from the literature are summarized in Table 3, but it is good to keep in mind that these tools have been developed and need adjustment according to respective utilization needs. For example, in the article Dawood & Abdullah, (2018) the 3R technique is implemented in the cement industry. In Zhu et al., (2018), the study approach an hospital perspective focused on Greening the supply chain.

From the Lean and Green frameworks list, presented on Table 3, five are VSMs merging the two concepts. VSM, the original tool, exposes value-adding and non-value-adding activities while measuring indicators. In this line, the adapted versions makes it possible to track Lean wastes and environmental while assessing both types of indicators (Faulkner & Badurdeen, (2014); Womack, James P, (2003)). The other tools of the list are varied, usually focusing on waste or specific improvements. Additionally, two toolkits are present, they cover different tools and extend the idea of applying more tools simultaneously.

Only 46% of Lean Green papers add the Green component in their tools (Siegel et al., (2019)). The Green Performance Map, GPM tool, is applied in 3 steps and follows the Lean principles. In the center of the tool, the factory and the metrics that are going to be assessed around it. The metrics and quantity of metrics assessed depend on the company focus of improvement and what it values. After identifying the process and collecting the actual state, it follows the prioritization plans as well as implementation plans to ensure that action is taken upon the findings. The framework promotes visualization, improvement and better communication between parts (Romvall et al., (2011)). Müller et al., (2014) tool, the EVSM, explores the energy use in a VSM diving it into value-adding activities and non-value-adding. In this way, identifying them through visualization, reducing waste and improving efficiency while improving environmental outcomes. The framework can also be applied in other domains such as in relation with transportation, because there is some percentage that it's not fully necessary. With the goal of reducing solid waste performance, Fercoq et al., (2016) developed a Lean/Green matrix with a checklist about best practices to minimise waste with Lean and 3R thinking (reduce, reuse, recovery).

From the frameworks and tools reviewed, four are conceptual Farias et al., (2019); Fercoq et al., (2016); Kurdve & Bellgran, (2021); Müller et al., (2014). While sixteen were successfully implemented in the industry Cai et al., (2019); Cherrafi, Elfezazi, Govindan, et al., (2017); Farias et al., (2019); Faulkner & Badurdeen, (2014); Garza-Reyes, Torres Romero, et al., (2018); Kurdve et al., (2015); Leme et al., (2018); Muñoz-Villamizar et al., (2019); Ng et al., (2015); Pampanelli et al., (2014); Romvall et al., (2011); Thanki & Thakkar, (2016); Verrier et al., (2016).

Table 3. Lean and Green Tools and Frameworks

V S M	
Green Performance Map: GPM	Romvall et al., (2011)
Sustainable Value Stream Mapping: Sus-VSM	Faulkner & Badurdeen, (2014)
EVSM	Müller et al., (2014)
Carbon Value Efficiency: CVE-VSM	Ng et al., (2015)
Waste Flow Mapping: WFM	Kurdve et al., (2015)
Overall Green Performance Mapping: OGP-VSM	Muñoz-Villamizar et al., (2019)
O T H E R T O O L S	
The Lean & Green Model	Pampanelli et al., (2014)
Lean/3R Matrix	Fercoq et al., (2016)
The Lean and Green House and maturity deployment model	Verrier et al., (2016)
Value-value load diagram	Thanki & Thakkar, (2016)
Green and Lean Six Sigma: GL2S	Cherrafi, Elfezazi, Govindan, et al., (2017)
PDCA-based approach to E-VSM	Garza-Reyes, Torres Romero, et al., (2018)
Lean-Green model based on ecoefficiency indicators	Leme et al., (2018)
Lean Energy Saving and Emission Reduction: LESER	Cai et al., (2019)
Lean and Green performance assessment (ANP-based approach)	Farias et al., (2019)
L&G approach	Leong et al., (2019)
Lean and Green assessment framework	Farias et al., (2019)
Framework for circular economy integration as part of the Green Lean approach	Kurdve & Bellgran, (2021)
The Lean and Environment Toolkit	US EPA, (2007)
Toolkit for simultaneously improving production and environmental efficiencies	Muñoz-Villamizar et al., (2020)

Other concepts such as Circular Economy, Lean Green Six Sigma and Lean Agile Resilient Green have been rising. Lean and Green is an ally in these models but with adjustments. For example, with the Circular Economy, the main objective is to keep the value of the residual material as much as possible (Kurdve & Bellgran, (2021)). Green Lean Six Sigma aims to complement in the Lean Green limitations by being data-driven, providing structure to control processes and alignment related with definitions and objectives (Cherrafi, Elfezazi, Govindan, et al., (2017); Garza-Reyes, (2015a)). In addition, Lean Agile Resilient Green objective is to provide a quick response to volatile demands while reducing waste, adapting eco-friendly practices and risk-free practices (Amjad et al., (2020)).

2.4. Performance Indicators

Measuring parameters is a recurrent problem in sustainability and there is a need for better measuring parameters (Martínez-Jurado & Moyano-Fuentes, (2014)). Bhattacharya et al., (2019) focused on the triple bottom line with environmental performance indicators (waste reduction in raw materials, time, energy and water, air emissions, VOC, pollution, carbon footprint), social performance indicators (corruption risk, employee satisfaction level, job hazards, occupational health & safety, business ethics, transparency, local suppliers, ergonomics motion) and economic performance indicators (cost (production and environmental related), time (lead time, cycle time, value-added time, set up time, process time, speed of delivery, flexibility), international sales, productivity, ROA, efficiency, quality, customer satisfaction, inventory levels). Zhu et al., (2013) used environmental performances, operational performance and economic (cost avoidance/operational) performance.

The definition of operation performance by Zhu et al., (2008) relates the manufacturing plant's capabilities to produce and deliver products efficiently to customers. Environmental performance conveys the ability of the manufacturing plants to reduce air emissions, water and solid wastes while decreasing consumption of hazardous and toxic materials. Financial performance can be translated as the manufacturing plant present and future market value and profitability (Miroshnychenko et al., (2017); Zhu et al., (2008)).

2.4.1. Relationship between Lean and performance

Implementing Lean practices is positively correlated with operational performance, says the study of Nawanir et al., (2013). The analysis of principal component of Lean proved improvement in all measures of operational performance. Therefore, implementing extensively will extent results. The benefits are lower cost, lower non-value-added activities, lower inventory level, higher profit, higher quality, higher flexibility, better productivity and better response time.

The relationship between the adoption of Lean practices and business performance follows a non-linear and S-shaped pattern. Organizations that adopt some Lean practices may be able to see significant improvements in business performance until reaching a saturation point, which follows little improvement. This means that organizations do not need to implement a wide range of Lean practices in an initial stage but rather make it a sustained journey (Negrão et al., (2020)). Supporting this idea and reinforcing the interdependency of Lean elements and the importance of implementing practices collectively are the results of Nawanir et al., (2013) study. Results of Lean practices implementation with financial performance are positively correlated and extended as the comprehensive implementation (Nawanir et al., (2013)).

Findings of the study of Valente et al., (2020), concerning the implementation of Lean as described in Shah & Ward, (2007) but refined along with the data from Portuguese manufacturing companies revealed that customer involvement, statistical process control, continuous flow and total productive maintenance leads to improvements in overall performance, specifically market, financial and operational performance.

From the literature, 83% of the studies confirm the positive relationship between Lean and environmental performance, 3% negative, and 14% mixed (Dieste et al., (2019)). The idea that Lean practices influence positively environmental performance is supported by Chiarini, (2014); Dieste et al., (2019); Jabbour et al., (2013); King & Lenox, (2001); Rothenberg et al., (2001). However, the results are not uniform through all Lean practices and the relationship is complex (Rothenberg et al., (2001)). Chiarini (2014) exposed that some tools are more effective than others. Nevertheless, the implementation of TPM activities lead to the reduction of oil leakage, dust, and fume emissions (VOCs and others). SMED and Cellular manufacturing lead to the reduction of electricity consumption. 5S lead a better treatment and reduction of waste. Dieste et al., (2019) findings suggest that Lean improves and sustains the environmental performance in the long run. In the 5 years of analyzing the 5 manufacturing companies, the pilot company declared environmental direct benefits, but the measures remained constant in the long term. Company A improved energy use, land use and material use. Company B improved materials use, water use and solid waste. Company C improved energy use, air emissions and solid waste. Company D improved energy use, air emissions, solid and hazardous waste. King & Lenox, (2001) proved that Lean influences the adoption of ISO14001. Rothenberg et al., (2001) research negatively associates Lean management and the reduction of air emissions of volatile organic compounds (VOCs). Nonetheless, the Lean aspects studied (buffer minimization, work systems and HR practices) showed that Lean leads to resource efficiency leading to resource conservation. Foremost, the workforce is seen a valuable resource in the waste reduction opportunities. Jabbour et al., (2013) study in Brazilian automotive companies showed that Lean management influences environmental management in a positive statistically moderate way.

2.4.2. Relationship between Green and performance

Green et al., (2012) reviewed GSCM practices, environmental performance, operational performance and organizational performance. Due to the positive results, the authors stated that it is imperative for organizations to adopt these practices. The positive practices evaluated were internal environmental management, Green information systems, Green purchasing, cooperation with customers, investment recovery and eco-design. Hajmohammad et al., (2013) surveyed Canadian manufacturing plants in relation with supply management, Lean management, environmental practices and environmental performance. The results demonstrated that environmental practices are the force behind better environmental performance. Deif, (2011) system model for Green manufacturing was successfully implemented in the industry delivering reductions in material, emissions, disposal, water and energy.

The Green manufacturing paradigm relates with financial and operational performance because as Deif, (2011) stated "*Time is money, energy is money and consumables are money*". (Yang et al., 2011) evaluated the environmental, market and financial performance between Lean manufacturing practices and environmental management practices. The conclusions were that the initial impact of environmental practices on market and financial performance is negative. However, the Green practices are positive for environmental performance, leading to further influencing market and financial performance, hence results are only seen with time. Miroshnychenko et al., (2017) study inquired about pollution prevention practices, GSCM practices, Green product development practices, and environmental management system standards in relation with financial performance. Pollution prevention and GSCM come first as environmental drivers on financial performance, while Green product development is secondary but relevant. Results showed that the adoption of ISO 14001 had a negative influence on financials outcome. Sroufe, (2003) study showed that the implementation of environmental management systems has a positive impact in operations performance measurements in the manufacturing firms in the United States. Eco-design is positively correlated with environmental performance but negatively correlated with financial performance (Green et al., (2012)).

2.4.3. Relationship between Operational, Environmental and Financial performance

Literature concerning the relationship between operational and environmental is relatively low Inman & Green, (2018). Nawanir et al., (2013) study proved the positive relation between operational performance and business performance, stating that all the measures are inter-dependent and influenced by one another. Green et al., (2012) study concluded that "environmental performance and economic performance leverage improved operational performance which leads to improved organizational performance".

2.5. Implementation challenges

Challenges described in the literature about Green-Lean difficulties among companies in different countries are related to metrics and measurements, awareness in management, and in culture, even though there is a focus in this last one. On the other hand, the success factors considered crucial are the same: employee involvement, management commitment , and adequate metrics (Siegel et al., (2019)). People involvement is mentioned vastly because the implementation process is eased when the workers are skilled, with know-how, open to "the learning to learn" and adaptation (Dhingra et al., (2014); Galeazzo et al., (2014); Hajmohammad et al., (2013); Piercy & Rich, (2015); Siegel et al., (2019)). Barriers to Lean Green implementation are not autonomous, meaning that all of them play a key role in the implementation. Some of the barriers considered are the lack of environmental awareness, lack of expertise training and education, lack of statistical, Lean and Green thinking, inappropriate identification of areas and activities to be 'Leaned and Greened' and unreliable 'data collection system', lack of top management involvement in adopting Green Lean initiative, among others as seen in Figure 7. These affirmations are in line with the contingencies deriving from the integration of Lean Green retrieved from Bhattacharya et al., (2019), which are cultural environment, top management or leadership support, cross-functional collaboration, trained employees, the existing management systems and certifications.

1. Lack of environmental awareness
2. Fear of failure
3. Poor quality of human resources
4. Lack of expertise training and education
5. Fund constraints
6. Lack of statistical, Lean and Green thinking
7. Inappropriate identification of areas and activities to be 'Leaned and Greened' and unreliable 'data collection system'
8. Lack of Kaizen culture
9. Lack of visual and statistical control during Green Lean implementation
10. Lack of government support to integrate Green practices
11. High cost
12. Lack of top management involvement in adopting Green Lean initiative
13. Resistance to change
14. Poor corporate culture separating environmental and continuous improvement decisions.
15. Lack of communication and cooperation between departments

Figure 7. Lean Green implementation barriers.
Adapted from Cherrafi, Elfezazi, Garza-Reyes, et al., (2017).

3. METHODOLOGY

The research aims to assess the degree of Lean practices and Green practices in the industry and the respective impacts on performance. The research philosophy followed is positivism, through an inductive approach. The research method was structured through Saunders et al., (2019). This research is an exploratory survey, the data collection was retrieved through a questionnaire in the Portuguese manufacturing context, therefore the adopted method is mono-method quantitative, and the data is cross-sectional. The questionnaire was selected as the most appropriate method because there was not any data concerning Lean and Green practices in Portuguese manufacturing companies. The electronic distribution was preferred because of the easiness of the distribution through the firms (e-mail and link).

3.1. Survey design

A survey questionnaire was design and then built in the platform LimeSurvey which was used to collect data from Portuguese manufacturing companies (APPENDIX A). The questionnaire consisted of 4 sections (group of questions) divided by: Lean Practices, Green Practices, Performance Indicators and General Information, presented in this order as seen in Table 4.

Lean Practices, environmental management, environmental performance, market performance and financial performance relationship was studied by Yang et al., (2011) through a questionnaire assessing through single and multi-item scale with perceptual measures and five point Likert scale. In Garza-Reyes, Kumar, et al., (2018) questionnaire, Lean bundles implemented were used to convey measures of environmental performance related with materials use, energy consumption, non-product output and pollutant releases, using a Likert scale from 0 to 100%.

In this study, the Lean Practices section, the questions are representative of Lean practices defined by Shah & Ward, (2007). The 10 bundles are linked to 48 operational elements, developed to be used as an operational measure of production, being sufficient to assess the Lean practices and by consequence the Lean implementation. Although, the practices were defined in 2007, there are recent articles such as Negrão et al., (2020), who followed this strategy to understand the S-curve relationship between Lean and business performance. The bundles are detailed in Table 4. In the Green Practices section, there are questions to assess the Green implementation and organizational presence regarding practices related with source reduction, eco-design and environmental management systems, following the questionnaire of Sarkis et al., (2010). The questions were asked to be answered in a seven-point Likert scale, in the Lean and Green section, it assessed the development of the activities being 1= not considering or planning practice and 7= practice currently implemented and industry leader.

The performance indicators follow the questionnaire of Negrão et al., (2020), they are divided by operational performance, environmental performance and financial performance. The questions are asked in comparison with the competitors using the seven-point Likert scale being 1= low end of industry and 7= superior. Operational performance questions were concerning the perfect orders, lead time, levels of stocks of finished products, raw materials stock, rework rates, inventory of materials in process. While financial performance asked about sales, market share and profitability (Negrão et al., (2020)). The environmental performance indicators follow Zhu et al., (2013) relatively to: air emissions, waste water, solid wastes, consumption of hazardous/harmful/toxic materials, environmental accidents, company’s environmental situation and energy consumption.

General Information inquired about the sector which respected the Portuguese system of economic activity identification (CAE-*Código de Atividade Económica*); the size from <10, 10-49, 50-249, 250-499, >500 employees ; the position of the respondent; the production strategy that reflected make-to-order, engineer-to-order, assembly-to-order and make-to-stock; the supply chain position asked in a four-point scale if the company was 1= the raw material supplier, 2=component supplier , 3=OEM, 4= distributer/retailer; and the supply chain characteristics requested in a seven-point Likert scale (1=strongly disagree to 7=strongly agree) to evaluate the changes in product mix, variations in supply requirements, demand fluctuation, volume fluctuation, technical modification of products and modifications to parts/components (by suppliers).The questions were adapted from Bode & Wagner, (2015); Maganha et al., (2020); Negrão et al., (2020); Wynstra et al., (2010).

Table 4. Questionnaire structure

Lean Practices Negrão et al., (2020); Shah & Ward, (2007)	Supplier feedback	SUPPFEED	5
	JIT delivery by suppliers	SUPPJIT	3
	Supplier development	SUPPDEVT	6
	Customer involvement	CUSTINV	7
	Pull	PULL	3
	Continuous flow	FLOW	5
	Single minute exchange of dies	SMED	4
	Statistical process control	SPC	5
	Human resource management	HRM	4
	Total productive/preventive maintenance	TPM	4
Green Practices Sarkis et al., (2010)	Source Reduction	FONT	3
	Eco-design	ECOD	4
	Environmental Management Systems	EMS	3
Performance Indicators Negrão et al., (2020); Zhu et al., (2013)	Operational Performance	COP	6
	Environmental Performance	CEP	7
	Financial Performance	CFP	3
General Information Bode & Wagner, (2015); Maganha et al., (2020); Negrão et al., (2020)	Sector, Production System, Size, Position of the respondent, Supply chain position and characteristics		7

Two groups of marker questions were used in order to understand if bias was occurring, the character of questions is related to the respondent's personal information, the first was adapted from Gu et al., (2021) and inserted in-between Lean practices and the latter from Wong, (2013) about the years of employment of respondents.

The questionnaire is a combination of previous studies that were tested and performed providing valuable data, nevertheless, a pilot test was performed to know if the questions were easy to understand since it suffered the translation to Portuguese. The pilot study involved asking the questions to a worker in a company that recently had implemented Lean, sending the electronic survey multiple times to grasp errors and validating the questions with two professors of the Lean area.

3.2. Data collection and sample

The distribution of the questionnaire was performed in different rounds. The first round sent by e-mail invitation through the LimeSurvey platform to database A, the second round was similar but to database B and the last was through an open link that was distributed with the help of a Lean expert. In the end, 1970 invitations were sent by e-mail. Because the databases weren't updated and some respondents declare that they did not wish to participate in the study, the final database had 1786 contacts. The dates with the distribution of e-mails can be seen in Table 5 and the message that was sent along is on the APPENDIX D.

The electronic survey has the advantage of low cost, large sample coverage, ease of secure information but may be problematic in terms of completeness, reliability and validity and response rate (Voss, (2016)). Reminders were sent to the e-mails that did not completed the questionnaire as seen in Table 5.

Table 5. Distribution of the questionnaire

			Number of answers	
Email with invitation	**To**	**When**	**Total**	**Complete**
1st invitation	Database A(921)	19/05/21	18	10
1st invitation	Database B(1049)	26/05/21	120	57
1st reminder	Database A, B	31/05/21	163	82
2nd reminder	Database A, B	07/06/21	191	99
3rd reminder	Database A, B	15/06/2021	225	131
4th reminder	Database A, B	21/06/2021	255	135

3.3. Response rate and testing for bias

The final number of responses from the different stages was 306. Responses coming from the link that was shared were 51 but most of the questions were blank, which means that the link was open but not completed. Link answers that were usable were 17. Regarding the e-mail, the response rate was 14,27%. During the data treatment, it was possible to notice that not all answers were appropriate because the crucial part (practices and performance) wasn't complete and in total 158 answers were used from both sources.

4. RESULTS

4.1. Sample demographics and descriptive statistics

The sector was evaluated through CAE sector C that has 24 options starting in 10 and going until 33, the full results can be seen in APPENDIX B . 10,2% was food industry, 8,8% manufacture of metal products and 16,8% other transforming industries. The sample is in line with the reality because in 2019, the 4 biggest industries in Portugal were the food industry (13,9%), clothing industry (12,7%), Manufacture industry of metal products other than machinery and equipment (17,3%) and other industries (17,1%) (*PORDATA - Empresas No Sector Da Indústria Transformadora: Total e Por Tipo*, (n.d.)).

The company size was measure through the number of collaborators, 39,2% has between 10 to 49 employees and 31% from 50 to 249 employees, which means that most of the respondents were small medium enterprises (SMEs). In Portugal, 96,1% of the manufacturing industry has less than 49 employees (INE, (2020)).

The business production strategy was investigated through a question in which the respondent had to choose the option that best defined the company strategy following Maganha et al., (2020). Companies that respect the make to stock strategy, meant that the respondent selected the option "*The products are dispatched immediately after receiving the customer's order*" which were 13.9%. Assembly to order, meant "*The assembly operations only take place after receiving the customer's order*" corresponding to 8.8%. Make to order meant "*The manufacturing operations only start after receiving the customer's order*" represents 35.8%. Lastly, engineer to order was 26.3% which meant "*Your products are designed and manufactured after receiving the customer's order*". Leading to the conclusion that the companies from the sample mostly follow a make to order strategy.

The most frequent respondents had the job title of Production managers 22,2% or General manager 20,3% which it's possible to conclude that they have a good overview of the practices that are implemented. The results can be seen in the Table 6.

The respondents were asked about the company's position within the supply chain, most of the sample were OEM (manufacturer or assembler of final product) representing 56.3%. Component's suppliers were 20,3%, raw material suppliers were 3.8%, and 3.8% were distributers/retailers.

Regarding supply chain characteristics, the majority agrees that the demand fluctuation and technical modifications of products occurs on a weekly basis as well as volume fluctuation, changes in product mix and variation in supply requirements. Modifications to parts/components is less frequent as seen in Table 7.

Table 6. Sample demographics

Colaborators	**Frequency**	**%**
<10	6	3,8
10-49	62	39,2
50-249	49	31,0
250-499	7	4,4
>500	9	5,7
Missing	25	15,8
Total	158	100,0
Production Strategy	**Frequency**	**%**
Make To Stock	22	13,9
Assembly To Order	15	9,5
Make To Order	57	36,1
Engineer To Order	39	24,7
Missing	25	15,8
Total	158	100,0
Respondent's function	**Frequency**	**%**
General Manager	32	20,3
Production Manager	35	22,2
Quality Manager	7	4,4
Process Or Industrial Engineer	11	7,0
Maintenance Manager	13	8,2
Industrial Manager	2	1,3
Comercial	5	3,2
Technical Manager	3	1,9
Administrator	12	7,6
Health And Safety Manager	3	1,9
Marketing	1	0,6
Financial Manager	2	1,3
Logistics	1	0,6
Missing	30	19,0
Total	158	100,0
Company's position in SC	**Frequency**	**%**
Raw Material Suppliers	6	3,8
Components Suppliers	32	20,3
OEM	89	56,3
Distributers/retailers	6	3,8
Missing	26	16,4
Total	158	100,0

Table 7. Supply chain characteristics

	Mean	SD
Demand fluctuation	3,87	1,743
Volume fluctuation	3,56	1,592
Changes in product mix	3,71	1,786
Variations in supply requirements	3,56	1,649
Technical modifications of products	3,92	1,801
Modifications to parts/components (by suppliers)	2,83	1,584

In the APPENDIX C ,it's possible to see the means and standard deviation from all questions related with the Lean and Green Practices. Since this is a study with an exploratory character, the next step will be an Exploratory analysis in order to understand if the questions can be grouped into practices as they are presented in the literature. Reinforcing that the data results are the direct translation of the companies' self-perception of Lean and Green activities.

4.2. Exploratory factor analysis

Exploratory Factor Analysis is a statistic tool that examines the pairwise relationships between individual variables, in this case questions, detailing factors that can be extracted from the variables (Osborne et al., (2011)). An Exploratory Factor Analysis was performed, in order to identify which constructs were significant in the eyes of the Portuguese companies. The results of the EFA provided a Kaiser-Meyer-Olkin (KMO) of 0,878 with 14 constructs. If KMO>= 0.7, the sample is adequate. Bartlett test also rejects the hypothesis, which means, the factors are related. Nevertheless, an additional analysis was performed in order to remove inconsistencies and constructs that were not strongly sufficient. Resulting in 10 constructs which can be seen in Table 8 with each component evaluated and respective factor loading (only coefficients above 0,1 are displayed). The majority of the constructs stayed the same: SPC, CUSTINV, HRM, TPM, ECOD, EMS and FONT. SUPPFEED, PULL and FLOW and SMED were altered. SUPPDEVT and SUPPJIT were eliminated due to low values that did not group, this means that the companies from the sample do not recognize these practices enough. In SUPPFEED, one measure was eliminated because it also had a low relationship (<0,38) and the same with one PULL measure <0,35. FLOW and SMED were combined, with the exception of one component of SMED. They are now classified by PRODELEMNT production elements because the questions were related with products and equipment.

Table 8. Factor loadings from the rotated component matrix

	1	2	3	4	5	6	7	8	9	10
SPC2	0,766	0,237	0,183	0,177	0,117		0,181	0,101		
SPC1	0,713	0,172	0,156	0,176	0,226	0,208	0,126	0,150		
SPC4	0,687	0,186	0,247		0,153		0,203		0,231	
SPC3	0,677	0,222	0,236	0,130	0,203		0,210			
SPC5	0,611	0,149	0,271	0,244	0,169	0,141		0,139	0,179	0,124
CUSTINV4	0,191	0,805	0,202	0,172			0,155			0,172
CUSTINV5	0,213	0,796	0,200	0,129			0,138			0,183
CUSTINV2		0,732				0,172		0,114		
CUSTINV6	0,321	0,629	0,185	0,138						0,115
CUSTINV1		0,582	0,143	0,218	0,303	0,251		0,238		-0,181
CUSTINV3	0,149	0,574		0,253	0,374	0,256				
CUSTINV7	0,226	0,339	0,157		0,307					
HRM2	0,217	0,197	0,840	0,133	0,153	0,111	0,127	0,119		0,121
HRM3	0,137	0,160	0,834	0,198	0,124	0,142				
HRM1	0,224	0,101	0,793	0,135	0,263	0,199		0,192		
HRM4	0,417	0,115	0,654	0,155	0,180		0,129		0,223	
SMED4	0,139		0,203	0,260		0,284		0,140	0,188	
FLOW2	0,161	0,193	0,126	0,805				0,109	0,107	
FLOW1	0,123	0,189	0,219	0,747	0,170					0,156
FLOW3	0,176	0,144	0,214	0,730			0,129		0,127	0,211
FLOW4	0,159	0,315	0,117	0,633			0,127			0,134
FLOW5				0,511	-0,108	0,183	0,240	0,154		0,150
SMED2	0,356		0,224	0,449	0,371	0,105			0,335	
SMED1	0,391		0,213	0,440	0,338		0,105		0,407	
SMED3	0,214		0,283	0,181		0,250	0,165	-0,185	0,404	
TPM3	0,221		0,120		0,783	0,243	0,156	0,217		
TPM2	0,176		0,188	0,124	0,759	0,167	0,125	0,154		0,184
TPM4			0,217		0,688		0,208		0,104	
TPM1	0,266			0,173	0,573	0,126		0,215		0,147
SUPPFEED1					0,103	0,843				
SUPPFEED5	0,123		0,210	0,139	0,169	0,752		0,116		
SUPPFEED4		0,241	0,111	0,272	0,156	0,707			0,102	0,141
SUPPFEED2		0,234		-0,128	0,102	0,653				0,187
SUPPFEED3	0,242	0,233	0,128			0,373			0,294	
ECOD3	0,151	0,153		0,102	0,146	0,104	0,837			
ECOD2	0,229					0,110	0,773	0,186		
ECOD4	0,108		0,126	0,211	0,239	0,101	0,737		0,202	
ECOD1	0,396	0,254			0,149	-0,123	0,543	0,160	0,151	
EMS2	0,188	0,163	0,201		0,268		0,114	0,728	0,151	
EMS1						0,104	0,208	0,697	-0,117	-0,104
EMS3	0,331		0,156	0,246	0,379			0,563	0,145	
FONT3	0,114				0,109	0,207		0,662	0,321	0,117
FONT2	0,213			0,109		0,180	0,198	0,208	0,749	
FONT1		0,127	0,334		0,274		0,236	0,123	0,630	
PULL1			0,125	0,208	0,104	0,106				0,790
PULL2	0,140	0,165		0,239	0,149				0,122	0,748
PULL3	0,341	0,275	0,171	0,254	0,148		0,208			0,287

4.3. Reliability and validity analysis

To trust the data received, the way of measuring it needs to be valid and reliable. Ensuring validity ensures accuracy of the measure, in the sense that the measures are measuring what was originally planned, and reliability reflects the extent of the consistency of the results if performed repeatedly. The construct validity was proven by the exploratory factor analysis. Factors that had low levels of correlation within the constructs were ignored, the KMO is higher than 0,7, implying that the sample is adequate, and the Bartlett test confirms that the factors are related.

The reliability in terms of internal consistency was evaluated through Cronbach's alpha, and the validity is through the correlation coefficient. The Cronbach's alpha for each individual set of questions retrieved from the EFA can be seen in the Table 9. It's considered acceptable if above >0,7 for exploratory research (Nunnally & Nunnaly, (1978)). The only value not achieving this criterion was FONT but, since the value was very close and it accessed important measures, it was considered ok to use.

Table 9. Practices with mean, standard deviation, Cronbach alpha

	Mean	S.D.	α
SPC	3,2234	1,7160	0,899
CUSTINV	5,2018	1,1437	0,847
HRM	4,2419	1,6473	0,930
PRODELEMNT	4,9894	1,2506	0,874
TPM	4,7776	1,4554	0,846
SUPPFEED	5,5983	1,0028	0,817
ECOD	3,3810	1,6977	0,854
EMS	5,8828	1,0430	0,758
FONT	4,4529	1,2487	0,677
PULL	4,6282	1,5587	0,746

Looking closely at Table 9, it's possible to see that the practices with higher means are customer involvement, supplier feedback and environmental management systems this leads to the conclusion that those practices are the most adopted being in the medium-high range. The practices that are least adopted with low implementation means are statistical process control and eco-design. Through the standard deviation, the practices that are most disperse in terms of implementation in the industry are statistical process control, human resources management and eco-design. Finally, the Cronbach alpha shows that the items that compose HRM, SPC, PRODELEMNT, CUSTINV are closely related making the argument that they are well defined and understood in the industry. These results are not descriptive enough of the manufacturing paradigm in study; therefore, there is a need to take another approach to categorize the industry.

4.4. Cluster analysis

In the literature, cluster analysis is used with the aim of grouping entities into exclusive subgroups based on the similar criteria (Forza, (2009)). Within this research, the goal was to identify homogenous groups of companies based on their response of the level of implementation of Lean and Green practices, in order to understand if there was a group of companies whose combination of practices could be translated into a better performance. Studies that have follow this approach are Maganha et al., (2020); Nordin et al., (2010); Valente et al., (2020).

The constructs that entered the cluster analysis were the ones retrieved from the EFA which were valid and reliable. Clustering literature is extensive in the field of operations management and the most popular methods are the Ward's hierarchical method and the K-means non-hierarchical method (Brusco et al., (2017)).The two-step approach includes both and has a first pre-cluster phase that creates small sub-clusters, proceeding to cluster the sub-clusters. This approach was used to find the number and clusters that were representative of Portuguese manufacturing companies. The software used was SPSS which automatically calculates and defines the number of clusters. The cluster criterion Schwarz's Bayesian Criterion (BIC) which estimates the number of clusters, and in a follow-up step redefines them based on the distances increases of the closest two clusters. The distance measure used was log-likelihood which is a probability-based distance.

Table 10. Clusters

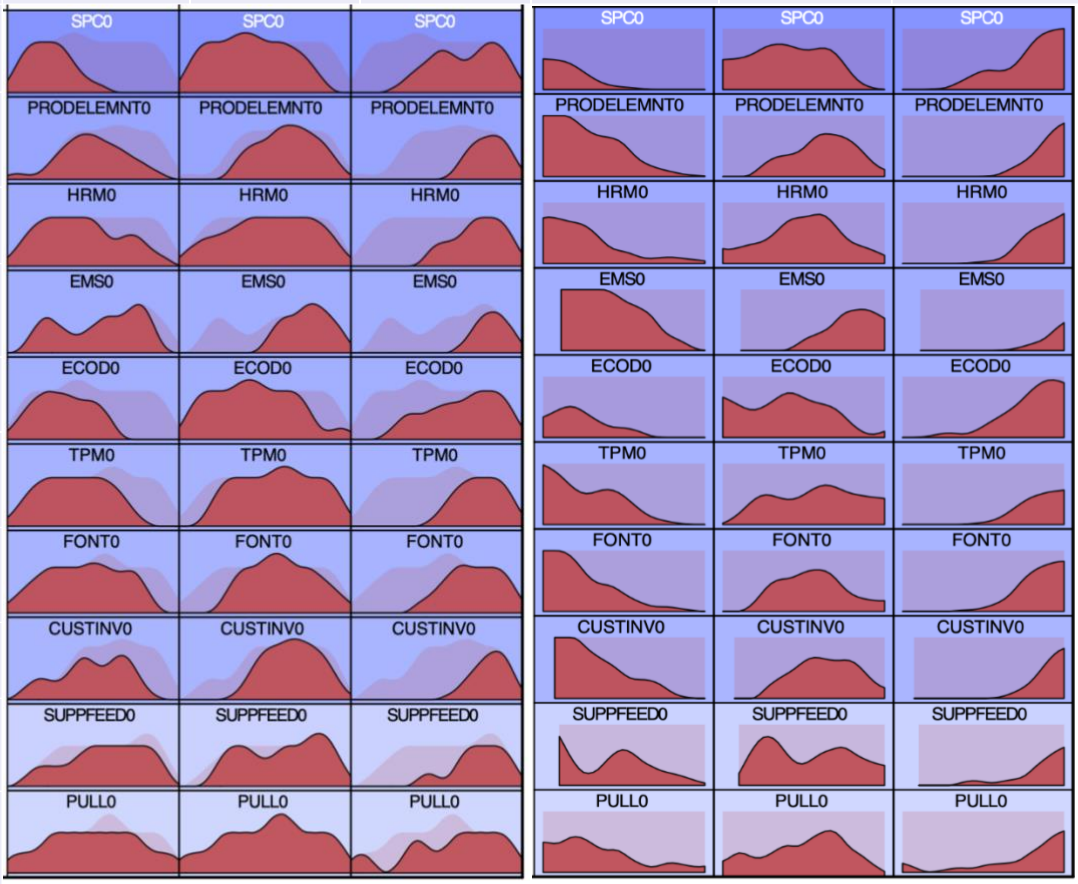
	Cluster 1		**Cluster 2**		**Cluster 3**	
Companies	42	26.6%	80	50.6%	36	22.8%

The cluster analysis produced three clusters, as seen in Table 10. The allocation of companies in each cluster appoints to the cluster 2 being the most predominant as by self-assess of most of Portuguese manufacturing companies. In the

Table 11, variables are ordered from most to least importance in the clustering process and with the respective relevance. The graphs show the distribution from each construct in the cluster, in relation to the sample. In the first way, the cells distribution is in frequency to Likert scale and in the second set of graphs, the cells distribution is in percentage to Likert scale. Through the graphs, it's possible to clarify the differences between clusters. The first conclusions from the graphs are: the predominance of higher answers in Likert scale in the third cluster, lower in the first cluster and medium in the second cluster. This will be proven in upcoming analysis.

Table 11. Construct's importance into clustering and the distribution of the results from cluster to sample

		Cell distribution from frequency to Likert scale			Cell distribution from percentage to Likert scale		
		Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
SPC	1						
PRODELEMN	0,8						
HRM	0,73						
EMS	0,71						
ECOD	0,69						
TPM	0,65						
FONT	0,64						
CUSTINV	0,62						
SUPPFEED	0,3						
PULL	0,23						



Looking at the means and standard deviation from each Lean Practices and Green Practices in each cluster, there are 3 cluster ranging for 1-low implementation, 2-medium implementation and 3-high implementation practices. This is verified in each practice in comparison to each cluster, confirming that in each practice in cluster 1 has a lower mean than the same practice in cluster 2 that also has a lower mean than the cluster 3, as seen in Table 12. To ensure that this interpretation was correct and that clusters differ from each other, further comparison analysis and post hoc tests were in need to be performed.

Firstly, there was a need to know if variables were normally distributed in regard to population. For that, Shapiro-Wilk test was performed for each question rejecting the null hypothesis for 5% significance level, which meant that the variables were not normally distributed. Therefore, constructs will be evaluated through non-parametric tests, Kruskal-Wallis test. In the Kruskal-Wallis test, the null hypothesis states that the population medians are equal. The test was performed using SPSS which provides a Bonferroni correction automatically, this correction prevents Type I errors, errors that can be commonly called false-positive result, it divides the number the significance level (α) by the number of tests (k), α/k. The test was performed with a significance level of 0,05. If $p<0,05$ it means that we reject the null hypothesis and that the clusters differ.

For the Lean Practices, the results reveal that all variables except SUPPFEED and PULL were different across all clusters. In the case of SUPPFEED, the cluster 1 and the cluster 2 have a p-value of 0,07, which means that in these clusters, the median is not statistically significant, therefore the clusters are considered equal in terms of supplier feedback characteristics and the cluster 3 stands out in this construct. In the case of PULL, the cluster 1 and the cluster 2 have a $p=0,117$, which means that in these clusters, the median is not statistically significant, therefore the clusters are considered equal in terms of Pull production characteristics and the cluster 3 stands out in this construct.

Concerning Green Practices, the Kruskal-Wallis test disclosed that all practices reject the null hypothesis of having equal medians, which means that all clusters differ. Nevertheless, and even though the Kruskal-Wallis did not recognize the difference between clusters, by looking at the means, it’s possible to notice that in EMS the cluster 2 and 3 have very close means. This reveals 1. The failure of KW test because non-parametric tend to be less powerful and 2. The implementation of environmental management systems is high in cluster 2 and 3. Regardless, the Kruskal Wallis result is the reference for analysis.

Table 12. Clusters with variable's means and standard deviation

LEAN PRACTICES	1 - LI		2 - MI		3 - HI	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*	*Mean*	*Std. Deviation*
SPC0	1,757	0,770	3,006	1,259	5,417	1,140
CUSTINV0	4,218	1,115	5,218	0,856	6,313	0,568
HRM0	2,857	1,447	4,153	1,229	6,056	0,779
FLOWSMED0	3,815	1,125	5,006	0,879	6,323	0,553
TPM0	3,429	1,147	4,883	1,227	6,118	0,713
SUPPFEED0	5,095	0,930	5,494	0,964	6,417	0,618
PULL0	3,869	1,601	4,528	1,350	5,736	1,344
GREEN PRACTICES	**1 - LI**		**2 - MI**		**3 - HI**	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*	*Mean*	*Std. Deviation*
ECOD0	2,185	1,054	3,126	1,380	5,344	1,226
EMS0	4,796	1,106	6,073	0,669	6,728	0,448
FONT0	3,363	1,220	4,473	0,880	5,679	0,726

Looking at Table 13 it's possible to see that there is an interval of degree of implementation that serves as a "jump" between clusters. For example, a company with SPC <1,8 implementation is considered cluster 1-LI but if that value is above >3, it is considered cluster 2-MI. This interval comes from the average of the answers but in the questionnaire is only possible to answer in Likert scale which is being evaluated as in the Table 14.

Table 13. Requirements of answers to be in each cluster

LEAN PRACTICES	answers to be in 1st cluster	1 - LI	asnwer to jump clusters	2 - MI	asnwer to jump clusters	3 - LI
SPC0	<1	LW	2 or 3	L	>3	MH
CUSTINV0	<4	M	4 or 5	MH	>5	H
HRM0	<2	LB	3 or 4	M	>4	H
FLOWSMED0	<3	L	4 or 5	MH	>5	H
TPM0	<3	L	3 or 4	M	>4	H
SUPPFEED0	<5	MH	none	MH	>5	H
PULL0	<3	L	none	M	>4	MH
LEAN PRACTICES						
ECOD0	<2	LB	2 or 3	L	>3	MH
EMS0	<4	M	4,5 or 6	H	>6	H
FONT0	<3	L	3 or 4	M	>4	MH

LW: low-worst; LB: low-bad; L: low; M: medium; MH: medium-high; H: high; HP: high-perfect

Table 14. Likert scale evaluation

1	2	3	4	5	6	7
not considering or planning practice	*Planning*	*Started implementing*	*Half implemented*	*Fully implemented*	*Implemented and rectified*	*practice currently implemented and industry leader*
Low-worst	**Low-bad**	**Low**	**Medium**	**Medium-high**	**High**	**High-perfect**
Strongly disagree	*Disagree*	*Disagree slightly*	*Dont agree or disagree*	*Agree slightly*	*Agree*	*Strongly agree*

4.4.1. Cluster characterization

The first cluster is named "Companies with Low Degree of Implementation of Lean and Green Practices"- Low Implementation (LI). This cluster is composed of 42 manufacturing companies, 27% are other transforming industries. Most of the companies in the cluster follow make to order (41%) and engineer to order strategy (41%). In relation with company's size, 51% have 10-49 followed by 50-249 with 30% of employees. The position in the supply chain is mostly OEM with 76%. Concerning the Lean Practices, LI has a low implementation of statistical process control, human resource management and total productive/preventive management. With medium customer involvement, production elements, supplier feedback and pull production. Whereas, Green Practices it has a low implementation of eco-design practices and source-reduction and has environmental management systems mediumly implemented.

The second cluster is named "Companies with Medium Degree of Implementation of Lean and Green Practices" – Medium Implementation (MI). This cluster is composed of 80 manufacturing companies,20% is food industry and 20% other transforming industries. The MI cluster mostly follows a make to order production system (42,19%), followed by engineer to order (25%) and make to stock (18,75%). In relation with company's size, 52% have 10-49 followed by 50-249 with 38% of employees. The position in the supply chain is mostly OEM with 72%. Concerning the Lean Practices, MI has a low implementation of statistical process control. With medium human resource management, customer involvement, production elements, total productive/preventive management, supplier feedback and pull production. Whereas, Green Practices it has a low implementation of eco-design practices, and medium in source-reduction and high in environmental management systems.

The third cluster is named "Companies with High Degree of Implementation of Lean and Green Practices" – High Implementation (HI). This cluster is composed of 36 manufacturing companies, 19% is metallic products with the exception of machinery. The HI cluster mostly follows a make to order production system (46,88%) followed by engineer to order (25%). In relation with company's size, 44% have 50-249 followed by 10-49 with 31% of employees. The position in the supply chain is OEM with 47% and 38% component supplier. Concerning the Lean Practices, HI has medium-high statistical process control and pull production. It performs high in customer involvement, human resource management, production elements, total productive/preventive management and supplier feedback. Whereas, Green Practices it has a medium-high implementation of eco-design practices and source-reduction while performing high in environmental management systems.

Table 15. Descriptive elements of each cluster

PRODUCTION SYSTEM	1		2		3	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*
MAKE TO STOCK	5	13,51%	12	18,75%	5	15,63%
ASSEMBLY TO ORDER	2	5,41%	9	14,06%	4	12,50%
MAKE TO ORDER	15	40,54%	27	42,19%	15	46,88%
ENGINEER TO ORDER	15	40,54%	16	25,00%	8	25,00%
TOTAL	37	100,00%	64	100,00%	32	100,00%
SIZE	1 - LI		2 - MI		3 - HI	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*
<10	3	8,11%	3	4,69%	0	0,00%
10-49	19	51,35%	33	51,56%	10	31,25%
50-249	11	29,73%	24	37,50%	14	43,75%
250-499	3	8,11%	2	3,13%	2	6,25%
>500	1	2,70%	2	3,13%	6	18,75%
TOTAL	37	100,00%	64	100,00%	32	100,00%
SC POSITION	1		2		3	
	Frequency	*%*	*Frequency*	*%*	*Frequency*	*%*
RAW MATERIAL SUPPLIER	0	0,00%	4	6,25%	2	6,25%
COMPONENTS SUPPLIER	8	21,62%	12	18,75%	12	37,50%
OEM	28	75,68%	46	71,88%	15	46,88%
DISTRIBUTER/RETAILER	1	2,70%	2	3,13%	3	9,38%
TOTAL	37	100,00%	64	100,00%	32	100,00%
SC CHARACTERISTICS	1 - LI		2 - MI		3 - HI	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*	*Mean*	*Std. Deviation*
Demand fluctuation	4,000	1,780	3,875	1,548	3,719	2,083
Volume fluctuation	3,784	1,601	3,531	1,425	3,375	1,897
Changes in product mix	4,027	1,641	3,438	1,717	3,906	2,038
Variations in supply requirements	3,838	1,537	3,359	1,547	3,625	1,947
Technical modifications of products	4,000	1,716	3,625	1,750	4,406	1,932
Modifications to parts/components (by suppliers)	2,865	1,549	2,750	1,533	2,938	1,759

4.4.2. Relationship with performance

To connect the implementation of the different practices to achievable results, the performance indicators that were assessed in the questionnaire will be used. There were in total 16 variables that were inquired in comparison to competitors, those fell under three categories: Operational Performance, Environmental Performance and Financial Performance. Each construct was combined with the respective parameters and analyzed in comparison with the clusters through Kruskal-Wallis test as seen in Table 16.

Concerning operational performance, Kruskal-Wallis test verified that the operational performance of cluster LI and cluster MI is equal, which means that cluster HI has a better operational performance. With respect to financial performance of cluster LI and cluster MI is equal, which means that HI has a better financial performance. Lastly, Environmental performance in Kruskal-Wallis did not revealed that cluster LI, MI and HI have an equal performance but, looking directly at the means, it's possible to see that the means are not very different. This is probably a failure of the KW test non-parametric since it is less powerful. Regardless, the Kruskal Wallis result is the reference for analysis.

Implication of these results are that performances from the LI and MI do not see significant results in comparison with high implementing practices, HI. Leading to the belief that the results appear when practices are highly implemented. The LI and MI clusters are already performing well when it comes to self-perception in comparison with their competitors.

Table 16. Clusters and performance

PERFORMANCE	1 - LI		2 - MI		3 - HI	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*	*Mean*	*Std. Deviation*
OPERATIONAL	4,391	0,803	4,753	0,594	5,290	0,941
ENVIRONMENTAL	4,431	0,936	4,989	0,940	5,556	1,343
FINANCIAL	4,578	1,125	4,822	0,898	5,442	1,005

In order to further examinate the implications of practices on performance the statistical method of regression analysis was used. With the regression analysis in the Table 17, the goal is to understand the influence of independent variables, the practices, in the dependent variables, operational performance, environmental performance and financial performance. The ANOVA, Table 18, confirmed that the set of independent variables was significantly related to the dependent variable in the significance level of 0,05. Evaluating the coefficients, Table 19, if the null hypothesis was rejected, it means that there is a nonzero (positive) association between the respective practice (independent variable) and the performance (dependent variable). The regression analysis coefficients showed that with the dependent variable of operational performance, the practices that revealed this relationship PRODELEMNT, TPM and ECOD. In the case of the dependent variable of environmental performance, none of the practices revealed significant relationship at 0,05 level. Finally, with the dependent variable of financial performance the practices that most contribute are CUSTINV, PRODELEMNT and PULL. The verification of the results of the Durbin-Watson test, Table 17, for autocorrelation revealed that for COP there is a negative autocorrelation (2.466) while in CEP (1.932) and CFP (1.976) indicates a positive autocorrelation, passing the rule of thumb that says that values between 1.5 to 2.5 are relatively normal. Analyzing the collinearity values, Table 19, the VIF values were between 1,353 to 2,493. The rule says that 1 means no collinearity until 5 indicates moderate and above high collinearity. Overall, this proves that the variables are indeed independent.

Table 17. Regression Models for COP, CEP and CFP

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
COP	.521[a]	0,272	0,222	0,708	0,272	5,484	10	147	0,000	2,466
CEP	.452[a]	0,204	0,150	1,024	0,204	3,777	10	147	0,000	1,932
CFP	.510[a]	0,260	0,210	0,915	0,260	5,168	10	147	0,000	1,976

a. Predictors: (Constant), PULL0, EMS0, SUPPFEED0, ECOD0, HRM0, CUSTINV0, FONT0, TPM0, PRODELEMNT0, SPC0

Table 18. ANOVA for the regression analysis of COP, CEP and CFP

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
COP	*Regression*	27,476	10,000	2,747	5,484	.000[b]
	Residual	73,647	147,000	0,501		
	Total	101,123	157,000			
CEP	*Regression*	39,578	10,000	3,958	3,777	.000[b]
	Residual	154,016	147,000	1,047		
	Total	193,593	157,000			
CFP	*Regression*	43,290	10,000	4,329	5,168	.000[b]
	Residual	123,133	147,000	0,838		
	Total	166,424	157,000			

b. Predictors: (Constant), PULL0, EMS0, SUPPFEED0, ECOD0, HRM0, CUSTINV0, FONT0, TPM0, PRODELEMNT0, SPC0

Table 19. Coefficients from regression analysis for COP, CEP and CFP

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
COP	*(Constant)*	3,961	0,448		8,843	0,000		
	SPC0	0,020	0,052	0,043	0,386	0,700	0,401	2,493
	CUSTINV0	-0,027	0,067	-0,039	-0,412	0,681	0,548	1,825
	HRM0	0,078	0,049	0,159	1,584	0,115	0,490	2,042
	PRODELEMNT0	0,137	0,067	0,213	2,032	**0,044**	0,451	2,218
	TPM0	0,106	0,054	0,193	1,977	**0,050**	0,519	1,926
	SUPPFEED0	-0,048	0,067	-0,060	-0,720	0,472	0,711	1,407
	ECOD0	0,116	0,043	0,246	2,681	**0,008**	0,587	1,702
	EMS0	-0,081	0,072	-0,105	-1,130	0,260	0,571	1,752
	FONT0	0,007	0,059	0,010	0,111	0,912	0,579	1,729
	PULL0	-0,065	0,042	-0,126	-1,542	0,125	0,739	1,353
CEP	*(Constant)*	3,554	0,648		5,486	0,000		
	SPC0	0,104	0,075	0,161	1,385	0,168	0,401	2,493
	CUSTINV0	-0,070	0,096	-0,072	-0,726	0,469	0,548	1,825
	HRM0	0,081	0,071	0,121	1,150	0,252	0,490	2,042
	PRODELEMNT0	0,071	0,097	0,080	0,729	0,467	0,451	2,218
	TPM0	0,034	0,078	0,045	0,437	0,663	0,519	1,926
	SUPPFEED0	-0,027	0,097	-0,024	-0,281	0,779	0,711	1,407
	ECOD0	0,085	0,063	0,129	1,347	0,180	0,587	1,702
	EMS0	0,087	0,104	0,082	0,837	0,404	0,571	1,752
	FONT0	0,074	0,086	0,083	0,860	0,391	0,579	1,729
	PULL0	-0,084	0,061	-0,119	-1,386	0,168	0,739	1,353
CFP	*(Constant)*	3,081	0,579		5,319	0,000		
	SPC0	-0,004	0,067	-0,006	-0,056	0,956	0,401	2,493
	CUSTINV0	0,230	0,086	0,256	2,669	**0,008**	0,548	1,825
	HRM0	-0,008	0,063	-0,013	-0,124	0,901	0,490	2,042
	PRODELEMNT0	0,184	0,087	0,223	2,114	**0,036**	0,451	2,218
	TPM0	-0,063	0,070	-0,090	-0,911	0,364	0,519	1,926
	SUPPFEED0	-0,013	0,086	-0,013	-0,156	0,877	0,711	1,407
	ECOD0	0,095	0,056	0,157	1,701	0,091	0,587	1,702
	EMS0	0,082	0,093	0,083	0,886	0,377	0,571	1,752
	FONT0	0,067	0,077	0,082	0,877	0,382	0,579	1,729
	PULL0	-0,212	0,055	-0,321	-3,885	**0,000**	0,739	1,353

4.5. Discussion of results and implication

The Exploratory Factor Analysis exposed 14 constructs, 10 of which had acceptable values. This reveals that 7 Lean practices are well understood (SPC, CUSTINV, HRM, PRODELEMNT, TPM, SUPPFEED and PULL) and 3 Green practices also (ECOD, FONT, EMS). Unlike the literature suggested, SUPPJIT and SUPPDEVT did not group. This is relevant because it divulges the need for focusing on supply chain green practices in the country. Some Lean and Green supply chain practices that are in line with the questionnaire could be: the use of green purchasing guidelines and sourcing from environmentally responsible sources, *just-in-sequence*, deliveries directly to the point of use, geographical concentration and single sourcing (Azevedo et al., (2012)).

Accordingly, to the achieved results from the cluster analysis, it's possible to say that the sample can be characterized in 3 clusters that are 1. Companies With Low Degree of Implementation of Lean and Green Practices – Low Implementation (LI) 2. Companies With Medium Degree of Implementation of Lean and Green Practices – Medium Implementation (MI) And 3. Companies With High Degree of Implementation of Lean and Green Practices – High Implementation (HI). The degree of implementation increases across the different practices, as seen in Figure 8.

Firstly, since cluster MI, Companies with Medium Degree of Implementation of Lean and Green Practices, is the biggest cluster (50,6% of companies) it means that most Portuguese manufacturing companies self-assess falling in the cluster of medium implemented Lean and Green practices. Regarding supply chain characteristics, supply chain position and production system, the answers of the companies are not statistically significant, meaning that they don't differ and that the clusters are uniformed in those characteristics and in the sample of Portuguese companies.

Likewise, in company size, the sample appoints for equal distribution, meaning that most of the respondents fall under the category of SMEs. In Portugal, most of the companies are SMEs. SMEs have respective implementation problems that can influence the integration of Lean and Green practices as mentioned in the study of Siegel et al., (2019): manpower constraints, financial constraints, poor management and leadership, lack of strategy, resistance and project selection. Silva et al., (2010) who compared the level of implementation of Lean in Portugal, Italy, UK and USA, stated that the Portuguese industry suffered from resource sharing with other projects, lack of senior management commitment and attitude of shop floor staff.

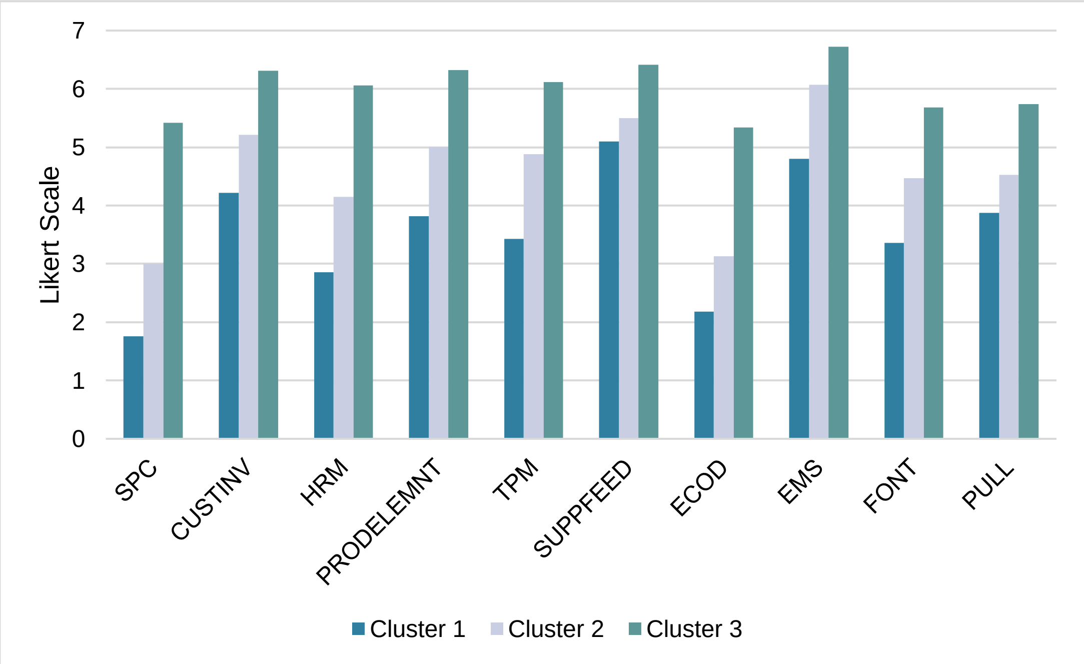


Figure 8. Cluster with each construct within scale

The lower scores in the first cluster (LI) give direction in the improvement of these practices. The practices with worst implementation answers, under Likert scale 2, are the answers in the questions of SPC and HRM and ECOD. Statistical process control questions inquire about the extent of the equipment and process that follow this practice, the extent of the use of this practice to reduce process variance, the use of charts and fishbone type diagrams and process capability studies before launching new products. Human resource management requests the shop-floor employees' proactivity in problem-solving and improvements. Eco-design requires an integrated approach from manufacturing design in order to ease the ecological implications. Equally, the lower scores in MI provide directions for improvement of these practices, which were similarly Eco-design and statistical process control.

Additionally, looking at Table 13. Requirements of answers to be in each cluster, it's possible to advise companies that self-assessed as being in the LI cluster that they should invest in improving SPC, HRM and ECOD since they perform low specifically low in these constructs. In the study of Cherrafi, Elfezazi, Garza-Reyes, et al., (2017), poor quality of human resources, lack of visual and statistical control during Green Lean implementation was identified as a barrier and it's confirmed since the limited implementation of LI cluster which performs worse in levels of implementation of overall Lean Green practices. They also refer fund constraints and lack of expertise which could explain the eco-design level. In contrast, one of the crucial players in the implementation of practices are the collaborators and, in the sample, the best implementation and performing cluster has a mean of 6,049/7 with 7 representing practice currently implemented and industry leader.

Furthermore, the results show that when there is a higher implementation of Lean and Green practices there is higher verified performance. But the performance results in the case of operational and financial performance only appear if Lean and Green are highly integrated in the company. This is in line with the literature that has been preaching those results are observed when there is a higher return, such as in the studies of Nawanir et al., (2013); Negrão et al., (2020).

At the same time, the regression analysis revealed that from the sample, the practices that affect the performance are only a few. This is in line with the study from Gonçalves et al., (2019) which concluded that not all Lean practices influence performance outcomes. PRODELEMNT influences both operational and financial performance, this is expected since this construct includes FLOW and SMED characteristics. Additionally, operational performance is notably influenced by TPM and ECOD. Whereas CUSTINV and PULL influence financial performance. The results are in line with the studies of Gonçalves et al., (2019), Chiarini, (2014) and Green et al., (2012). The regression analysis did not clarify the interference off all constructs in the relationship, for this a further Fuzzy-set qualitative comparative analysis would be most appropriate.

Finally, and noteworthy, the level of Green Practices implementation, mostly EMS is high, but this construct does not reveal himself in the regression analysis. One explanation for this would be that employing environmental management systems is complying with regulations rather than a deliberated strategy for improving environmental performance.

5. CONCLUSION

The objective of this study was to provide a better understanding of Lean and Green practices in Portuguese manufacturing companies in relation to performance.

This research counted with a sample of 158 answers from the manufacturing industry which asked about the implementation of Lean and Green practices. The data was used to confirmed that practices could represent a construct, and this was performed through an Exploratory Factor Analysis. It resulted in 10 constructs evaluating 7 Lean elements and 3 Green elements. A Cluster Analysis followed to group the sample into 3 different types of companies: LI – low implementation, MI– medium implementation and HI – high implementation of Lean and Green practices. Most Portuguese companies assess as being in MI cluster and, overall, the least practices implemented are statistical process control and eco-design.

The results of the study allow concluding that wider implementation of practices results in a better performance. However, operational and financial performances results are only revealed from MI to HI cluster while environmental performance results grow with implementation. Through regression analysis, the most prominent practices that affect each performance are revealed. In the case of operational performance, the practices are PRODELEMNT, TPM and ECOD. While in financial performance it is PRODELEMNT, CUSTINV and PULL. Lastly, for environmental performance results, none of the practices reveal as causing effects.

Contributions from the research come from the understanding of how many Lean and Green practices are implemented and to which degree they result in performance improvements. Providing insights into which practices companies should invest in and guarantee that the broader implementation will translate in desired performance. Companies can use this study along with the self-assessment model from Cherrafi et al., (2021), which helps companies to understand their readiness for Lean Green implementation initiatives.

Study limitations are the sample size and distribution because it was only targeted at manufacturing companies operating in Portugal. The results are influenced by the greater percentage of SMEs answers, which was already expected since SMEs are a big part of the manufacturing companies in the country. The study is cross-sectional rather than longitudinal; therefore, it doesn’t include the time effects. Lastly, the research relies upon a company respondent perception which could cause biased answers.

Further directions can be taken from this point on:

- Fuzzy Set QCA of this sample in order to better understand how all practices relate with performances;
- A detailed study of how each lean practice combined with each green practice influences performance;
- Include the social component so it can fully evaluate sustainability.

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APPENDIX A

Lean Practices

Please assess the degree to which you have developed the following activities in your company (1= not considering or planning practice… 7= practice currently implemented and industry leader)		
Lean practice	*Lean practice Lean operating element*	*code*
Supplier feedback (SUPPFEED)	We frequently are in close contact with our suppliers	SUPPFEED1
	Our suppliers frequently visit our plants	SUPPFEED2
	We frequently visit our supplier's plants	SUPPFEED3
	We give our suppliers feedback on quality and delivery performance	SUPPFEED4
	We strive to establish long-term relationship with our suppliers	SUPPFEED5
JIT delivery by suppliers (SUPPJIT)	Suppliers are directly involved in the new product development process	SUPPJIT1
	Our key suppliers deliver to plant or JIT basis	SUPPJIT2
	We have a formal supplier certification programme	SUPPJIT3
Supplier development (SUPPDEVT)	Our suppliers are contractually committed to annual cost reductions	SUPPDEVT 1
	Our key suppliers are located in close proximity to our plants	SUPPDEVT 2
	We have corporate level communication on important issues with key suppliers	SUPPDEVT 3
	We take active steps to reduce the number of suppliers in each category	SUPPDEVT 4
	Our key suppliers manage our inventory	SUPPDEVT 5
	We evaluate suppliers on the basis of total cost and not per unit price	SUPPDEVT 6
Customer involvement (CUSTINV)	We frequently are in close contact with our customer	CUSTINV1
	Our customers frequently visit our plants	CUSTINV2
	Our customers give us feedback on quality and delivery performance	CUSTINV3
	Our customers are actively involved in current and future product offerings	CUSTINV4
	Our customers are directly involved in current and future product offerings	CUSTINV5
	Our customers frequently share current and future demand information with marketing department	CUSTINV6
	We regularly conduct customer satisfaction surveys	CUSTINV7
Pull (PULL)	Production is "pulled" by the shipment of finished goods	PULL1

	Production at stations is "pulled" by the current demand of the next station	PULL2
	We use a *kanban*, squares, or containers of signals for production control	PULL3
Continuous flow (FLOW)	Products are classified into groups with similar processing requirements	FLOW1
	Products are classified into groups with similar routeing requirements	FLOW2
	Equipment is grouped to produce a continuous flow of families of products	FLOW3
	Families of products determine our factory layout	FLOW4
	Pace of production is directly linked with the rate on customer demand	FLOW5
Single minute exchange of dies (SMED)	Our employees' practices setups to reduce the time required	SMED1
	We are working to lower setup times in our plant	SMED2
	We have low setup times of equipment in our plant	SMED3
	Low supply lead times allow responding quickly to customer requests	SMED4
Statistical process control (SPC)	Large numbers of equipment/process on shop floor are currently under SPC	SPC1
	Extensive use of statistical techniques to reduce process variance	SPC2
	Charts showing defects rates are used as tools on the shop floor	SPC3
	We use fishbone type diagrams to identify causes of quality problems	SPC4
	We conduct process capability studies before launching a new product	SPC5
Human resource management (HRM)	Shop-floor employees are key to problem solving teams	HRM1
	Shop-floor employees drive suggestion programmes	HRM2
	Shop-floor employees lead product/process improvement efforts	HRM3
Total productive/preventive maintenance (TPM)	We dedicate a portion of everyday to planned equipment maintenance related activities	TPM1
	We maintain al our equipment regularly	TPM2
	We maintain excellent records of all equipment maintenance related activities	TPM3
	We post equipment maintenance records on shop floor for active sharing with employees	TPM4
Reference: Shah & Ward, (2007)		

Green Practice

Please assess the degree to which you have developed the following activities in your company (1= not considering or planning practice… 7= practice currently implemented and industry leader)		
Green practice	*Green practice or element*	*code*
Source Reduction (FONT)	Reduction in the variety of materials employed in manufacturing the company's products	FONT1
	Reduction in raw materials (i.e. the use of recycled material) to manufacture products	FONT2
	Avoidance of materials that are considered harmful, but not illegal	FONT3
Eco-design (ECOD)	Use of LCA for product design	ECOD1
	Use of easy-to-break joints between components to facilitate disassembly	ECOD2
	Clear identification of materials (colours, codes, etc.) to facilitate disassembly	ECOD3
	Use of standardized components to facilitate their use	ECOD4
Environmental Management Systems (EMS)	Recycling of solid wastes	EMS1
	Environmental management procedures for internal use	EMS2
	Use of advanced prevention and safety systems at work	EMS3
Reference: Sarkis et al., (2010)		

Performance Indicators

Please assess the following performance indicators in comparison to your main competitor(s) (1= low end of industry ... 7= Superior)		
Operational Performance (COP)	Perfect order (right product, delivered in the right quantity, on the right date, free of defects and with the correct documentation)	COP1
	Leadtime	COP2
	Levels of stocks of finished products	COP3
	Levels of raw material stocks	COP4
	Reworkrates	COP5
	Levels of inventory of materials in process	COP6
Environmental Performance (CEP)	Energy consumption	CEP1
	Reduction of air emission	CEP2
	Reduction of wastewater	CEP3
	Reduction of solid wastes	CEP4
	Decrease of consumption for hazardous/harmful/toxic materials	CEP5
	Decrease of frequency for environmental accidents	CEP6
	Improve a company's environmental situation	CEP7
Financial Performance (CFP)	Sales	CFP1
	Market share	CFP2

	Profitability	CFP3
Reference: Negrão et al., (2020); Zhu et al., (2013)		

General Information

SEC2	Select the manufacturing sector where your company operates
MARK0	years of employment of respondents
PROD0	Select the statement that best fits your production system:
	The products are dispatched immediately after receiving the customer's order
	The assembly operations only take place after receiving the customer's order
	The manufacturing operations only start after receiving the customer's order
	Your products are designed and manufactured after receiving the customer's order
TAM1	Select the size of your company (number of collaborators)
FUN3	Please specify your position in the organisation
CAD6	If one compared your firm with an automotive supply chain which of the following would be your supply chain position: (1: supplier of raw material to 4: distributer/retailer).
DEM0	To what extent do you agree with the following statements? (1= strongly disagree, 7=strongly agree).
	Your demand fluctuates drastically from week to week
	Your total manufacturing volume fluctuates drastically from week to week
	The mix of products you produce changes considerably from week to week
	Your supply requirements (volume and mix) vary drastically from week to week
	Your products are characterised by a lot of technical modifications
	Your suppliers frequently need to carry out modifications to the parts/components they deliver to your plant
Reference: Bode & Wagner, (2015); Maganha et al., (2020); Negrão et al., (2020); Wynstra et al., (2010)	

Marker questions

MARK0	I am feeling very good to have a lot of friends.
	I am a cheerful person full of energy.
	I enjoy talking with others.
MARK1	Years of employment
Reference: Gu et al., (2021); Wong, (2013)	

APPENDIX B

	Frequency	Percent
Indústria Alimentar	17	10,8
Indústria das bebidas	1	0,6
Fabricação de têxteis	10	6,3
Indústria do vestuário	5	3,2
Indústria do couro e dos produtos do couro	3	1,9
Indústria da madeira e da cortiça e suas obras, excepto mobiliário; fabricação de obras de cestaria e de espartaria	2	1,3
Impressão e reprodução de suportes gravados	2	1,3
Fabricação de coque, de produtos petrolíferos refinados e de aglomerados de combustíveis	1	0,6
Fabricação de produtos químicos e de fibras sintéticas ou artificiais, expecto produtos farmacêuticos	1	0,6
Fabricação de produtos farmacêuticos de base e de preparações farmacêuticas	2	1,3
Fabricação de artigos de borracha e de matérias plásticas	12	7,6
Fabricação de outros produtos minerais não metálicos	2	1,3
Indústrias metalúrgicas de base	10	6,3
Fabricação de produtos metálicos, excepto máquinas e equipamentos	12	7,6
Fabricação de equipamento eléctrico	1	0,6
Fabricação de máquinas e de equipamentos, n.e.	10	6,3
Fabricação de veículos automóveis, reboques, semi-reboques e componentes para veículos automóveis	6	3,8
Fabricação de outro equipamento de transporte	2	1,3
Fabricação de mobiliário e de colchões	6	3,8
Outras indústrias transformadoras	27	17,1
Total	132	83,5
Missing	26	16,5
TOTAL	158	100,0

APPENDIX C

	N	Mean	Std. Deviation
SUPPFEED1	158	5,89	1,082
SUPPFEED2	158	4,83	1,573
SUPPFEED3	158	3,35	1,690
SUPPFEED4	158	5,56	1,269
SUPPFEED5	158	6,115	0,9902
SUPPJIT1	158	4,25	1,798
SUPPJIT2	158	4,30	1,856
SUPPJIT3	158	4,22	2,170
SUPPDEVT1	158	3,00	1,868
SUPPDEVT2	158	3,59	1,806
SUPPDEVT3	158	4,25	1,730
SUPPDEVT4	158	4,23	1,656
SUPPDEVT5	158	1,82	1,363
SUPPDEVT6	158	4,089	1,8933
CUSTINV1	158	6,11	0,971
CUSTINV2	158	5,01	1,586
CUSTINV3	158	5,89	1,143
CUSTINV4	158	5,23	1,559
CUSTINV5	158	5,108	1,5458
CUSTINV6	158	4,465	1,7721
CUSTINV7	158	4,599	2,2027
PULL1	158	4,712	1,7810
PULL2	158	4,545	1,7093
PULL3	158	3,013	2,1205
FLOW1	158	5,253	1,6913
FLOW2	158	5,026	1,7665
FLOW3	158	4,896	1,8757
FLOW4	158	4,474	2,0102
FLOW5	158	5,403	1,4996
SMED1	158	4,851	1,6694
SMED2	158	4,994	1,6453
SMED3	158	4,552	1,5477
SMED4	158	5,019	1,5120
SPC1	158	3,468	2,0196
SPC2	158	3,481	1,9654
SPC3	158	2,994	2,0612
SPC4	158	2,656	1,9133
SPC5	158	3,519	2,1892
HRM1	158	4,390	1,8727
HRM2	158	4,448	1,7847
HRM3	158	4,227	1,7541

HRM4	158	3,903	1,8331
TPM1	158	4,260	1,8401
TPM2	158	5,344	1,3841
TPM3	158	5,039	1,7224
TPM4	158	4,468	2,0290
FONT1	158	4,145	1,4887
FONT2	158	3,828	1,7093
FONT3	158	5,386	1,6009
ECOD1	158	2,862	1,9439
ECOD2	158	3,221	1,9855
ECOD3	158	3,345	2,1006
ECOD4	158	4,097	2,1065
EMS1	158	6,269	1,0663
EMS2	158	5,910	1,2914
EMS3	158	5,469	1,4279

APPENDIX D

First e-mail

Caro(a),
Este questionário faz parte do trabalho de conclusão do mestrado em Engenharia e Gestão Industrial, realizado no Departamento de Engenharia Mecânica da Universidade de Coimbra pela aluna Teresa Ribeiro, e sob orientação do Prof. Doutor Luís Miguel D. F. Ferreira (luis.ferreira@dem.uc.pt).
O objetivo deste trabalho é explorar se combinação de práticas Lean e Green nas organizações industriais resulta em melhorias de desempenho ambientais, operacionais e financeiras.
O tempo de resposta deste questionário é inferior a 10 minutos.
Agradeço a sua colaboração!
Para participar, por favor, utilize o endereço abaixo.
Com os melhores cumprimentos,
{ADMINNAME} ({ADMINEMAIL})

Clique aqui para aceder ao inquérito:
{SURVEYURL}
Se não quer participar deste inquérito e não deseja receber mais convites clique p.f. na seguinte ligação:
{OPTOUTURL}

Reminder

Caro(a),
Recentemente, foi convidado a participar no estudo sobre a implementação de práticas Lean e Green.
Notamos que ainda não completou o questionário, e queremos relembrar que o inquérito ainda está disponível, caso queira tomar parte dele.
Este questionário faz parte do trabalho de conclusão do mestrado em Engenharia e Gestão Industrial, realizado no Departamento de Engenharia Mecânica da Universidade de Coimbra pela aluna Teresa Ribeiro, e sob orientação do Prof. Doutor Luís Miguel D. F. Ferreira (luis.ferreira@dem.uc.pt).
O objetivo deste trabalho é explorar se combinação de práticas Lean e Green nas organizações industriais resulta em melhorias de desempenho ambientais, operacionais e financeiras.
Para participar, por favor, carregue no endereço abaixo.
Com os melhores cumprimentos,
{ADMINNAME} ({ADMINEMAIL})

Clique aqui para aceder ao inquérito:
{SURVEYURL}
Se não quer participar deste inquérito e não deseja receber mais convites clique p.f. na seguinte ligação:
{OPTOUTURL}