



# Framework para a implementação sistemática de Green-Lean 4.0 e Sustentabilidade em PME

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julho de 2024

***A framework for the systematic implementation of  
Green-Lean 4.0 and Sustainability in SMEs***

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**Dissertation to fulfil the requirements to obtain the Master degree in  
Mechanical Engineering, with a specialization in  
Industrial Management**

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# ACKNOWLEDGMENTS

I want to start by thanking my Professor, José Carlos Vieira de Sá for all the help and guidance throughout the development of this dissertation. I am also very grateful to Dr. Olivia McDermott for sharing her knowledge and guiding me during this period.

A big note of appreciation to all the companies that answered my call or responded to my email and became part of this journey.

A heartfelt thanks to my mother for all the love, belief in me, support and for always putting food on the table.

A special thanks to my dad for all the sacrifices and hard work. You know you are my example and the person I look up to.

To my lovely girlfriend, who understood and listened to all my difficulties and complaints and supported me throughout this journey.

To all my family and friends for all the assistance provided.



# Abstract

Lean and Green methodologies have been the subject of case studies over the last few years, and several beneficial relationships have been found with these and with the three pillars of Sustainability: environmental, economic and social. The topic of Sustainability has been highlighted as a strategic imperative in many business discussions due to high pressure from stakeholders, and, as such, companies have invested in methodologies that contribute to sustainable development. However, smaller companies tend to face difficulties when implementing Lean-Green (LG) and sustainable practices. Therefore, the main objective of this dissertation is to understand how a framework for the systematic implementation of Lean-Green and Sustainability (LGS) aided by the integration of Industry 4.0 technologies, with a focus on helping small and medium-sized companies (SMEs) can be developed by gathering different insights through face-to-face interviews. To this end, a systematic literature review (SLR) was carried out, combined with a bibliometric analysis, focusing on the relationship between Lean, Green and Sustainability, and also with Industry 4.0. By collecting data from the Web of Science platform and using the VosViewer software, it was possible to analyse the most researched themes, the geographical regions and areas of application where research is being carried out, as well as the most used Lean and Green tools depending on whether the topic of the article was LG or LGS. The same analysis was then conducted but with the topic of Industry 4.0 incorporated, with a focus on the influence of Industry 4.0 technologies on each pillar of Sustainability.

Subsequently, a qualitative study was carried out using face-to-face interviews with Portuguese SMEs. A detailed analysis of all the answers given to the proposed questions was carried out using the qualitative data analysis software WebQDA, in which it was possible to uncover the main barriers experienced in implementing these methodologies, such as resistance to change, lack of training, initial investment and uncertainties in the process. The way that different organizations approach the implementation of Lean, Green and the three pillars of Sustainability was also investigated. Industry 4.0 technologies were found crucial to monitor and improve LG actions and most companies emphasized the implementation of sustainable strategies to have higher competitive advantage and to match client's requirements. The interviews, therefore, serve as a basis for validating the proposed framework. A four-phase framework consisting of thirteen practical steps tailored to the specific needs and constraints of SMEs was developed to facilitate and provide guidance for the implementation of Lean Green Sustainability 4.0 (LGS 4.0) methods, which can be applied to various sectors and different environmental and social contexts.

**KEYWORDS:** Lean, Green, Sustainability, Industry 4.0, Framework, SMEs, Lean Green



# RESUMO

As metodologias Lean e Green têm sido alvo de estudos de caso ao longo dos últimos anos, tendo sido encontradas várias relações benéficas entre estas e os três pilares da Sustentabilidade: ambiental, económico e social. O tema da Sustentabilidade tem sido apontado como um imperativo estratégico em muitas discussões empresariais devido à elevada pressão das partes interessadas e, como tal, as empresas têm investido em metodologias que contribuam para o desenvolvimento sustentável. No entanto, as empresas de menor dimensão tendem a enfrentar dificuldades na implementação de práticas Lean-Green (LG) e sustentáveis. Assim, o principal objetivo desta dissertação é compreender como pode ser desenvolvida uma framework para a implementação sistemática de Lean-Green e Sustentabilidade (LGS) auxiliada pela integração de tecnologias da Indústria 4.0, com foco na ajuda às pequenas e médias empresas (PMEs), através da recolha de diferentes insights por meio de entrevistas presenciais. Para o efeito, foi realizada uma revisão sistemática da literatura (RSL), combinada com uma análise bibliométrica, com foco na relação entre Lean, Green e Sustentabilidade, e também com a Indústria 4.0. Através da recolha de dados na plataforma Web of Science e com recurso ao software VosViewer, foi possível analisar as temáticas mais pesquisadas, as regiões geográficas e áreas de aplicação onde a investigação está a ser realizada, bem como as ferramentas Lean e Green mais utilizadas consoante o tema do artigo fosse LG ou LGS. De seguida, foi realizada a mesma análise, mas com o tema da Indústria 4.0 incorporado, com foco na influência das tecnologias da Indústria 4.0 em cada pilar da Sustentabilidade.

Posteriormente, foi efetuado um estudo qualitativo com recurso a entrevistas presenciais a PME portuguesas. Foi efetuada uma análise detalhada de todas as respostas dadas às questões propostas, com recurso ao software de análise de dados qualitativos WebQDA, na qual foi possível descortinar as principais barreiras sentidas na implementação destas metodologias, como a resistência à mudança, a falta de formação, o investimento inicial e as incertezas no processo. Foi também investigada a forma como diferentes organizações abordam a implementação das metodologias Lean, Green e os três pilares da Sustentabilidade. As tecnologias da Indústria 4.0 foram consideradas cruciais para monitorizar e melhorar as ações de LG e a maioria das empresas enfatizou a implementação de estratégias sustentáveis para ter maior vantagem competitiva e corresponder aos requisitos do cliente. As entrevistas, portanto, servem de base para validar o quadro proposto. Foi desenvolvido um quadro de quatro fases, composto por treze etapas práticas adaptadas às necessidades e restrições específicas das PME, para facilitar e fornecer orientações para a implementação dos métodos Lean Green Sustentabilidade 4.0 (LGS 4.0), que podem ser aplicados a vários sectores e a diferentes contextos ambientais e sociais.

**Palavras-chave:** Lean, Green, Sustentabilidade, Indústria 4.0, Framework, PMEs, Lean Green



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# ACRONYMS AND SYMBOLS

## Acronyms

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AI	<i>Artificial Intelligence</i>
DMAIC	<i>Define, Measure, Analyse, Improve and Control</i>
EVSM	<i>Environment Value Stream Mapping</i>
GLSS	<i>Green Lean Six Sigma</i>
GM	<i>Green Management</i>
GVSM	<i>Green Value Stream Mapping</i>
IoT	<i>Internet of Things</i>
ISEP	<i>Instituto Superior de Engenharia do Porto</i>
JIT	<i>Just-in-Time</i>
KPIs	<i>Key Performance Indicators</i>
LCA	<i>Life Cycle Assessment</i>
LG	<i>Lean Green</i>
LGS	<i>Lean Green Sustainability</i>
LGS 4.0	<i>Lean Green Sustainability 4.0</i>
LM	<i>Lean Management</i>
LT	<i>Lead Time</i>
N.D	<i>Not Defined</i>
OEE	<i>Overall Equipment Effectiveness</i>
OEEO	<i>Overall Environmental Equipment Effectiveness</i>
P.Porto	<i>Instituto Politécnico do Porto</i>
PRISMA	<i>Preferred Reporting Items for Systematic Reviews and Meta-Analyses</i>
SLR	<i>Systematic Literature Review</i>
SMED	<i>Single Minute Exchange of Die</i>
SMEs	<i>Small and Medium Enterprises</i>
Sus-VSM	<i>Sustainability Value Stream Mapping</i>
TBL	<i>Triple Bottom Line</i>
TPM	<i>Total Productive Maintenance</i>
USA	<i>United States of America</i>
VAT	<i>Value Added Time</i>
VSM	<i>Value Stream Mapping</i>
WFM	<i>Waste Flow Mapping</i>
WIP	<i>Work-in-Process</i>
WoS	<i>Web of Science</i>

---

## Symbols

%	Percentage
€	Euro





# 1. Introduction

In this chapter, the intention is to provide an initial introduction to the approach and contextualisation of this dissertation's topic, as well as to outline the objectives, research methodology, and structure of the report.

## 1.1. Contextualization

The growing concern about environmental issues and the urgent need to mitigate the effects of climate change have placed Sustainability at the centre of global agendas. Increasingly, cases of extreme temperatures, droughts, and floods have created greater urgency on this topic.

While industrial activities play a crucial role in the advancement and development of humanity, they inevitably have a negative impact on the environment. Additionally, it is essential to consider the effect of population growth on the scarcity of natural resources and pressure on natural ecosystems. Therefore, improving the efficiency and effectiveness of these activities to achieve a balance between human needs and the environment's need for support is essential (Dhingra et al., 2014).

In contrast to the predominant mass production of the last century, companies have faced huge changes in the last two decades with increasingly competitive markets and have begun to adopt a mindset of continuous process improvement, enhanced flexibility, improved quality, and faster response times to customers (Fullerton et al., 2014). This approach, called Lean methodology, focuses on eliminating all waste associated with production by reducing processes that do not add value to the final product (Womack et al., 1990).

The Lean philosophy identifies eight main sources of waste: overproduction, waiting, transportation, defects, overprocessing, inventory, and motion (Lewis, 2000; Verrier et al., 2014), with a final type of waste, the under-utilisation of workers' capabilities or skills (Nunes, 2015).

On the other hand, Green management, like Lean methodology, aims to improve process efficiency, but to enhance environmental impact and reduce ecological footprint. The Green approach aims to interfere with a significant decrease in waste production, energy and raw material consumption, reduction of atmospheric emissions, and the use of hazardous materials (Miller et al., 2008; Verrier et al., 2014). The implementation of Green practices contributes to many benefits, such as cost reduction through more efficient resource usage (Walker et al., 2010; Carvalho et al., 2017), improved business Sustainability, environmental preservation, and

## Introduction

an enhanced corporate reputation (Lee et al., 2013). Regarding Green management, the eight main types of waste are excessive water and energy consumption, immoderate use of resources, pollution, waste, greenhouse gas effects, eutrophication, and health and safety issues (Hines, 2009).

Companies have been encouraged to adopt a more proactive approach to their environmental and social policies, moving towards more sustainable practices (Elkington, 1994), aligning the concept of Sustainability and the Triple-Bottom-Line (TBL) that suggests that a company can achieve sustainable results by simultaneously improving its performance in environmental, social, and economic areas (Abualfaraa et al., 2020). According to Alves and Alves (2015), companies cannot be truly sustainable if they do not take employee and community well-being into account, alongside their long-term financial goals, undertaking actions around corporate social responsibility (CSR) that will generate economic value and meet stakeholder's expectations.

SMEs represent 99% of all businesses and have created approximately 85% of new employment in the past five years (European Commission, 2024). However, SMEs' general lack of financial resources prohibits large investments in training, infrastructure, or new technology and can prevent them from maintaining or improving their Sustainability and competitiveness (Wessel & Burcher, 2004). According to Masood & Sonntag (2020), lack of financial and knowledge resources, coupled with a lack of technology awareness, are limitations faced by SMEs when adopting Industry 4.0 technologies to improve process efficiency and Sustainability. Achanga et al. (2006) has shown that SMEs infrequently use Lean methods because of a lack of expertise and leadership.

## 1.2. Objectives & Methodology

The main objective of this study is to understand how a comprehensive framework for the systematic implementation of LGS 4.0 and Sustainability methodologies can be developed specifically designed for SMEs, considering their unique needs, constraints, challenges, practices, methods, strategies, and benefits.

The methodology chosen to develop the framework for the LGS 4.0 implementation in SMEs was by conducting face-to-face interviews with Portuguese companies. By asking the same questions, different overviews and perceptions can then be compared to form and validate the proposed framework.

## 1.3. Report structure

This report consists of five main chapters, structuring the document coherently. The first and current chapter (Introduction) pertains to the report's introduction and aims to contextualise the subject under analysis, presenting the established objectives, the methodology used, and the report's structure.

The second chapter (Literature Review - State of the Art), related to the literature review, provides a brief theoretical overview and an in-depth exploration of the study area. Initially, all criteria for article selection are defined, and the database is established. Subsequently, a bibliometric analysis of the selected publications and literature is carried out. Lastly, a synthesis and analysis of the literature review is executed.

The third chapter (Methods and Applications) presents the methodology that will be used to develop the framework. It includes a presentation of the companies interviewed, the requirements that each company had to meet, an outline of the data collection period, and an explanation of how the data is going to be collected and processed.

The fourth chapter (Results and Discussion) is where the work is presented and discussed in detail. Initially, all the responses to the questions of the different phases of the questionnaire are examined. Afterwards, the framework is built by using the interview's responses to validate each step.

In the fifth and final chapter (Conclusion), conclusions are drawn regarding the research conducted, the most important topics of the analysis are gathered, and recommendations for future work and projects are made.

## Introduction

## 2. Literature Review - State of the Art

In this chapter, it is presented the SLR and bibliometric analysis, which serve as the foundation for the current research. An SLR aims to identify, assess, and interpret all relevant studies on a specific topic and detect possible gaps in current research to suggest areas for additional investigation (Kitchenham & Charters, 2007). On the other hand, bibliometric analysis relies on quantitative and statistical analysis to describe patterns of article distribution according to topic, area of study, journals, countries, and citation numbers (Li & Zhao, 2015). The three phases of the SLR are presented in Figure 1.

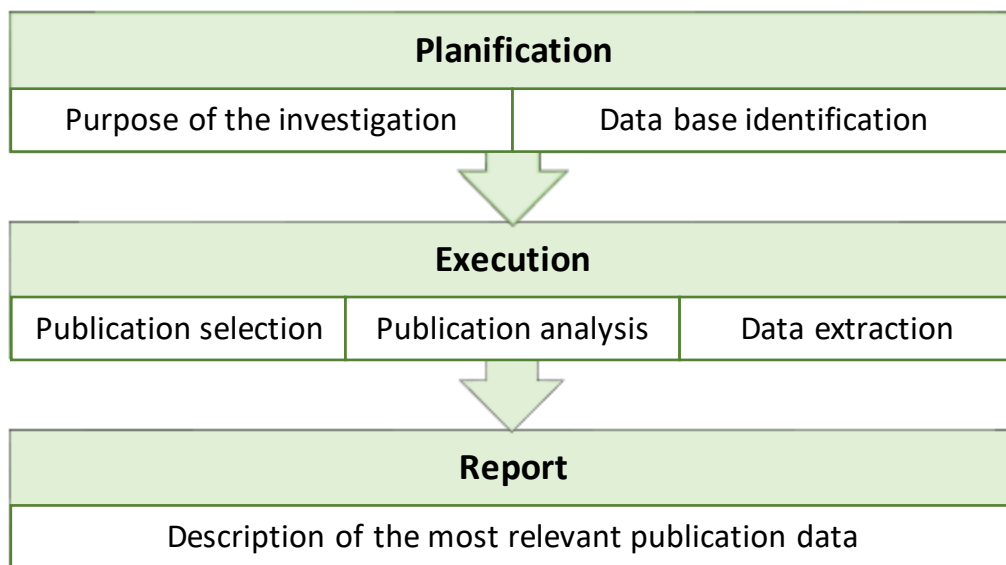


Figure 1- SLR phases (adapted from (Li & Zhao, 2015))

This chapter also aims to provide a comprehensive overview of the state of the art in lean and green concepts, as well as their interconnection. Various perspectives from different authors on the relationship between lean/green will be examined, along with an analysis of real-world case studies to determine how this connection can be beneficial for organizations. Then, a synergy between Industry 4.0 and each pillar of Sustainability is going to be studied using the same method.

## 2.1. Database and Publication Selection Parameters

With the aim of identifying publications to be studied, the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) methodology was employed, involving the screening of various publications integrated into one or multiple databases on a specific topic (Page et al., 2021).

Firstly, the academic search database was defined as the Web of Science (WoS) due to its coverage of major journals and publications related to the subject under analysis. Additionally, only publications written in English were considered.

Secondly, the research period was established between 1900, the limit year of the WoS platform, and November 2023, the date of the SLR research, to incorporate all publications related to this theme.

Thirdly, a search was conducted covering the title, abstract, and keywords of each publication, with the combination of the keywords "Lean", "Green" and "Sustainability" obtaining a total of 513 publications.

Lastly, a second screening was performed on these 513 publications, this time adding the keyword "Lean manufacturing," searching it as "all fields," which considers the entire content of the publication, excluding only acknowledgements and bibliographic references. After this, 117 publications were obtained, and after a more rigorous analysis, 4 publications diverging from the topics were discarded, resulting in a total of 113 publications as the outcome and review basis for this entire literature review.

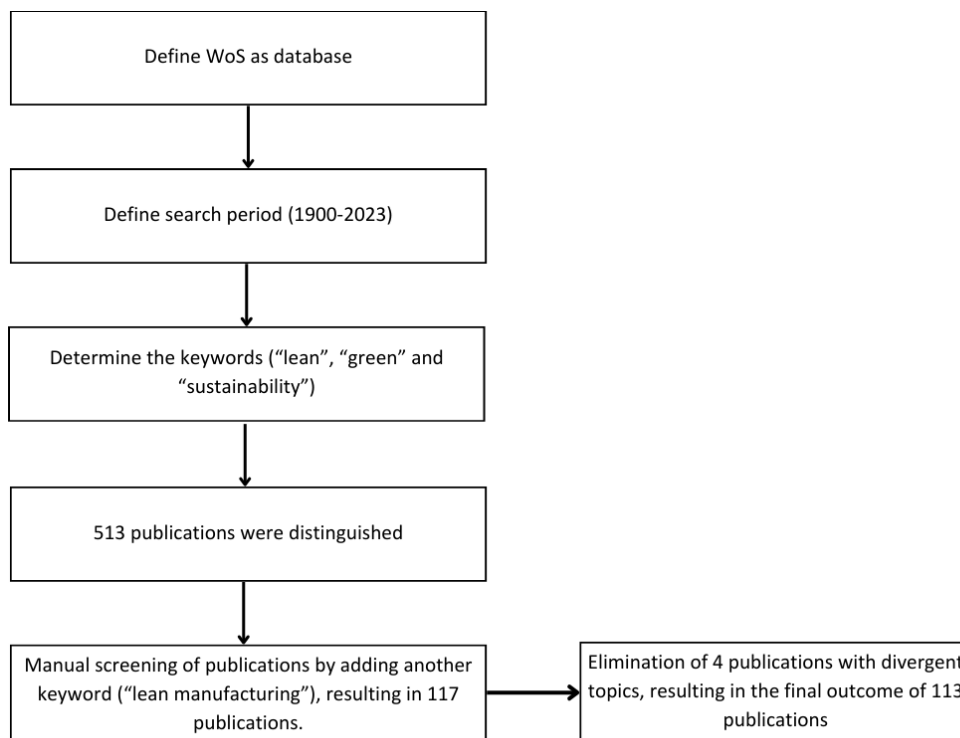


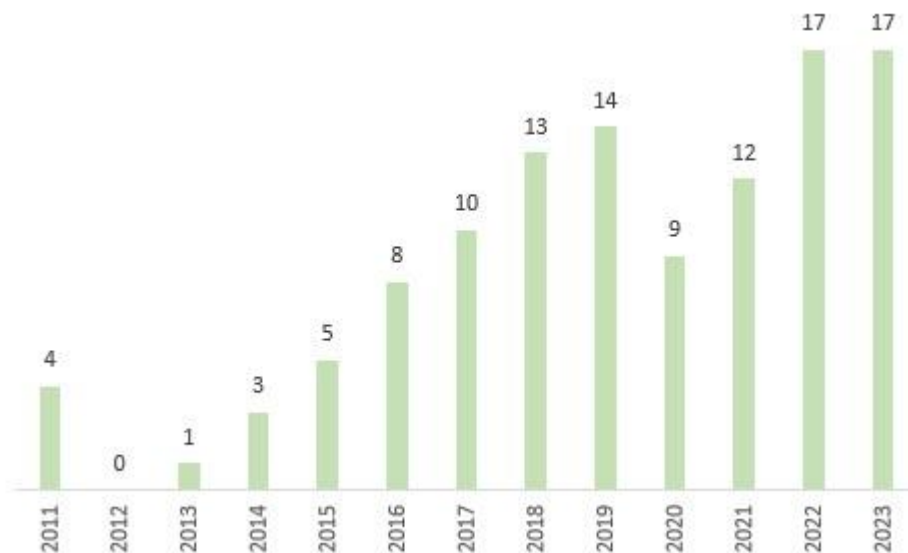
Figure 2- Screening and selection through PRISMA methodology.

Next, through the WoS platform, it was possible to export a Microsoft Excel file with all the available information about the publications, including title, list of authors, publication year, journal in which they were published, and the total number of citations. After a more in-depth investigation of each publication, additional information was also added, such as the geographical region associated with the study, the research application area, the Lean and Green tools used, and the main objectives of each publication. Finally, considering the associated content, they were also classified as "Lean Green" (LG) or "Lean Green and Sustainability" (LGS).

## 2.2. Bibliometric Analysis of Publications

### 2.2.1. Distribution by publication year, number of citations, journal, and geographic region

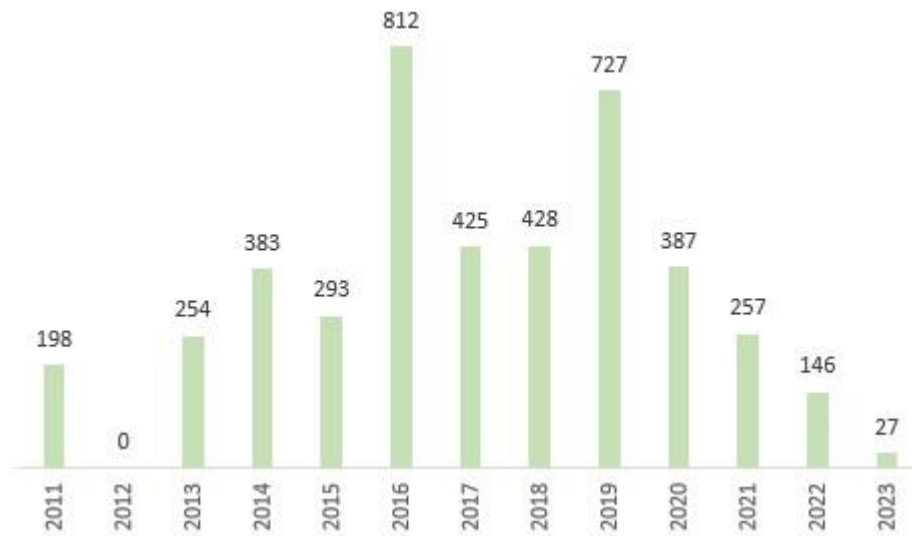
As mentioned previously, the research period established in the WoS database spans from 1900 to November 2023, obtaining the values presented in Graph 1. As can be observed, the first publications resulting from the combination of the keywords "Lean," "Green," and "Sustainability" appeared in the year 2011, with a significant increase in the number of publications since then peaking in the years 2022 and 2023 with 17 publications each year respectively. However, in the years 2020 and 2021, there was a slight decrease in the number of publications, most likely due to the global pandemic, Covid-19.



Graph 1- Distribution by publication year

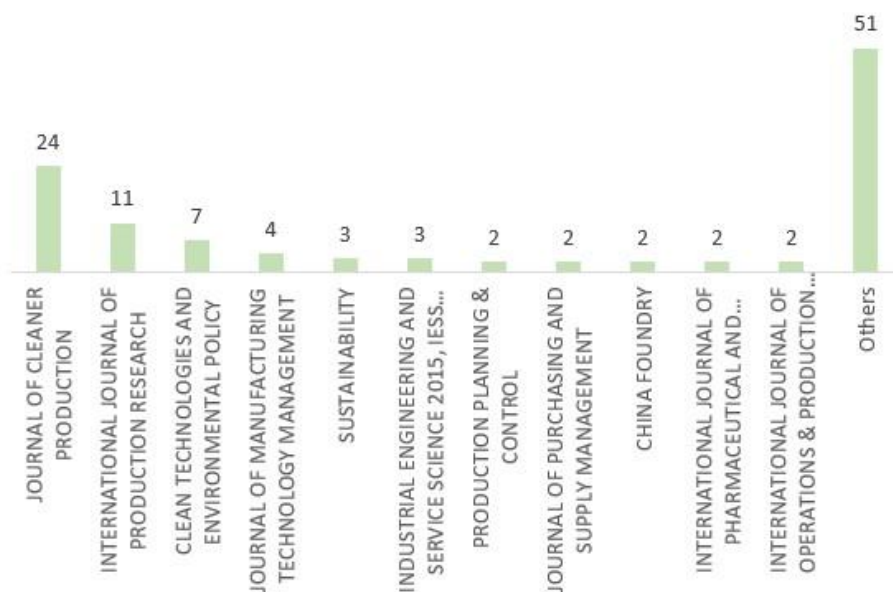
Regarding the total number of annual citations, the peak years are 2016, with 812 citations and 2019, with 727 citations (Graph 2). Increased concern about environmental issues has led companies to be the subject of case studies using LG tools with a focus on Sustainability. This has resulted not only in a higher number of publications over recent years but also in an increased number of citations. However, as shown in Graph 2, the number of citations has remained low in the last two years due to the publications being more recent.

Literature Review - State of the Art



Graph 2- Total number of citations per year

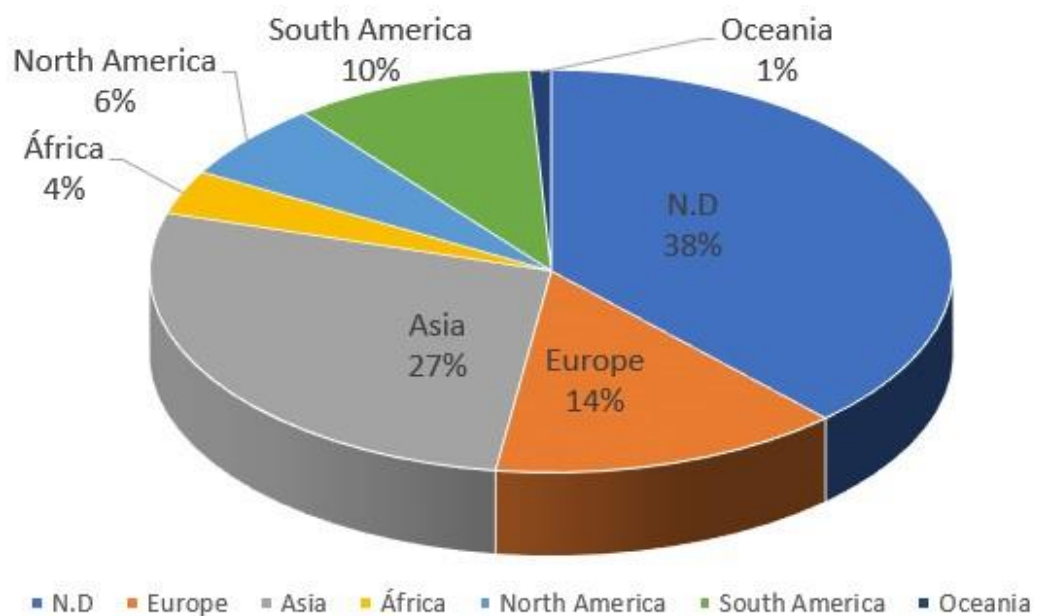
Regarding the distribution of publications within scientific journals, the *Journal of Cleaner Production* stands out as the most recurrent publisher, with a total of 24 publications accounting for approximately 21% of the total publications (Graph 3). In second and third place, respectively, are the *International Journal of Production Research* with 11 publications and *Clean Technologies and Environmental Policy* with 7 publications. The column labelled "Others" is due to the high mixture of various journals, each with only 1 publication that addresses this topic containing the three search keywords.



Graph 3-Distribution of publications by scientific journals

Regarding the geographical spread of the research associated with the 113 examined publications (Graph 2), only the country related to the case study or research conducted and presented in the article was considered, not the country of origin of the main author(s). When nothing was mentioned regarding the geographical region, it was designated as "Not Defined" (N.D).

Within this category, 25 different countries across 5 continents were noted, dividing America into North America and South America. Thus, Asia stands out with 27% of the total number of publications, with India being the country with the most publications (18) and the highest total number of citations (879) (Table 1). Brazil and the United States of America (USA) are in second and third place, with 10 and 6 publications and 691 and 468 citations, respectively. Portugal is fourth in terms of the number of citations, with 152 citations associated with 3 publications. The N.D category holds a significant position, representing 38% of the total publications and accumulating 1237 citations.



Graph 4-Distribution of publications by continents

Table 1- Top10 Countries with more citations

Country	Occurrences	Citations
India	18	879
Brazil	10	691
USA	6	468
Portugal	3	152
Australia	1	144
France	1	138
Spain	4	114
Ghana	2	82
United Kingdom	2	81

Country	Occurrences	Citations
Sweden	1	77
N.D	43	1237

### 2.2.2. Clusters identified

Using the VosViewer application (version 1.6.18), it was possible to combine the keywords Lean, Green, and Sustainability to obtain a visualisation map (Figure 1) of all study topics associated with these words and their relationships. In order to identify the most mentioned keywords in all 113 publications, a restriction was applied, requiring a keyword to be repeated at least eight times. This resulted in the identification of three clusters with 28 different study topics. Of these three clusters, the first encompassed 13 items, and the second and third cluster has 10 and 5 items, respectively.

One of the functionalities of the VosViewer application is that it allows us to understand the most and least mentioned topics in a keyword combination. In this case, amongst the 10 most mentioned topics, Green, Lean, supply chain management, business performance, Sustainability, environmental performance, impact, implementation, framework and Six Sigma stand out. Among the least mentioned topics are barriers, drivers, innovation, performance, strategies, model, operations, system, mapping SUS-VSM and management. Consequently, it is concluded that the less referenced topics may warrant further attention and analysis to build greater clarity regarding this area of study.

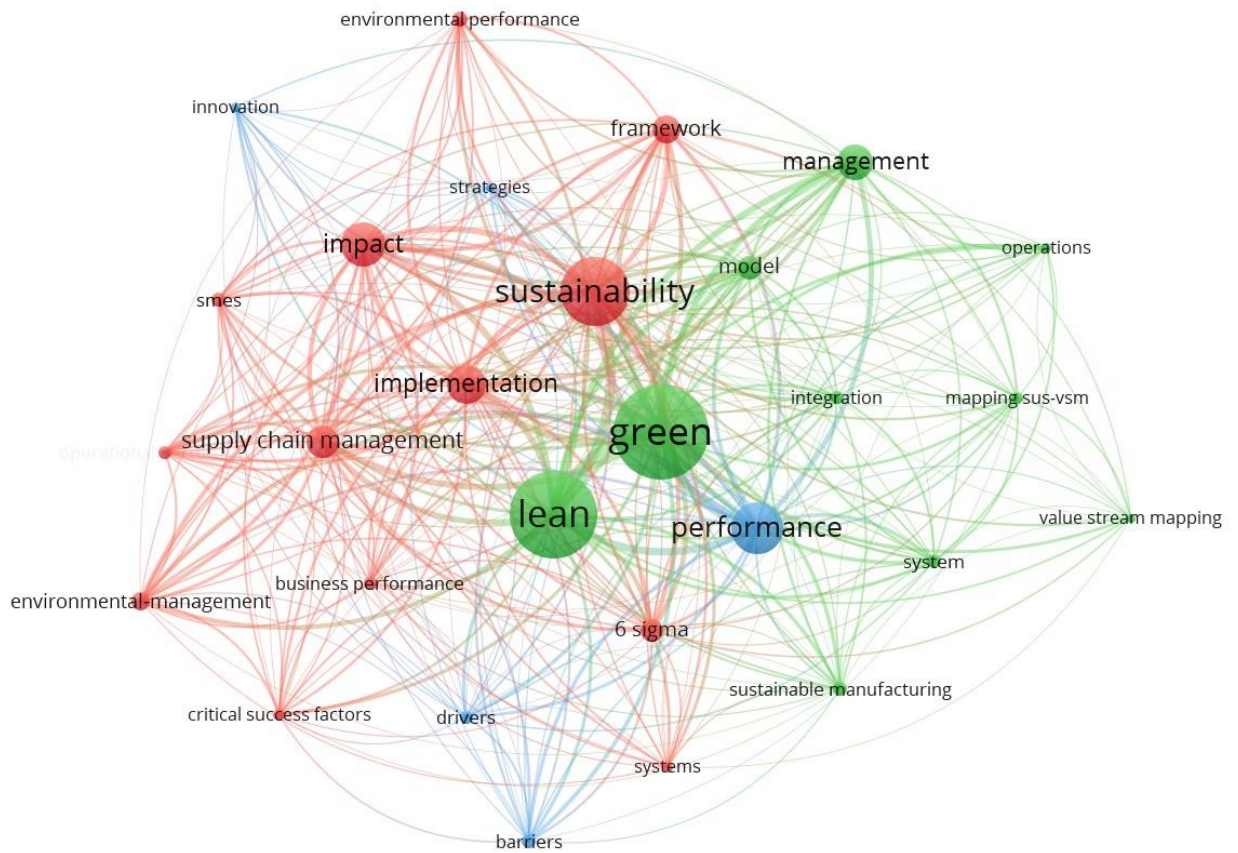


Figure 3-Most relevant topics about Lean, Green and Sustainability

As it can be observed on the Table 2, regarding cluster 1, there is a focus on the integration of Six Sigma methodologies, Sustainable practices and critical success factors within supply chain management. On the other hand, cluster 2 suggests a comprehensive model that incorporates environmental Sustainability, Lean principles, and Value Stream Mapping (VSM) for improved operations management in manufacturing. Finally, in cluster 3, the main topic revolves around analysing strategies to employ to navigate barriers, enhance drivers and improve overall innovation performance.

Table 2- Most relevant clusters from the SLR

Clusters	Items
<i>Cluster 1</i> (13 items)	6 sigma, business performance, critical success factors, environmental performance, environmental management, framework, impact, implementation, operational performance, SMEs, supply chain management, sustainability and systems
<i>Cluster 2</i> (10 items)	Green, integration, lean, management, mapping sus.vsm, model, operations, sustainable manufacturing, system, value stream mapping

<i>Clusters</i>	<i>Items</i>
<i>Cluster 3</i> (5 items)	Barriers, drivers, innovation, performance and strategies

## 2.3. Systematic Literature Review Analysis

### 2.3.1. Distribution by topic and application area

In this subchapter, the distribution of publications obtained through the combination of the keywords Lean, Green, and Sustainability is made into two distinct topics: Lean Green (LG) and Lean Green Sustainability (LGS) (Table 3). The categorisation of publications follows a structured approach, where LG encompasses studies exploring practices and tools for efficient and Sustainable management in operations, highlighting initiatives aimed at reducing waste and harmful atmospheric emissions, as well as increasing energy efficiency and water consumption.

On the other hand, LGS covers works that go beyond operational efficiency, delving into issues related to the three pillars of Sustainability: environmental, economic, and social. This determined that the most addressed topic among the 113 publications was “Lean Green,” with 62 publications (55%). Consequently, the topic “Lean Green Sustainability” obtained 51 publications (45%).

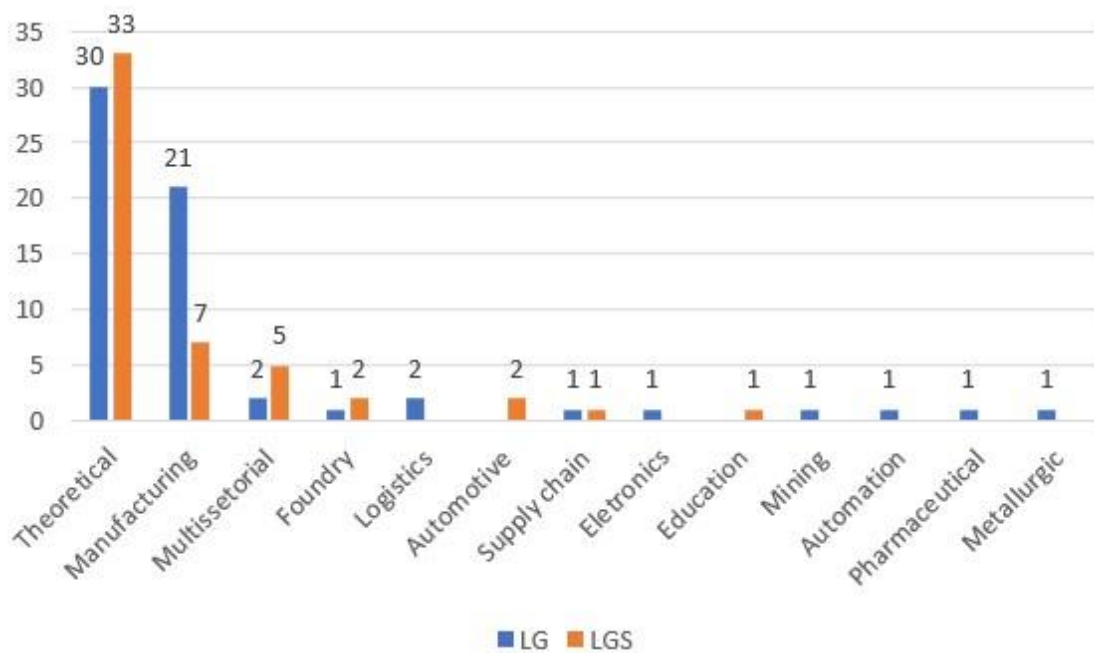
Table 3- Distribution of publications by topic

<b>Topic</b>	<b>Publications</b>
<b>Lean Green (LG)</b>	(Jabbour et al., 2013); (Thanki et al., 2016); (Caldera et al., 2019); (Vinodh et al., 2011); (Verrier et al., 2016); (Kurdve et al., 2015); (Domingo & Aguado, 2015); (Choudhary et al., 2019); (C. Singh et al., 2021); (Ramos et al., 2018); (Ugarte et al., 2016); (Torielli et al., 2011); (Prasad et al., 2016); (R. K. Singh et al., 2016); (Bem Ruben et al., 2018); (S. J. Thanki & Thakkar, 2018); (Agyabeng-Mensah et al., 2021); (Agyabeng-Mensah et al., 2020); (Baysan et al., 2019); (Gupta et al., 2018); (Cheung et al., 2017); (Leong et al., 2019); (Júnior et al., 2018); (Mittal et al., 2017); (Farias et al., 2019); (Awan et al., 2022); (Marcilio et al., 2018); (Touriki et al., 2021); (; (Ahmad et al., 2021); (Mishra et al., 2020); (Ruben et al., 2017); (; (Maqbool et al., 2019); (Ghobakhloo et al., 2018); (Kalemkerian et al., 2022); (Gandhi et al., 2021); (Shafiee et al., 2022); (Tayyab et al., 2018); (Nicholls & Bumgardner, 2018); (Lorenzon dos Santos et al., 2019); (Muñoz-Villamizar et al., 2018); (Hallam & Contreras, 2017); (Caldarelli et al., 2022); (Ikatinasari et al., 2018); (Dale, 2011); (Calvete Gaspar et al., 2017); (Abobakr et al., 2023); (N. Kumar et al., 2022); (Machingura et al., 2023); (Maldonado-Guzmán & Garza-Reyes, 2023); (Paraschos et al., 2023); (Tripathi et al., 2023); (Abdullah et al., 2023); (Zhu et al., 2022); (Carrera et al., 2021); (Van Boggelen, 2011); (Gopi & P.G., 2023); (Jum’a et al., 2023); (Ciannella & Santos, 2022); (Reyes et al., 2023)

Topic	Publications
<b>Lean Green Sustainability (LGS)</b>	(Cherrafi et al., 2016); (Faulkner & Badurdeen, 2014); (S. Kamble et al., 2020); (Helleno et al., 2017);(Verrier et al., 2014);(Henao et al., 2019); (Sajan et al., 2017); (Varela et al., 2019); (Souza & Alves, 2018); (Hartini & Ciptomulyono, 2015); (Alhuraish et al., 2017); (W. Abualfaraa et al., 2020); (Longoni & Cagliano, 2015); (Teixeira et al., 2021); (Jum'a et al., 2022); (Sartal et al., 2018); (Baumer-Cardoso et al., 2020); (N. Kumar et al., 2020); (Resta et al., 2016); (Gholami et al., 2019); (J. K. Y. Lee et al., 2021); (Gaikwad & Sunnapwar, 2021); (Hartini et al., 2020); (Saetta & Caldarelli, 2020); (Dahmani et al., 2022); (Qureshi et al., 2022); (Mathiyazhagan et al., 2022); (Naeemah & Wong, 2022); (Aminuddin et al., 2014); (Ebrahimi et al., 2023); (Maginnis et al., 2017); (Rupasinghe & Wijethilake, 2020); (Sant'Anna et al., 2017); (Lima et al., 2023); (N. Kumar & Mathiyazhagan, 2020); (W. A. Abualfaraa et al., 2017); (Panigrahi et al., 2023); (Akanmu & Nordin, 2022); (Prasad et al., 2022b); (Bem Ruben et al., 2020); (W. Abualfaraa et al., 2023); (Goyal et al., 2022); (Prasad et al., 2022); (Taucean et al., 2018); (Henao & Sarache, 2023); (Punj et al., 2023); (Queiroz et al., 2023); (Gopi & Saleeshya, 2022)

Regarding the application areas associated with the publications, a total of 13 different areas were identified (Graph 5). Firstly, with 63 publications, or 56% of the total publications, the "Theoretical" area was predominant, mainly due to the need to develop a comprehensive and clear understanding of these topics. However, theory needs to be tested in organisation. In second place, with 30 publications, the "Manufacturing" area stood out, noting that 22 out of the 30 publications are on the LG topic. In third and fourth place, with 7 and 3 publications, respectively, are the "Multisectoral" and "Foundry" areas. The "Logistics" and "Automotive" areas both have the presence of 2 publications each. Finally, the remaining areas are addressed only once, respectively.

The presence of various distinct study areas such as "Education," "Mining," and "Pharmaceutical" proves that Lean and Green thinking can be applied across a wide range of industrial sectors, emphasising the focus on environmental, economic, and social Sustainability.



Graph 5-Distribution of application areas by topics

### 2.3.2. Lean Green

The paradigm of Lean Management (LM) involves continuous improvement of quality and productivity, reducing costs, time, and waste in all processes involved. On the other hand, Green Management (GM) aims to reduce environmental risks, impacts, and waste while improving ecological efficiency (Duarte & Cruz-Machado, 2013). From an administrative perspective, these two philosophies and practices are synergistic in that they both focus on reducing waste and inefficiencies (Yang et al., 2011). Dues et al (2013) identified common attributes between these two paradigms, including waste reduction techniques, people and organisation, lead time reduction, supply chain relationships, and Key Performance Indicators (KPIs), sharing various practices and tools.

Rothenberg & Pil (2001), through their study, analysed the interconnection between LM and GM and deduced that companies should implement Lean and environmental practices to gain ecological advantages through improvements in environmental performance and thereby achieve their objectives in terms of organizational performance. Simpson & Power (2005) demonstrated that investing in resources that allow companies to improve their waste reduction performance has beneficial implications for organisational competitive advantage. Silva et al. (2020), in their case study, were able to have environmental gains such as reduction in raw material and energy consumption and environment emissions, and economic gains by implementing lean tools and techniques. They proved that lean brings value to organizations and that all the expenses needed to implement it has a return in the short or medium term.

On the other hand, Larson & Greenwood (2004) concluded that incorporating eco-sustainable ideologies into Lean initiatives can positively amplify the overall results of Lean implementation, helping address ecological risks and activities. In general, the increased efficient use of

resources and raw materials directly contributes to the improvement of organisational environmental performance.

However, Ramos et al. (2018), through their study, they identified several cases of large and medium-sized companies that, solely through the application of lean methods, were able to achieve better results in terms of environmental performance and present better forms and techniques of cleaner production.

The United States Environmental Protection Agency describes environmental waste (Epa & of Strategic Environmental Management, 2013) as a resource or substance that is used unnecessarily and is released into the atmosphere, water, or land, potentially harming public and environmental health; Lean wastes do not add any value to the final product and also represent costs associated with the company and society in general. Table 4 represents the relationship between environmental impacts associated with some of the types of Lean waste.

Table 4-Environmental impacts on types of lean waste (Epa & of Strategic Environmental Management, 2013)

Type of waste	Environmental impact
Overproduction	<ul style="list-style-type: none"> <li>• Energy and raw material spent on producing unnecessary products</li> <li>• Use of hazardous materials that can result in emissions and waste</li> <li>• Products may become obsolete and require disposal</li> </ul>
Inventory	<ul style="list-style-type: none"> <li>• More packaging and deterioration of Work-in-Process (WIP)</li> <li>• Use of material and energy to replace WIP and store it</li> </ul>
Transportation and handling	<ul style="list-style-type: none"> <li>• Energy and emissions spent on transportation</li> <li>• More space for WIP movements and associated energy consumption</li> <li>• More packaging needed during movement</li> <li>• Transportation of hazardous raw materials require special and more protected shipments</li> <li>• Damages and spills during transportation</li> </ul>
Defects	<ul style="list-style-type: none"> <li>• Raw material and energy consumed in manufacturing defective products</li> <li>• Defective products require recycling and waste disposal</li> <li>• More space needed for repair and rework, and energy spent on heating, cooling and lighting</li> </ul>
Underutilization	<ul style="list-style-type: none"> <li>• Raw material consumed per piece produced</li> <li>• Unnecessary processing increases waste, energy and emissions</li> </ul>
Waiting	<ul style="list-style-type: none"> <li>• Energy wasted on heating, cooling and lighting during periods of inactivity</li> </ul>

In Figure 4, all the practices/tools applied in all selected screened publications that fall under the LG topic are demonstrated. These include real case studies in various sectors, theoretical works, and literature reviews that analyse and investigate various existing LG tools.

To highlight the most utilised tools, Kaizen appeared the most (21) in LG publications. Kaizen according to Thanki et al. (2016), ensures continuous improvement in performance, costs, and quality through small improvements throughout the entire production process, thereby

eliminating waste. In second place, with 12 appearances, is the Just-in-Time (JIT) practice. Ugarte et al. (2016), reduced Greenhouse gas emissions in the logistics and transportation area through the application of JIT. In third and fourth place were the 5S tool (12 appearances and Total Productive Maintenance (TPM) (11 appearances), utilised to improve organisations and implement preventive maintenance plans to reduce machine downtime, prevent accidents and reduce safety issues (Cheung et al., 2017; Hartini et al., 2020) aligning with the Lean pillar of respect. Next, both with 8 appearances, Single Minute Exchange of Dies (SMED) and VSM tool were mentioned. SMED is essentially used to reduce setup times and consequently increase productivity, but also to achieve better results in terms of CO2 emissions (Júnior et al., 2018) and energy consumption (Ikatinasari et al., 2018). The VSM tool is applied to visualise the entire flow of material and information and identify points of improvement regarding environmental and material waste (Vinodh et al., 2011). On the other hand, there are variants of this tool that are focused on environmental performance presented by various authors such as Sus-VSM, Green Integrated VSM (GIVSM), and Environmental VSM (EVSM). Finally, Plant-design as highlighted with 7 appearances, which involves changing the factory or production line layout. Baysan et al. (2019) used plant design to halve the lead time and significantly reduce electricity consumption in a case study organisation.

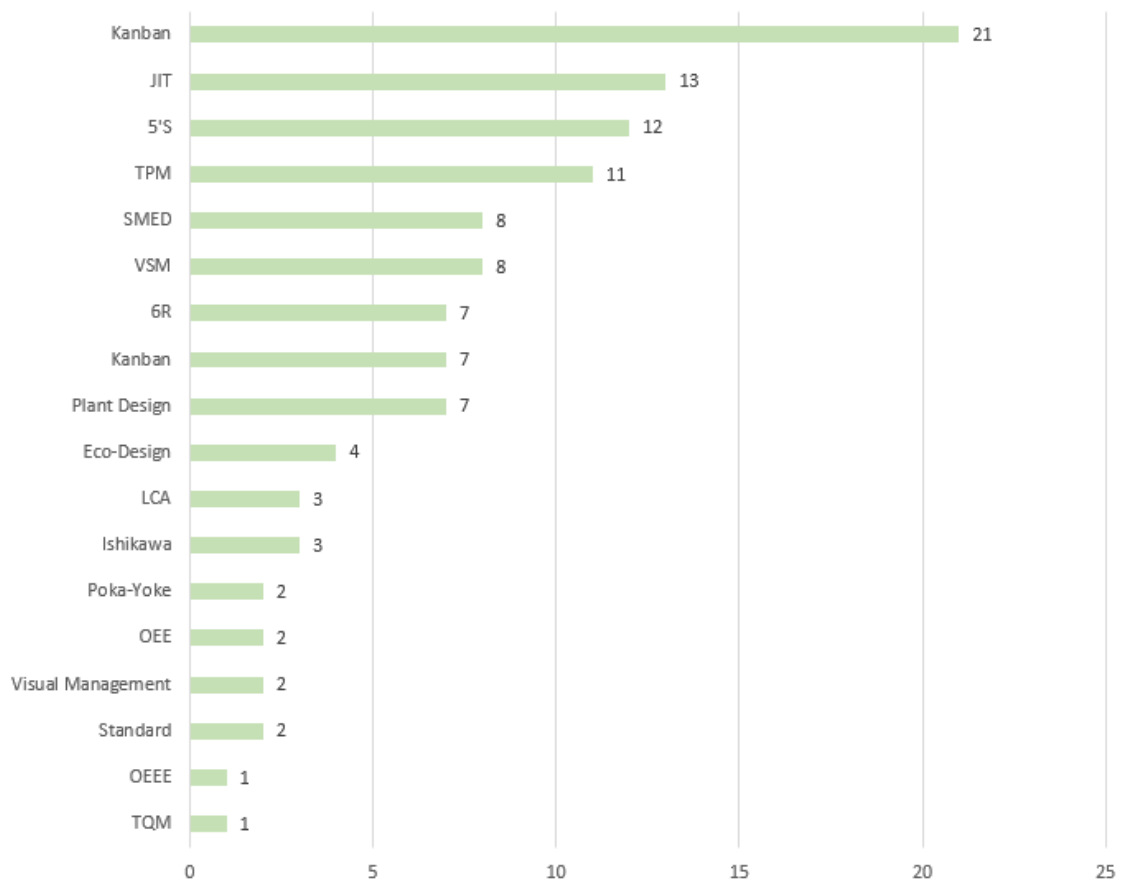


Figure 4- Practices/tools used in LG publications

On Table 5, various real-world cases from different sectors were analysed, where LG practices and tools were implemented. The purpose of this analysis is to comprehensively present the

concrete benefits and results obtained through these initiatives in challenging business contexts.

Table 5- LG tools impact

AUTHORS	APPLICATION AREAS	RESULTS
(Júnior et al., 2018)	Metallurgy	With the aim of reducing cycle time, resource waste, and Greenhouse gas emissions to enhance the company's eco-efficiency, an integrated SMED system with a carbon footprint was implemented. After this application, it was possible to decrease setup time by 70% and the carbon dioxide footprint by 81%.
(Domingo & Aguado, 2015)	Manufacturing	The metric used in this case was Overall Environmental Equipment Effectiveness (OEEE), which encompasses all the traditional components of the OEE indicator and incorporates the concept of Sustainability and environmental impact throughout the product life cycle. With this, several improvements were achieved, such as replacing raw materials with ones of lower environmental impact and lower cost, reducing the total product cost by 6.2%, and, in some cases, eliminating stock between stations and production batches, thereby increasing flexibility to meet customer requirements.
(Maqbool et al., 2019)	Production of bolts and nuts	With the integration of the Lean VSM tool and the Green 6R tool (Reduce, reuse, recycle, recover, redesign, and remanufacture), it was possible to reduce the overall Value-Added Time (VAT) by 36%, the global lead time by 40%, worker utilisation by 22%, and the total heating cost by 50% by replacing oil furnaces with more efficient and less polluting gas furnaces.
(Cheung et al., 2017)	Plastic Injection Molding	With the implementation of the pull Kanban system and the LG Life Cycle Assessment (LCA) tool, the total operation time was reduced by 90%, carbon dioxide emissions decreased by 40%, and significant reductions of 41% in energy expenditure and consumption were achieved with the assistance of the TPM and 5S tools.
(Kurdve et al., 2015)	Multisectoral	A tool called Waste Flow Mapping (WFM) was developed for the analysis of two Swedish companies. This tool identifies all types of waste associated with the production process and analyses waste management logistics. Through this tool, various possibilities for sustainable improvements were detected, leading to significant financial savings.
(Choudhary et al., 2019)	Manufacturing	To identify possible improvements in environmental performance, the LG GIVSM tool was used. It mapped all important production activities and types of associated lean waste through the use of the Ishikawa diagram, carbon footprint, energy waste, and greenhouse gas emissions. This reduced lead time by 63%, the average carbon footprint by 77%, and energy consumption by 77%.

AUTHORS	APPLICATION AREAS	RESULTS
(Ugarte et al., 2016)	Logistics	The application of Lean practices in logistics and transportation, such as JIT and Kaizen, allowed for the optimisation of routes and, consequently, the reduction of Greenhouse gas emissions, as well as the improvement in product availability and customer service through the Pull system.
(Baysan et al., 2019)	Manufacturing	Focusing on identifying and eliminating waste to reduce energy consumption and lead time, the Energy-VSM tool was used in conjunction with the Kanban methodology and changes to Plant Design. This resulted in a 72.37% reduction in electricity consumption and a 55.96% reduction in lead time, thus improving customer service and satisfaction.
(Mishra et al., 2020)	Manufacturing	With the assistance of the Sus-VSM tool, it was possible to assess the entire production process and analyse potential improvements using the Ishikawa and FMEA tools. This led to an overall improvement in OEE, a reduction in cycle times, atmospheric emissions (air acidification), energy consumption, and water eutrophication.

### 2.3.3. Obstacles in *Lean Green implementation*

Various obstacles prevent the successful implementation of the LG approach, which combines Lean Manufacturing principles with a focus on environmental Sustainability. Cherrafi et al (2017) highlighted several barriers, as represented in Table 6, for this implementation. The most notable is a lack of environmental awareness and government support, translating to a lack of clear policies, financial incentives, and favourable regulations to encourage organisations to invest in more sustainable practices (Jadhav et al., 2014).

On the other hand, also studied by Cherrafi et al. (2017) and Leong et al. (2019), promoting strong education about the implications and long-term benefits of sustainable practices and active involvement from top management in organisations to integrate new environmental-focused strategies and initiatives was emphasised.

Kumar et al (2016) identified as a barrier to LG implementation, the lack of statistical control, visualization, and performance indicators or even obtaining unreliable statistical data because these enable the identification of problems and continuous process evaluation.

From another perspective, Singh et al. (2021) examined various existing literature and incorporated expert opinions about barriers and drivers of LG implementation, concluding that, overall, the lack of support from top management, financial support from the government, financial constraints, and a lack of awareness and perception about potential benefits are significant challenges.

Table 6- Obstacles in LG implementation (Cherrafi, Elfezazi, Garza-Reyes, et al., 2017)

NO.	OBSTACLES IN LG IMPLEMENTATION	IMPORTANCE
1	Lack of environmental awareness	High
2	Fear of failure	High
3	Bad quality of human resources	High
4	Lack of training and education	High
5	Limited funds	High
6	Lack of LG thinking and statistics	High
7	Inappropriate identification of areas and activities for LG improvement	High
8	Lack of Kaizen culture	High
9	Lack of visual and statistic control during LG implementation	High
10	Lack of government support	High
11	High costs	High
12	Lack of communication and cooperation between departments	Medium
13	Lack of involvement from top management	High
14	Resistance to change	High
15	Weak cooperation that separates continuous improvement and environmental decisions	High

#### 2.3.4. Lean Green Sustainability

According to Cherrafi et al. (2016), improving sustainable performance and reducing the negative environmental and social impact of industrial processes is no longer just an option but a necessity because Sustainability has emerged as a competitive advantage. Thus, Faulkner & Badurdeen (2014), emphasised that companies should move away from traditional techniques that only focus on cost minimisation and efficiency improvements but rather adopt approaches that consider the environmental and social implications of operations.

In Figure 5, all the practices/tools used in all publications on the LGS topic are demonstrated, whether they are real case studies in various sectors or theoretical works and literature reviews that analyse and investigate various Lean tools and how they affect the three pillars of Sustainability.

Of a total of 51 publications addressing the LGS topic, considering the combination of the keywords "Lean," "Green," and "Sustainability," the two most used Lean tools/practices, both with 10 occurrences, were Kaizen, highlighted by Souza & Alves (2018) as an important tool for reducing accidents and process improvements, and the JIT practice. Despite providing excellent results in most case studies, in the study by Sartal et al. (2018), after surveying 5672 companies, it was concluded that the JIT Lean practice, in most cases, worsened environmental performance because, with the intention of reducing stock, more trips/deliveries were made, resulting in higher CO2 emissions. In third place, the VSM tool has 9 occurrences. According to Faulkner & Badurdeen (2014), it is a rising tool in Sustainability due to its ability to identify possible improvements and waste associated with production processes, but also for the

possibility of incorporating environmental and social performance indicators, highlighting in Figure 5 demonstrates the presence of variants of this tool such as SUS-VM and Socio-VSM. Next, the TPM tool has 8 occurrences. Longoni & Cagliano (2015) stated that, environmentally, by reducing setup times and avoiding machine breakdowns, there is a reduction in energy and material consumption; socially, there is better organization and education for problem and breakdown identification as well as improvement in employee well-being. With 7 occurrences, the 5S tool, was referenced by Resta et al (2016) as a widely used methodology to improve hygiene and safety conditions in the workplace. Finally, Eco-Design and LCA tools, with a total of 5 occurrences, are used to reduce environmental impact through technological solutions and material selection that minimise waste and can be recycled and reused (Dahmani et al., 2022).

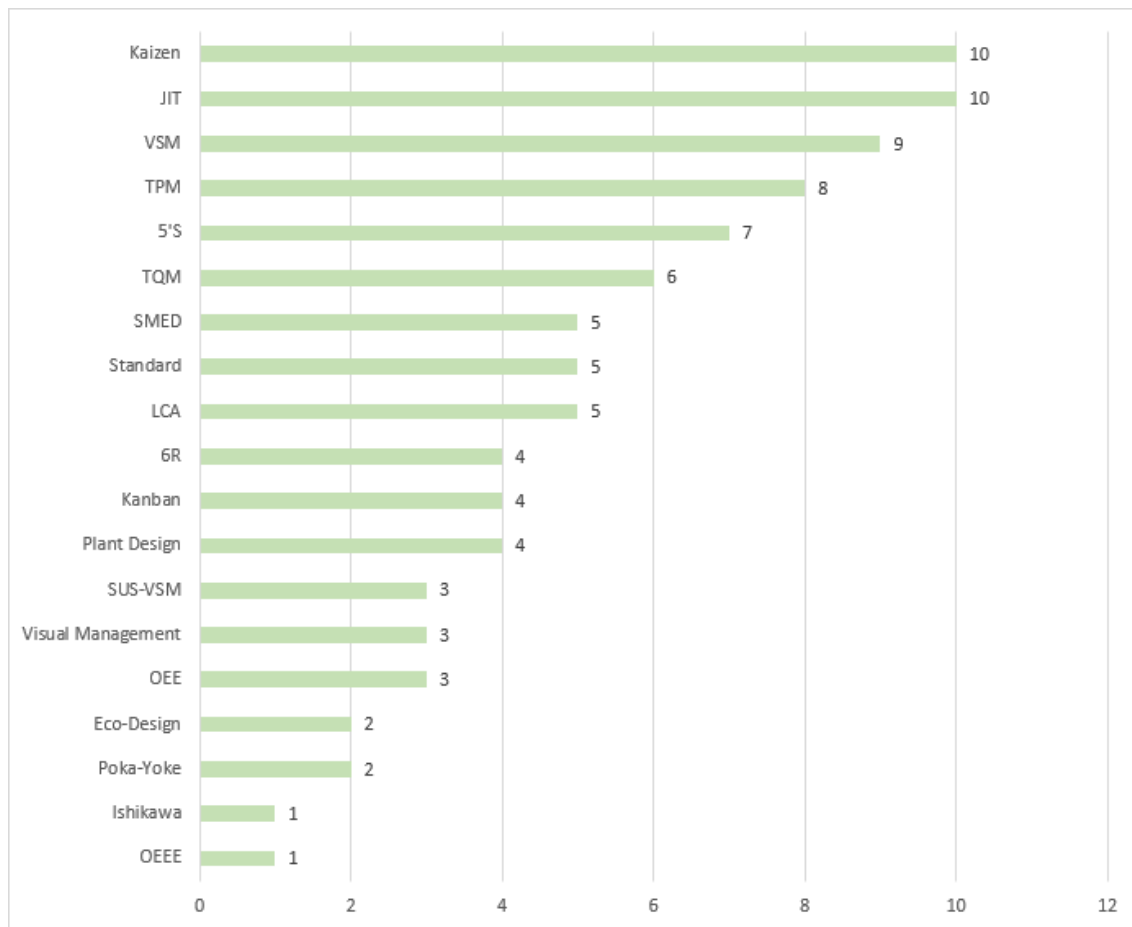


Figure 5- Practices/tools used in publications on the Lean Green Sustainability (LGS) topic.

In Table 7, various real-life cases from different sectors were thoroughly analysed where Lean Green practices and tools were implemented. The purpose of this analysis is to comprehensively present the concrete benefits and results of these initiatives in adverse business contexts across the three sustainability pillars: environmental, economic, and social.

Table 7- The impact of LG tools on sustainability

AUTHORS	APPLICATION AREA	RESULTS
(Faulkner & Badurdeen, 2014)	Production of bolts and nuts	The Sus-VSM tool allowed us to analyse the current state of the production lines and identify areas for improvement. In this case, waste related to energy consumption and natural resources such as water was detected.
(Helleno et al., 2017)	Multisectoral	Instead of traditional VSM usage, economic, social, and environmental indicators were added and applied in three different case studies. The OEE tool also played an important role in characterising the economic Sustainability of the manufacturing process. By applying water and energy consumption indicators, bottlenecks related to these indicators were identified, leading to the development of an efficiency improvement action plan.
(Baumer-Cardoso et al., 2020)	Foundry	By implementing Lean practices such as Kanban, VSM, JIT, and Kaizen, it was possible to determine reductions in lead time, raw material usage by 13%, 14% in energy consumption, better inventory control, and shorter work time.
(Hartini et al., 2020)	Wood Manufacturing	To verify how the use of Lean tools such as VSM, 5S, Kaizen, and JIT influence the three pillars of Sustainability, it was tested in a wood production company, observing improvements in waste and energy reduction, recycling usage, improved satisfaction, health and training of employees, and consequently cost reduction.
(Gholami et al., 2019)	Manufacturing	This case study presents a methodology to measure performance in terms of social Sustainability called Socio-VSM. In this methodology, the work environment was evaluated for ergonomics, physical effort, and noise, considering also work accident risks, employee well-being, and associated economic and environmental benefits.
(Ebrahimi et al., 2023)	Multisectoral	Using the combination of VSM and SMED tools with a focus on sustainable setup called 3SM, setup time decreased by 318 minutes (external + internal), electricity consumption and inventory waste were reduced by 20%, operator downtime during setup improved, and 4254€ on average per setup were reduced, saving 255,240€ annually.
(Lima et al., 2023)	Education	By visualising the entire information flow of a university through the VSM tool and consequently using Kaizen for small but multiple improvements, it was possible to save more than 280,000 litres of water, save approximately 67 trees annually by transitioning from paper to computers, reduce CO2 emissions, and improve service and flexibility in responding to customers through online service provision.

## Literature Review - State of the Art

<b>AUTHORS</b>	<b>APPLICATION AREA</b>	<b>RESULTS</b>
(Sartal et al., 2018)	Multisectoral	In this case, in a questionnaire to several manufacturing companies about the use of the JIT and Jidoka tools, it was concluded that in the case of the JIT tool, there were operational and economic improvements but worsening of environmental performance due to an increase in travels/deliveries. As for the Jidoka tool, there was an overall improvement in the three pillars of Sustainability due to a decrease in production defects.

## **2.4. Sustainable Industry 4.0**

### **2.4.1. Selection and Bibliometric Analysis of Publications**

In the 21st century, the world is experiencing the onset of the fourth industrial revolution and the digital transformation of the business landscape, commonly known as Industry 4.0. This fourth industrial revolution is characterised by the convergence of digitalisation, automation, connectivity, and intelligent data analytics by applying different technologies, reshaping the way products are manufactured, services are delivered, stakeholders' relationships and supply chains are managed (Büchi et al., 2020). Industry 4.0 technologies include autonomous robots, big data and analytics, additive manufacturing, cybersecurity, cloud, Internet of Things (IoT), artificial intelligence (AI), vertical and horizontal system integration, and machine learning. These technologies allow for the collection and analysis of data across connected systems, leading to more efficient processes, better-quality products, and reduced costs (Toktaş-Palut, 2022; Rübmann et al., 2015). Many authors like Cardoso et al. (2024), found that organizational competitiveness depends on productivity, the adoption of digital technology, commitment to digital transformation, and knowledge management and that due to digital transformation, organizations improve productivity, efficiency, organizational performance, increase revenue, and reduce costs.

So, the PRISMA methodology was employed with the intention of identifying publications about Industry 4.0 combined with LGS methods to understand its impact on companies.

Using the same database (WoS), defining the search period to be between 1900, which is the limit of the platform WoS, and February 2024, establishing the keywords "Lean," "Green," and "Sustainability," and adding "Industry 4.0," these keywords were searched as "topic" that involves title, abstract, and keywords of publications.

So, as observed in Figure 6, there were a total of 42 publications that served as the basis of this SLR.

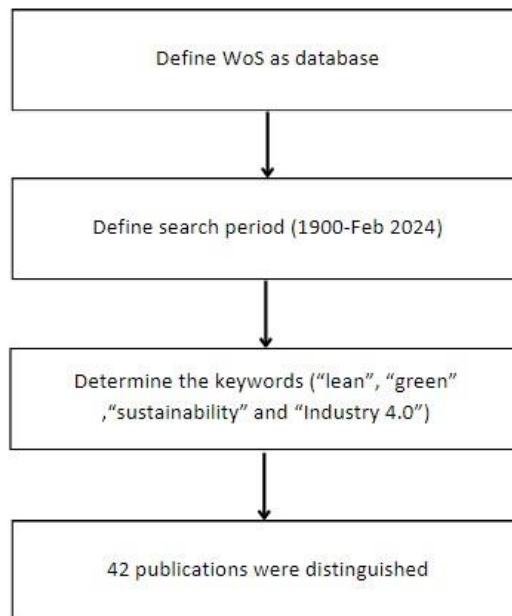
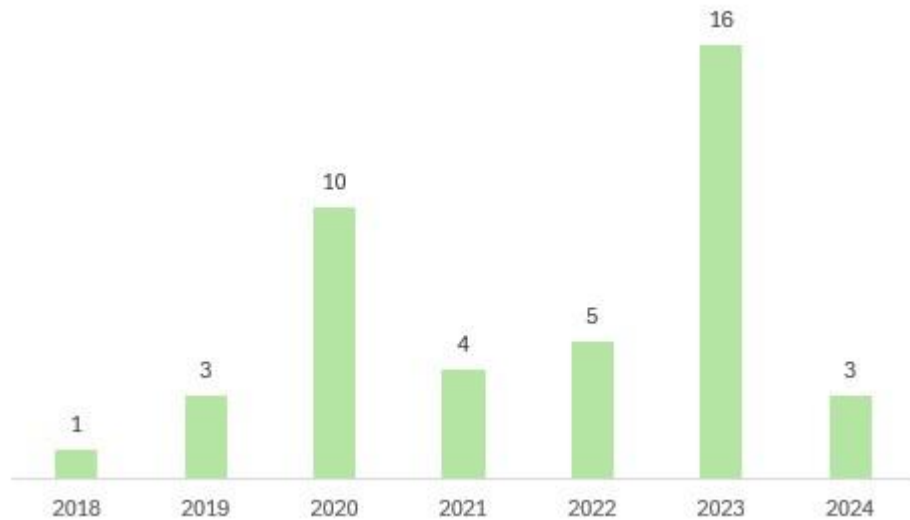


Figure 6- PRISMA methodology adding Industry 4.0 as keyword

Next, through the WoS platform, it was possible to export a Microsoft Excel file with all the available information about the publications, including title, list of authors, publication year, journal in which they were published, the total number of citations and geographic region that they were associated with. On the other hand, the main objective of this SLR is to comprehend the influence of Industry 4.0 technologies and how they can affect each of the three pillars of Sustainability: economic, social and environmental.

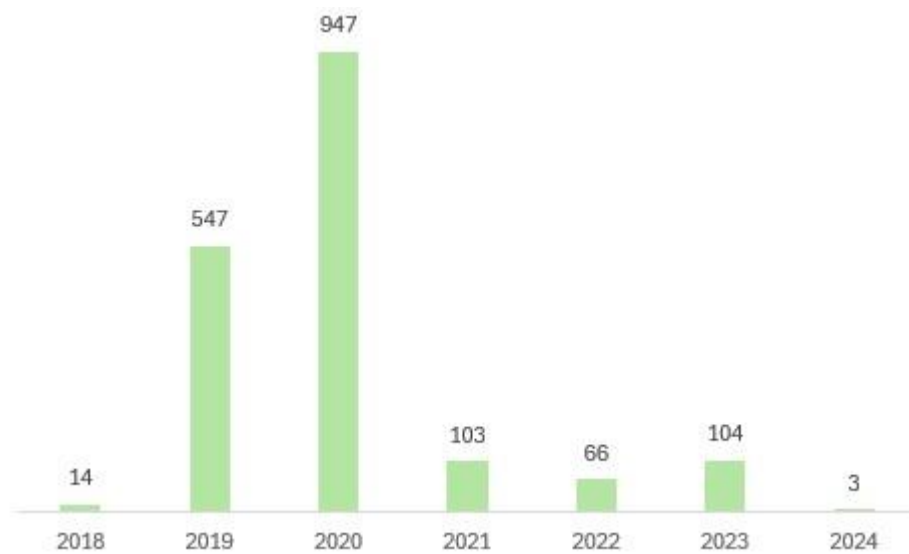
#### **2.4.2. Distribution by publication year, number of citations, journal, and geographic region**

Although the search period was initially set to begin in 1900, the first article or publication with the primary focus on the association of the keywords “Lean”, “Green”, “Sustainability”, and “Industry 4.0” was published in 2018. This can be attributed to the fact that the term “Industry 4.0” was first used in the early years of the 2010-2020 decade, and Sustainability and LG tools/practices are a topic that has been gaining attention over recent years. As it can be observed in Graph 6, 2023 was the year with the greatest number of publications about this topic published, with 16 publications (Graph 6).



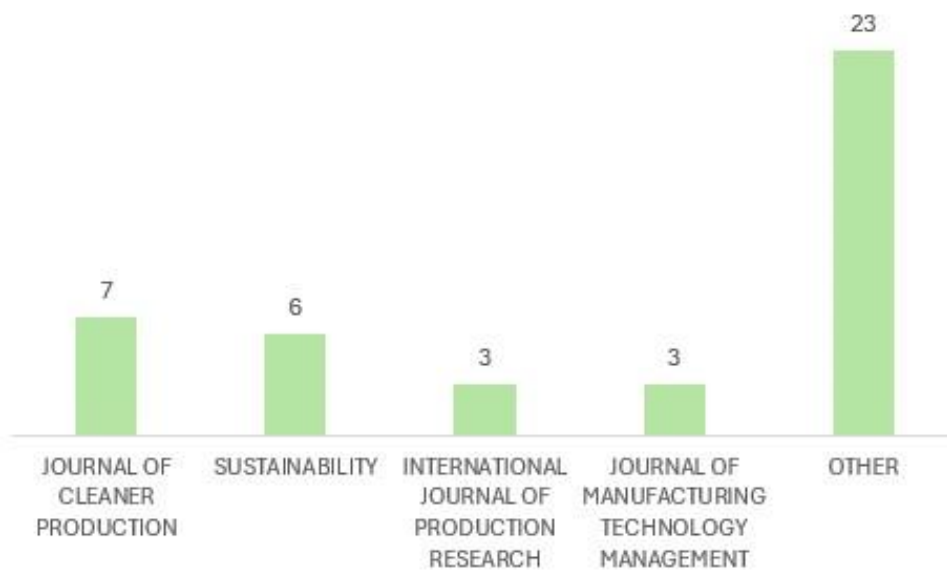
Graph 6- Number of Publications by year adding Industry 4.0 as keyword

Although the year 2023 was the year with the most publications (Graph 6), and in Graph 7, it had only 104 citations. The year with the most citations was 2020, with 947 citations across 10 different articles. The year 2024 was incomplete as the research was carried out up to and including February 2024.



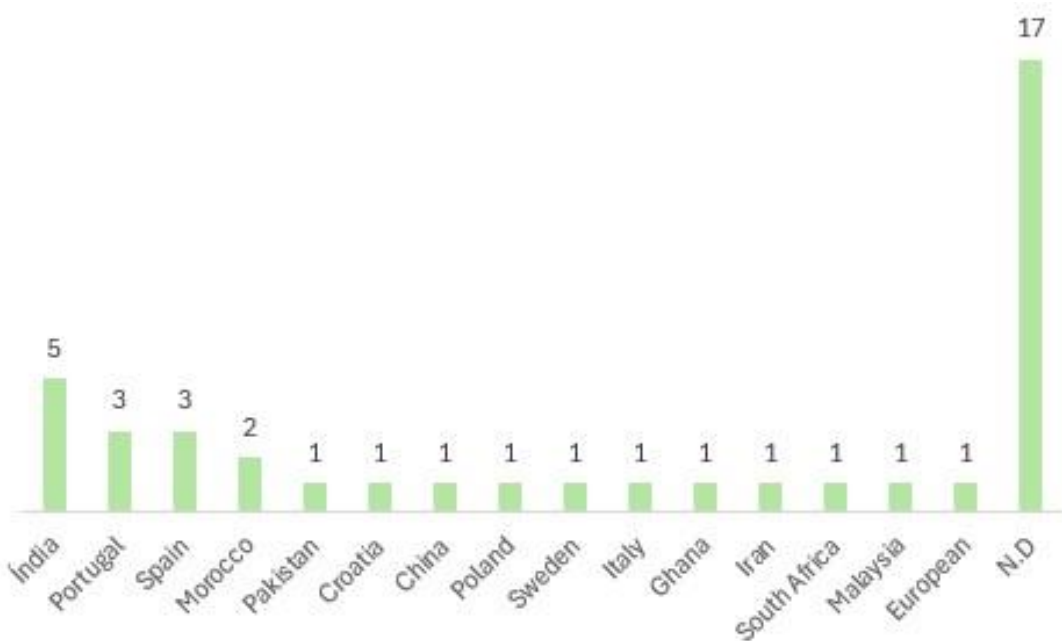
Graph 7- Number of citations by year adding Industry 4.0 as keyword

As registered in Graph 8, the “*Journal of Cleaner Production*” was still the scientific journal with the greatest number of articles published, with 7 publications. In second place, the journal “*Sustainability*” had 6 publications. On the other hand, the “*OTHER*” category refers to journals with only 1 publication, spanning 23 different journals.



Graph 8-Distribution of publications by scientific journal

With 15 countries across almost every continent, India has the greatest number of publications, with 5, followed by Portugal and Spain, with 3 each. When the article doesn't have a country associated, it is represented with "N.D" This category has 17 publications, representing 41% of the total.



Graph 9- Distribution of publications by country

### 2.4.3. Clusters identified

By using the VosViewer application (version 1.6.18), it was possible to generate a visualisation map (Figure 7) by combining the keywords "Lean," "Green," "Sustainability," and "Industry 4.0." This map illustrates all study topics associated with these words and their interrelationships.

Across all 42 analysed publications and the various keywords employed, a restriction was imposed: a keyword must appear at least 5 times across all publications. With this restriction, a total of three clusters were identified with a total of 17 keywords/topics. Of these three clusters, the first encompasses 7 items, and the second and third clusters have 6 and 4 items, respectively.

In this case, employing the VosViewer software allows one to identify the most mentioned topics. Industry 4.0, Green, implementation, Sustainability, management, and supply chain stand out the most. On the other hand, the least mentioned topics are challenges, barriers, environmental Sustainability, systems and Six Sigma.

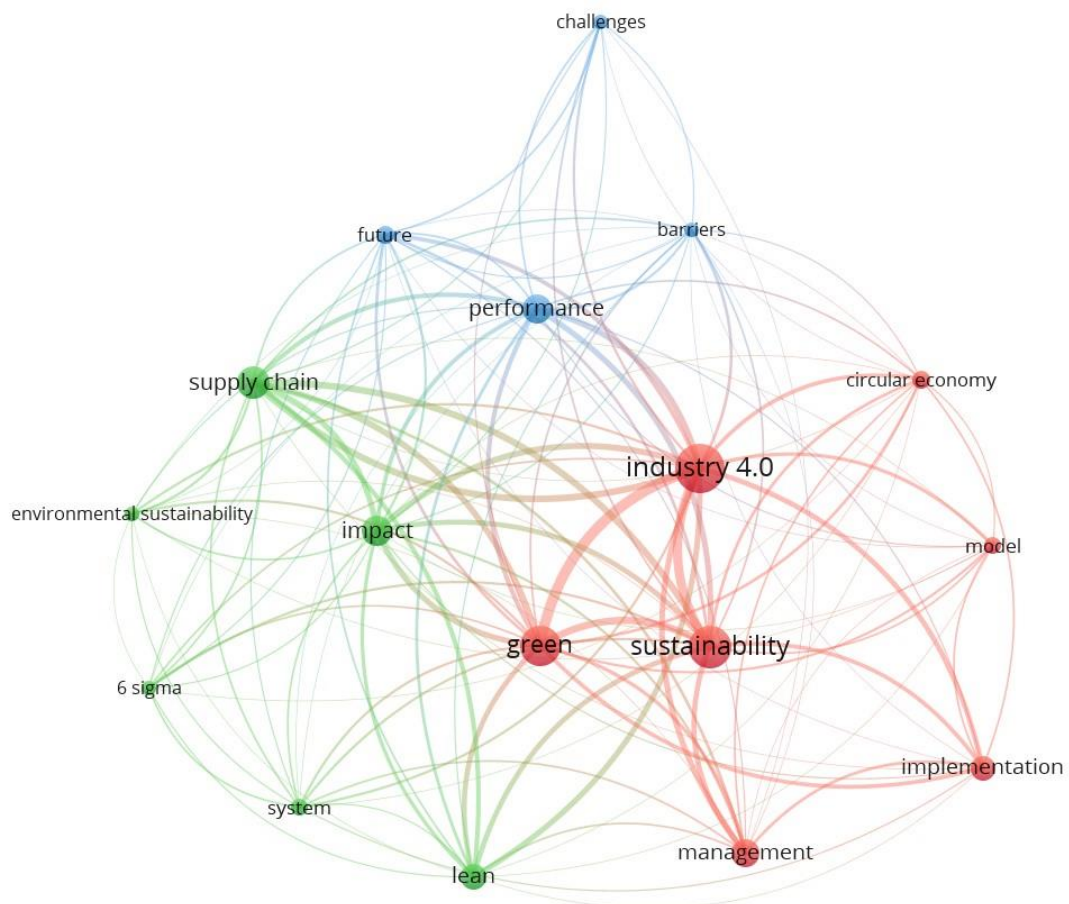


Figure 7- Most relevant topics about Lean, Green, Sustainability and Industry 4.0

As it can be observed on Table 8, in cluster 1, the main topic revolves around the challenges and future considerations associated with integrating Green practices, circular economy principles, and Sustainability considerations within the context of Industry 4.0. In cluster 2, topics are centred around the convergence of Six Sigma methodologies, environmental Sustainability, impact, Lean principles, and supply chain practices. Cluster 3 revolves around the identification of barriers and challenges that impact future performance.

Table 8-Most relevant clusters with the additional keyword "Industry 4.0"

<b>Clusters</b>	<b>Items</b>
<i>Cluster 1</i> (7 itens)	Circular economy, green, implementation, industry 4.0, model, management, and sustainability
<i>Cluster 2</i> (6 itens)	6 sigma, environmental sustainability, impact, lean, supply chain and system
<i>Cluster 3</i> (4 itens)	Barriers, challenges, future and performance

#### 2.4.4. Influence of Industry 4.0 technologies in each sustainable dimension

The Sustainability impact of Industry 4.0 and its contribution to sustainable economic, environmental, and social development are increasingly gaining attention (Ghobakhloo, 2019).

According to Toktaş-Palut (2022), customers are becoming more sensitive about purchasing products from companies that produce eco-friendly products and care about social welfare and not just economic wealth. This encourages supply chains to invest in Sustainability initiatives and Industry 4.0 technologies.

In Table 9, the most mentioned effects/impacts of Industry 4.0 technologies on economic, environmental, and social Sustainability according to the selected research is highlighted.

Table 9- Influence of Industry 4.0 technologies in each sustainable dimension

<b>The Three Pillars of Sustainability</b>	
<b>Economic Pillar</b>	<b>References</b>
<ul style="list-style-type: none"> <li>• Improve efficiency of predictive maintenance and procurement process.</li> <li>• Reduce product development and operational costs</li> <li>• Technologies to monitor real-time costs of manufacturing and detect redundant ones</li> <li>• Increase turnover and create new business models</li> <li>• Improve processes performance</li> <li>• Increase renewable resources</li> <li>• Improve circular economy</li> <li>• Reduce lead and storage time and logistics costs</li> <li>• Increase transparency and integration in supply while also increasing flexibility in logistics</li> </ul>	(Toktaş-Palut, 2022);(S. S. Kamble et al., 2018);(Ramadan et al., 2017);(Brettel et al., 2016);(de Sousa Jabbour et al., 2018);(Hofmann & Rüsçh, 2017);(Varela et al., 2019)
<b>Environmental Pillar</b>	<b>References</b>

The Three Pillars of Sustainability	
<ul style="list-style-type: none"> <li>• Increase renewable energy sources and smart materials</li> <li>• Decrease water and energy usage, hazardous materials, emissions and waste</li> <li>• Increase practice of circular economy</li> <li>• IIoT technology to collect and analyze real-time energy usage data and improve energy efficiency</li> <li>• Optimize transportation routes and therefore reduce carbon footprint</li> <li>• Reduce waiting times, wrong deliveries and damaged goods</li> <li>• Transparency of greenhouse gas emissions</li> </ul>	(Wang et al., 2015);(Stock et al., 2018);(Modak et al., 2016);(de Sousa Jabbour et al., 2018);(Shrouf & Miragliotta, 2015);(Strandhagen et al., 2017);(Qiu et al., 2015);(Herrmann et al., 2014);(Kiel et al., 2017)
Social Pillar	References
<ul style="list-style-type: none"> <li>• Decrease work accidents</li> <li>• More ergonomic and safer work conditions</li> <li>• New job opportunities</li> <li>• Data analytics tools to develop learning programs</li> <li>• Fair wage assessments</li> <li>• Better integration, communication, and inclusion of employees</li> <li>• Increase participation of employees in decision-making</li> </ul>	(Herrmann et al., 2014);(Kiel et al., 2017);(Ghobakhloo, 2019);(Stock et al., 2018);(Modak et al., 2016); (Müller & Voigt, 2018); (Bonekamp & Sure, 2015); (Branke et al., 2016); (Tesch et al., 2017)

While many authors highlight numerous beneficial improvements related to Sustainable Industry 4.0, as shown in Table 9, there are still obstacles to its implementation. Sanders et al. (2016) in his study mentions that the initial implementation costs and unforeseen financial benefits of Industry 4.0 technologies may become an obstacle for companies.

Regarding the environmental dimension of Sustainability, Stock et al. (2018) identified two areas that may have negative impacts: material usage and initial energy consumption.

On the other hand, concerning the social dimension of Sustainability, Tesch et al (2017) and Müller & Voigt (2018) note that there is still an unclear effect on job creation or reduction due to the substitution of people for machines and the necessity to have more skilled personnel for IT-related jobs.

## 2.5. Literature Review Discussion

In this subchapter, the literature review's findings, challenges encountered, and gaps identified are discussed.

By investigating and understanding how lean tools/practices and Industry 4.0 technologies affect, not only the environmental performance, but also the economic and social performance of the organizations, it was possible to verify a positive correlation, indicating that the effective implementation of this methods results in significant gains in terms of operational efficiency and cost reduction, and on the other hand, contributes substantially to environmental sustainability and social commitment.

The application of the PRISMA methodology in this study proved to be an essential element for conducting a rigorous and comprehensive SLR. The use of PRISMA provided a robust methodological foundation for the formulation of the research question to the analysis and synthesis of data. The bibliometric analysis and SLR allowed the finding of a growing interest in combining LG practices and Industry 4.0 technologies to enhance Sustainability. Furthermore, the analysis of real-world case studies demonstrated diverse perspectives and practical benefits of implementing LGS 4.0 methodologies. It is worth highlighting that, in both LG topic articles and LGS topic articles, the most frequently used LG tools/practices that enhanced environmental, economic, and social improvements were Kaizen, VSM, SMED, 5S, and JIT, which contributed to making organizations more competitive and socially responsible. With this SLR, it was also possible to identify LG implementation barriers such as resistance to change and lack of training and Industry 4.0 implementation barriers such as initial investment and initial energy consumption.

Some difficulties and gaps were encountered during the literature review process. The screening and inspection of a large volume of publications and studies required significant effort as the aim was to extract information on the area of application, geographic region, journal, year of publication, LG tools used and whether they mentioned the three pillars of Sustainability of each publication.

On the other hand, most existing research focused on large organizations with a lot of resources finding it easier to implement LGS 4.0 initiatives. A very low number of publications were related to SMEs, which face constraints and sometimes don't have access to the same amount of resources. So, there is a significant gap in research focusing on the challenges and opportunities that SMEs face regarding LGS 4.0 implementation.

Lastly, while many studies document short-term benefits, there is a lack of longitudinal studies that mention not only Lean, sustainable and Industry 4.0 long-term benefits, but also the potential drawbacks of this implementation.

So, the aim of this study is to address the identified gaps and develop a framework for the systematic implementation of LGS 4.0 methodologies specifically designed for SMEs by understanding and discovering the challenges and opportunities that SMEs face by doing face-to-face interviews and gather information of their experience.

## 3. Methods and Applications

This chapter demonstrates and clarifies all the methodological procedures used during the investigation. Firstly, it explains how data is collected and processed.

### 3.1. Data Collection and Processing

In this section, the data collection method and the way information is processed are characterised. According to Sá et al. (2021), data collection techniques are described as “rigorous, well-defined and transmissible operation procedures” and are applied and adapted to various types of problems and areas of investigation (Baptista & Sousa, 2011).

The data collection strategy depends on the problem, the method, the questions, and the research objectives, as well as on a systematic set of questions that can obtain responses from a particular population under study through resources and techniques such as interviews about a specific reality (Almeida, 2022).

Therefore, a qualitative investigation method was selected, considering the nature of the study. Data was obtained by conducting visits to companies and directly interviewing face-to-face the individuals responsible for the quality department, continuous improvement department or Lean managers. Interviews are a technique that allows contact between the researcher and the interviewee; it enables the identification, through expressions and emotions, of a better perception of the responses given.

Each participating company was required to have implemented and used Lean for six months or more. This was to ensure that the company had some reasonable time to assess the impact of the new system.

Companies fulfilling all the criteria and willing to participate in the study were located across Portugal. The companies were approached via email and telephone, and interviews were arranged. All the data was collected in the period between April 2024 and June 2024, and due to their in-depth nature, semi-structured interviews are time-consuming. Therefore, the sample sizes were limited to a total of 20 SMEs that agreed to make part of this study. The name of the companies, type of industry, company and interviewee’s experience with Lean is presented in Table 10.

Table 10- Companies and interviewees involved and their experience with lean.

Company	Size (number of employees)	Type	Company experience with Lean (years)	Interviewee	Interviewee experience with Lean (years)
<b>Moldart</b>	<120	Manufacturing (Molds)	7	Production Engineer	5
<b>RCM Etiquetas</b>	<100	Manufacturing (Labels)	3	General Manager	3
<b>VincoValves</b>	<50	Manufacturing (Valves)	3	Production Manager	5
<b>Cplas</b>	<50	Manufacturing (Plastic)	5	Department of Environmental, Safety, and Innovation Management Systems Responsible	5
<b>Lidergraf</b>	<200	Manufacturing (Printing)	12	Operational Research Technician	10
<b>Clínica Veterinário Animar</b>	<30	Veterinary Healthcare Clinic	4	Clinical Veterinarian Doctor	3
<b>Clínica Oftalmológica Doutor Miguel Sousa Neves</b>	<30	Ophthalmology Healthcare Clinic	1	Human Resource Manager	1
<b>ROQ Laser</b>	>500	Metallurgy and metalworking	4	Production Director	15
<b>Artevasi</b>	<200	Manufacturing (Pots)	10	Sustainability and Quality Department Director	10
<b>Cunha Ribeiro</b>	<150	Confection	8	ISO 9001 Responsible	8
<b>Solidal</b>	400	Manufacturing (Electrical conductors)	1	Continuous Improvement Department Responsible	7
<b>Colquímica Adhesives</b>	>250 & <500	Manufacturing (Adhesives)	3	Corporate Director of Quality, Environment, Security and Sustainability	21
<b>Becri</b>	<250	Confection	4	ISO 9001 and ISO 14001 Responsible	6
<b>Mesa-Ceramics</b>	<200	Manufacturing (Ceramics)	3	Continuous Improvement Team Member	3

Company	Size (number of employees)	Type	Company experience with Lean (years)	Interviewee	Interviewee experience with Lean (years)
<b>Corksupply</b>	660	Manufacturing (Corks)	12	Safety and Continuous Improvement Manager	7
<b>Nimco</b>	<150	Manufacturing (Shoes)	9	Continuous Improvement Responsible	5
<b>Promecel</b>	90	Metallurgy	5	Quality, Environment, and Sustainability Director	5
<b>CIN</b>	1600	Manufacturing (Paints and coatings)	10	Continuous Improvement Department Responsible	7
<b>Fricon</b>	<300	Manufacturing (Refrigeration)	5	Production Manager	4
<b>Mystic</b>	<150	Travel and Tourism	0,5	Sustainability Director	3

Data analysis is based on interview records, which are recorded whenever authorisation is granted for better accuracy in information details. The interviews are transcribed into digital format (Word), and subsequently, the responses are categorised using the WebQDA software to facilitate comparison among the various responses provided by the interviewees. Data collected during the interviews can be supplemented with information gathered through direct observation by the researcher and through the company's website, where reports and charts may contain additional information important to this study.

The twenty questions asked of the companies were all the same and are presented in Appendix A.

These questions were originally developed in the study by Siegel et al. (2024), where they interviewed German SMEs and developed a framework. This research extends their work by incorporating two additional questions related to Industry 4.0 and by developing a framework based on interviews with Portuguese SMEs.



## 4. Results and Discussion

In this chapter, all the interview responses and important themes are described and analysed to form a foundation for the framework. To make it clearer, this chapter was divided into distinct moments and in line with the questionnaire. So, firstly, the Lean questions were reviewed, followed by the questions about LGS. Afterwards, a comparison between Industry 4.0-related questions is made. Lastly, there is an explanation of the step-by-step development of the framework and a final discussion about the results obtained.

### 4.1. Lean-Related Questions

A set of Lean-related questions were derived from the literature, with each question supported by at least one source. All the questions can be found in Appendix A.

The first question of this questionnaire regarding Lean is:

- What is your understanding of the term “Lean”, and how do you define it from your perspective?

In Table 11, some of the responses given to answer this question can be observed.

Table 11- Answers given about how people from different companies define lean in their perspective.

	Answers
CIN	Lean means defining the desirable state of activities by guaranteeing the flow with minimum waste.
Solidal	For me, Lean is the capacity of an organisation to examine any issue or difficulty that arises and consider a solution. Problems are improvement opportunities, and problems always happen.
Fricon	From my point of view, Lean is a philosophy that settles in elimination, in the habit of eliminating the greatest number of wastes, that is, reducing activities that do not add value to the final product.
Corksupply	I see Lean as the way to optimize our daily energy so that we can reach our goals. Since I have this available energy, if I use it critically, we can get everything done in the time window that the client defined.

## Results and Discussion

	Answers
Lidergraf	For me, Lean is continuous improvement. It means continuously learning and improving. It means looking at the current state of production and understanding how we can improve efficiency and reduce waste.
RCM	For me, Lean is a methodology for process improvement, whether in industrial or administrative processes. It involves several stages, starting with analysing the problem, determining where to act, brainstorming, and evaluating the results.
Becri	Lean has zero defects and zero waste. To do more with less. Sometimes, it is hard because not everything depends on us, but we try to minimise the maximum of our own.

In general, the concept of Lean led to different viewpoints amongst the interviewees, but all were unanimous in favour of its beneficial aspects. Overall, Lean was seen as a systematic approach to enhancing productivity, minimising waste, and driving continuous improvement across a wide range of organisational processes.

By using the WebQDA software, a list of the most common topics discussed in the interviews to define Lean is presented in Figure 8. “Waste reduction” was the most common topic with 12 appearances, as they define Lean as a way to reduce activities that do not add value and minimise production waste by implementing different tools and practices. The second and third most common benefits are “Productivity and efficiency optimisation” and “Better organisation”, as these companies observed that Lean has helped them obtain higher outputs in less time by improving efficiency, decreasing the chance of errors, setting standards, and improving the workplace. “Resource management” and “Product quality” also appear as the most referenced topics, as ensuring efficient use of resources enhances product quality by reducing activities that do not add value to the final product.



Figure 8- Most common topics while defining lean.

The second and third question regarding Lean methods are:

- What are the strategic goals of Lean for the current management? (Zhang & Awasthi, 2014)
- What are your company’s current operational, strategic and tactical benefits? (Zhang & Awasthi, 2014)

In Table 12, some answers to this question can be observed.

Table 12-Answers given about the strategic goals and benefits related to Lean.

	Answers
ROQ Laser	<p>With the assistance of the Kaizen Institute, we set a goal to improve all production processes and related processes by 20% and shorten the lead time.</p> <p>With lean practices well applied, we have observed a lot of benefits related to the organization of process flows. Better process flow, less waste and, depending on what we are talking about, less takt-time or lead time to have better client service.</p>

## Results and Discussion

	Answers
Promecel	<p>The clients are the main pillar of every company. Every organization needs clients to stay alive. We intend to satisfy the costumers well within the deadline with the service quality that the customer likes and is satisfied with and gain profit. That is our main goal, and we use several lean tools to achieve that.</p> <p>The operational benefits are obvious. You can easily identify where your waste is and eliminate it by optimizing your process. With that, you produce more and better, deliver faster and became more profitable.</p>
Corksapply	<p>The clients are the main pillar of every company. Every organisation needs clients to stay alive. We intend to satisfy the customers well within the deadline with the service quality that the customer likes and is satisfied with and gain profit. That is our main goal, and we use several Lean tools to achieve that.</p> <p>The operational benefits are obvious. By optimising your process, you can easily identify where your waste is and eliminate it. This allows you to produce more and better, deliver faster, and become more profitable.</p>
Mesa-Ceramics	<p>Promoting Lean practices helps optimise our people's daily efforts to fulfil our goals, decrease errors, and increase process capability. We aim to minimise noise to improve the workplace and the well-being of our employees, and we are setting standards to achieve that.</p> <p>We have a goal to increase the maturity of the system in each of the sectors through implementing good practice standards. We also want to increase the participation of each collaborator as a fundamental piece for the Sustainability of what is implemented and suggest better practices. This is extremely important because people are the base of the company, and we take advantage of those who work with the machines directly to overcome some difficulties. This improves motivation and positivity.</p>
Cplas	<p>Currently, the next step is to improve the one-time delivery in terms of the level of service. In the production part, we have some projects to reduce water and raw material waste. We want to consolidate information and make Lean training transversal to all areas of the company to improve the flexibility of the company's resources.</p> <p>We have reduced production errors and wastes and made many different productivity gains.</p>
Artevasi	<p>The key strategic goals of Lean implementation are process automation and optimisation, which aim to reduce process variation, defects, and waste.</p> <p>The benefits that we are currently observing are essentially related to performance enhancement achieved by transitioning manual tasks to automatic processes. We reduced costs and unnecessary waiting times by avoiding defects through process automation, and all of this adds value to the final product and satisfies our customers in some way.</p>
Clínica Oftalmológica Sousa Neves	<p>The strategic goal is to maximise the appointments per hour by minimising the time clients spend in the clinic and increasing the quality of service.</p> <p>We have verified an increase in productive time and a decrease in waiting time, and as we all know, time is money. Communication between departments has also become more agile and easier.</p>

Based on the answers given, companies have found that implementing lean tools and practices can help them achieve beneficial improvements not only in their production processes, level of service, and workplace but also in upgrading their competitiveness and strengthening the company's image.

Figure 9, presents the most referenced strategic goals and operational and tactical benefits associated with Lean implementation for the current management of each company. Most of the companies focused on achieving "waste" reduction by minimising waste in all forms, including time, materials, and efforts to boost efficiency and improve "productivity" and they also aimed to enhance "service quality", shorten lead time and improve "flexibility" by developing the quality of service provided to the customers to increase satisfaction and loyalty and reduce general complaints. Improving "communication" and "organisation" is found crucial for better collaboration and coordination within the organisation, while creating better "work conditions" is a goal to ensure a safer, more comfortable, and more productive work environment that reduces work accidents and injuries. Reducing "costs", setting "standards", and detecting "defects" are also part of the most common strategic goals and benefits associated with production optimisation and control.



Figure 9- Most mentioned topics regarding strategic goals and lean benefits.

The fourth question in this questionnaire is:

- How much of investment has your company allocated to continuous improvement methods? (Zhang & Awasthi, 2014) In your view, what is the ratio of investment on Lean to benefits achieved from Lean implementation (on a scale of 1:1 to 1:10)?

In Table 13, some answers to this fourth questions are presented.

Table 13- Answers given about the amount of investment and ratio to benefits achieved by lean implementation.

	Answers
Lidergraf	I do not know values, but if you look at me, for example, my job is an investment from the company on continuous improvement and Lean methods. If they have people working and responsible for Lean methodology who spend their time on this, that is already a big investment for the company. On the other hand, investment varies a lot depending on the type of project because sometimes there is a necessity to implement some tool or practice, and sometimes there is not. I will give an 8:10.

	Answers
Soldal	Up until now, the investment has been focused on creating a department dedicated solely to continuous improvement methods. While the combined annual salaries make this expensive, continuous improvement is impossible without adequate resources. There is a balance to maintain, but the return on investment is not as quick as we would like, especially since we started from scratch. Without the right motivation and mindset, all our efforts could disappear. This process takes time, and patience can sometimes run thin, but from my experience, I know it works. Given that we are still in the early stages, I would rate this a 7:5.
Corksupply	Considering that we are expanding our production zone with a Lean strategy base, we can easily estimate an annual investment of one million euros. Each year, we expand or create a new pavilion or work area, requiring new equipment and machines, leading to substantial investment throughout the year. We are a recent unit, so a lot of initial investment is being made. I will give an 8:10 ratio.
CIN	We find this information confidential, so we can't reveal it, but it's been growing throughout the years. I will give an 8:10 ratio.
Promecel	It depends; there are times when you do not need investment, like when you invert the circuit of operations. When we move to bigger projects, that is when the investment comes in. A machine that is faster, more profitable and returns faster. Initially, there is always a process of evaluation, implementation, and establishment that takes almost a year. Therefore, I would say that in the first two years, you do not need to make much investment. I would say that there is a 2:7 ratio because it takes time to get results.
Animar	We do not register the amount spent on these methods. However, to summarise, it was the initial training given to all the employees and the time spent by the administration on this topic. We did not resort to external consultancy, and we did not have to buy new materials. We used the same materials as before but in a more organised manner. I think it is a 3:7 ratio because we did not invest much but had great results.

Only one of the twenty companies interviewed knew the value of the investment that their company has allocated to Lean and continuous improvement methods. Corksupply, as referred to in Table 13, has an estimated annual investment of one million euros in these methods. CIN stated that this value was confidential, and the rest of the companies did not track or were not aware of the amount of money invested. On the other hand, all the companies point out that monetary and time investments have increased throughout the years and that now Lean is part of their everyday jobs, meetings, and training. Some organisations also mention that now they have employees and departments dedicated to continuous improvement methods. In general, Lean has gained more recognition from SMEs.

Regarding the investment-to-benefits ratio for Lean, only Solidal gave a higher score to investments compared to benefits (7:5) because they recently invested a lot and have not yet had time to receive huge benefits. However, on average and rounding off, it is a 5:9 ratio for these companies. This means that Lean methodologies are considered to be highly beneficial, yielding positive returns (9), taking into account a medium investment in terms of money and time (5).

The fifth question is:

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- What percentage of the employees have been trained on Lean Production System and how many days of training have they received? (Daily & Huang, 2001)

In Table 14, some answers from the companies interviewed about Lean production system training are presented.

Table 14- Answers given about lean production system training

	Answers
Artevasi	In terms of Lean training, when we install new software related to Lean practices tools and practices, we have initial training, but we do not have regular training related to this. There was a big training related to quality system management where a lot of continuous improvement terms were talked about, so every employee has a slight idea about this topic.
Becri	When the Kaizen Institute worked here, we had a lot of Lean-related training. This year, we are going to have dedicated 5S and production management training, and everyone in the company will receive it, but we do not have regular training related to Lean.
Colquímica	Yes, there must be one for every 100% of the employees so everyone is working towards the same goal.
ROQ Laser	When new employees are recruited, they receive training related to quality, environment, safety, and the company's politics and strategies. During those trainings, they learn about some Lean tools and practices, such as 5S and organisational maintenance methods. When we had the Kaizen Institute here, all the employees had training regarding 5S, the Mizusumashi technique, etc... Now, we have more advanced training programs related to Lean, where tools like 5 Whys, Ishikawa, and 8D are explained.
VincoValves	Our workers from all sectors receive training programs regarding Lean, especially when a new tool is implemented. The objective is to make workers more autonomous in applying a tool or Lean practice.
Moldart	Every employee gets trained in the Lean Production System. We have a consultant teacher expert on Lean implementation who comes once a week. We form different groups of employees every week and train them about Lean implementation and the seven different types of waste. That helps our employees have a better understanding and perception of types of waste.

Only CIN, Corksupply, Moldart and ROQ Laser have regular daily, weekly, or monthly training related to the Lean production system. The rest of the companies have initial Lean and quality-related training when a new employee is recruited or when a new tool or practice is implemented. 50% of the companies, that is, 10 out of the 20 companies studied, also have 2/3 more advanced Lean training sessions per year.

40% of companies have all their employees trained in Lean, whether it be initial or advanced training, meaning that everyone has the basic concept and general idea of Lean methodologies. In the remaining 60% of companies, only employees involved in production are trained in Lean tools and practices, with this percentage ranging between 50% and 80% of the company.

The sixth Lean-related question is:

- How many Lean projects on average have employees executed per year?(Cherrafi, Elfezazi, Chiarini, et al., 2017) Have the projects been carried out in production setting or have you deployed Lean across the whole business? If so, where else you have applied Lean within the business (e.g. Lean in HR, Lean in Finance? Lean in Product design and development)?(Piercy & Rich, 2015)

In Table 15 some answers given about sixth question are presented.

Table 15- Answers given about how many lean projects they do a year and if it is deployed across the whole business.

	Answers
Lidergraf	We basically execute Lean projects when necessary. If we talk about big projects involving most of the machines and processes, I think I can say that we do like 1/2 a year. If we talk about small projects involving only a machine or two, we can have 4/5/6 projects a year. Yes, we have Lean applied globally within this company, all the way through the sales department to the offices, production floor and expedition department.
Mesa-Ceramics	Last year, we completed 12 projects, but now we are going to slow down a bit because we don't have many resources and still have some open projects to finish. At this moment, all the open projects are related to production processes, logistics, or quality. We haven't reached the offices yet, but it's present on the action plan for this year. The idea is to implement daily kaizen and 5S.
Colquímica	There weren't many, but about five projects per year. Within the industry, besides production areas, it was also implemented in customer service and support, human resources, logistics, and finance, so Lean is deployed across the whole business.
Cplas	We have only been implementing big projects until now, so it takes more time. With that in mind, we have executed about 1 project per year since 2020. As I said before, we strictly implement Lean on the production floor, but we are also studying ways to implement it here in the offices.
Fricon	We divide projects among the teams, and currently, we have a total of 24 ongoing Lean projects, not only on the production floor but also in the finance and purchasing departments. Essentially, we have implemented Lean practices throughout the company.
CIN	Lean methods are applied across operations like production, distribution, and maintenance only. On average, we do 3 Lean projects a year per department.

50% of the companies in the study did not keep track of the number of Lean projects that their employees execute per year on average, while the other 50% kept track. As can be seen in Table 15, the number of projects can vary widely from just 1 project per year, as in the case of Cplas, to 24 ongoing projects spread throughout the entire organisation, like Friction. Lidergraf divides it into 1 -2 big projects and 4-6 small projects per year.

70% of these companies don't have Lean applied to all their different business areas, meaning Lean is not implemented throughout the entire company. In these companies, Lean is majorly applied on the production floor, product development, and design, while the rest of the companies have Lean implemented in the offices, human resources, logistics, finance, and customer service.

The seventh Lean-related question is:

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- How do you measure the success of Lean implementation? (Aguado et al., 2013)

In Table 16, there are examples of answers to the question about how companies measure the success of lean implementation.

Table 16- Answers given about how companies measure the success of lean implementation.

	Answers
Artevasi	To measure the success of Lean implementation, we monitor waste percentage, energy efficiency, and the number of client complaints received. We have many indicators associated with continuous improvement.
Corksupply	We have KPIs to measure the success of Lean implementation, such as defect percentage, 6'S audit results, operational costs, internal and external audit results, and customer feedback.
Nimco	We have indicators related to production and quality, such as pairs of shoes per hour, necessary reworks, rework costs, time per piece, and the percentage of non-quality. All these indicators are influenced by the Lean tools and practices that we have implemented over the years.
Promecel	We have production and quality-related indicators such as OEE, waste and rework percentage, for example.
Clínica Oftalmológica Sousa Neves	We measure the success rate of turning phone calls into appointments daily and through a Google Forms file. We are now at a 95% success rate, so Lean has helped us a lot recently.
Fricon	We have two major indicators: the defects indicator and the amount of equipment produced. Additionally, we measure the 5 S indicator monthly to track our improvements over time.

The companies had different overviews about how to measure the success of Lean implementation.

Figure 10 demonstrates the most referenced KPIs used to measure, monitor and track various aspects of organisational performance to ensure effective management and continuous improvement. Each KPI serves a specific purpose, and collectively, they offer a balanced view of performance across different dimensions, which are critical to the success of lean practices. The most common KPIs are productivity-related indicators such as outputs per hour, and 5 companies had OEE indicators as well that provide insights into efficiency, effectiveness and quality of production processes. 5'S audits and waste percentage were mentioned 6 times each as a way to evaluate the success of Lean implementation because, as Fricon answered in Table 16, 5'S helps to track improvements over time by improving the workplace organisation and waste percentage is a way to measure the proportion of waste produced relative to total output, reflecting the success of Lean efforts in waste reduction. Defects-related indicators were also one of the most mentioned ways to analyse areas that need quality improvement. 3 out of the 20 companies also analyse client complaints as it helps identify areas for service improvement.



Figure 10- Most referenced KPIs

The eighth and last question of this lean-oriented segment is:

- What are the key lessons learned from the implementation of Lean? What are the difficulties of implementation and what should other businesses look out for when considering implementing Lean? (Aguado et al., 2013)

In Table 17, various overviews concern the difficulties and lessons that companies encountered during the implementation of Lean and continuous improvement methods.

Table 17- Answers given about the key lessons and difficulties of lean implementation.

	Answers
Cunha-Ribeiro	Yes, people are very resistant to change, both in production and outside of production.

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	Answers
ROQ Laser	The main difficulty has been overcoming resistance to change and making people realise that these changes are made to make their jobs better and easier through process automation, optimising processes, and adding value to the product. In my opinion, the initial investment was not a big problem because this company has a high budget dedicated to investing in improvement opportunities.
Artevasi	This company is only 16 years old and is primarily comprised of a very young team. Consequently, we encounter fewer obstacles, as young individuals tend to be more adept at adapting to change and digitalisation.
Becri	Initial implementation costs and the availability of human resources are the two major obstacles. Resistance to change is a lesser obstacle, but once we overcome it, things become easier.
Promecel	The first difficulty we encounter is the lack of human resources and availability from the people who work here. Then, there is resistance to change. Operators who have had the same work routine for about 10 to 15 years tend to be uncomfortable when something changes, and we totally understand that. However, changes need to be made so we can achieve greatness.
Corksupply	When you think about a Lean implementation, you quickly associate it with investments. Investments exist and are necessary to direct the productive flow in the right way and feed it only with the necessary energy to meet the process window. Nevertheless, there are quick wins that will bring us great benefits with little effort and deeply support the Lean movement, as many of these quick improvements come from the operators. The weight of Lean Sustainability should rest on the operators.

Figure 11 provides a clear visual representation of common challenges that companies face when implementing Lean practices. Each obstacle highlights a critical area that can hinder the successful adoption and execution of Lean methodologies.

75% of the companies, which amounts to 15 out of 20 in total, have indicated that “Resistance to change” is the most significant barrier as they find it difficult to change some people’s mindset. As stated by Promecel and ROQ laser in Table 17 respectfully, changing the work routine for some operators makes them uncomfortable and “these changes are made to make their jobs better and easier though process automation and to optimise processes and add value to the product”. The second and third most referenced difficulties were “Initial investment” and “Unavailability of human resources”, respectively. These companies find it complicated to invest in restructuring processes or buy new technology or equipment to achieve better Lean results and lack the personnel available to dedicate themselves to Lean initiatives due to time constraints. Companies also find “Impatience” to be an obstacle because some Lean projects are abandoned due to the time it takes for Lean implementation to show results, and companies desire immediate results. “Communication between shifts” is challenging because companies operate with three different eight-hour shifts, and information is not effectively disseminated across shifts. Lastly, “Lack of information and training” is considered an obstacle due to insufficient knowledge and know-how within the company, which slows down the adoption of Lean principles and techniques.

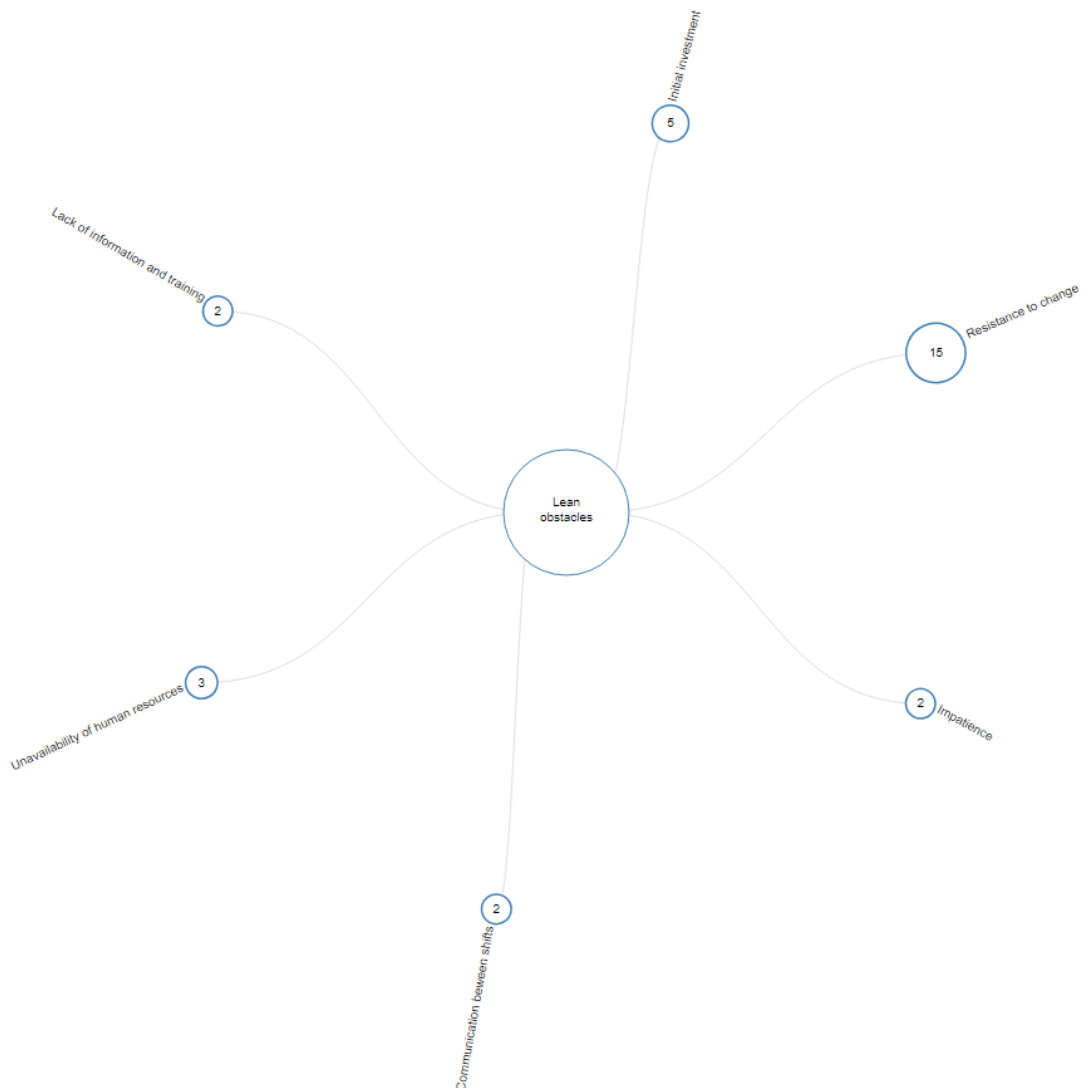


Figure 11- Most references topics regarding lean implementation obstacles and difficulties.

## 4.2. Lean Green and Sustainability-Related Questions

This set of questions aims to explore the integration of Lean practices with environmental management- referred to as Lean-Green- to enhance resource efficiency and reduce costs. It has the intention to find if SMEs see a synergy between these two approaches and explore the implementation of environmental management systems, the benefits and challenges of combining Lean and Green practices and implementing sustainable strategies, and how and if these companies address all the three pillars of Sustainability: environment, economic and social. This set of seven questions can be found in Appendix A

The first question related to LGS is:

- The term Green-Lean addresses the combination of Lean efforts with environmental management to increase resource efficiency and reduce costs. Do you see a synergy with these two approaches, or are they competing with each other? (Dües et al., 2013)

In Table 18 shows different ways that companies view whether there is a synergy between these two approaches or if they are competing with each other.

Table 18- Answers given about if companies find a synergy between the LG approach or not.

	Answers
Nimco	Yes, it makes sense that Lean and Green have synergy. Lean is all about reducing waste and increasing efficiency. For example, if we reduce the amount of rework we do each month, we save a lot of electrical energy and time that can be allocated to other tasks. By reducing rework, we also decrease the amount of animal fur that we waste. In my opinion, Lean and Green are holding hands together.
Promecel	I do not see a direct connection between these two approaches. We make many Green investments that don't require any Lean tool or practice to sustain them.
Animar	Yes, of course. When we implemented Lean methods and practices, we became much more organized, and information between the departments was transmitted much quicker. In terms of X-ray exams, having all the information about the dog or cat available at all times has helped us reduce exam errors and, therefore, shorten the number of X-rays we perform.
Artevasi	I connect Lean and Green in the sense of energy efficiency and waste management. Basically, everything is related to environmental performance. So, in my opinion, Lean is connected to the environment. Not in all aspects, but in general, there is a big energy difference between these two approaches.
CIN	Both approaches are aligned. When efficiency-related actions are taken, environmental impact should be an important factor in determining whether to implement them or not.
Colquímica	Yes, complete synergy. When we save resources by doing more with less, there is always an environmental benefit. This can result from optimising machine time, reducing energy consumption, or decreasing production waste. Avoiding quality defects also has an impact by reducing the need for rework. At this moment, I see them as totally interconnected.
Mesa-Ceramics	Yes, Lean applies to all areas, including the environmental and production parts. Directly or indirectly, we will always be talking about two methodologies that work in the same direction.

Only one company of the twenty did not observe a synergy between these two approaches, stating that "We do a lot of Green investments that do not need any Lean tool or practice to sustain it". The rest of the companies found a "complete synergy" and that Lean and Green are "holding hands together" (Nimco) and "totally interconnected" (Colquímica). Most argue that Lean focuses on reducing waste, optimising processes, and improving efficiency, which inherently reduces resource consumption and environmental impact, and that by integrating Lean and Green principles, organisations can achieve both operational excellence and environmental sustainability.

The second question of the questionnaire is:

- Does your company deploy any environmental management systems, or does it address the environment with other methods such as energy or water management, reduced CO2 emissions, etc.? If not, why? (Garza-Reyes et al., 2014)

In Table 19 there are some answers about how companies decrease their environmental impact by implementing “Greener” methods.

Table 19- Answers given about environmental management systems.

	Answers
Fricon	Yes, we installed solar panels to use Greener energy and save costs. We measure and control water and electricity usage. We have a suggestion box where employees can submit ideas, and we recently implemented one by purchasing a Greenhouse for the painting area to control emissions. We also switched all harmful gases to R290, a Greenhouse gas that does not affect the ozone layer. Our focus on a Greener approach is our differentiation, as we are not very competitive in price compared to the rest of the market. However, we stand out by prioritising Sustainability and environmental concerns.
Becri	We have solar panels installed across all the roofs and some skylights to allow natural light to come in and save energy. We changed the car fleet to electric ones and do waste management and recycling.
Artevasi	Yes, we have a quality management system certified according to the ISO 14001 standard. Therefore, we monitor resource usage, including electricity, fuel, raw materials, and waste, and evaluate trends to improve environmental performance.
Corks supply	For example, we buy cork with the verification of forest Sustainability. We strive to be sustainable and promote forest Sustainability. We installed solar panels to increase our Green energy use, achieving an annual saving of 20%. We have a system that allows us to utilise 100% of the harvested cork. When we cut the cork, we achieved a 48% yield. The remaining 52%, which consists of dust and dirt, is used to fuel our boiler. Sometimes, by using biomass, we are completely sustainable in terms of energy. We installed a highly efficient cork boiling system that optimises both thermal energy and water usage. After boiling each pallet of cork, the hot residual water is transferred to a containment tank, passing through a heat exchanger that transfers the thermal energy from the residual water to the clean water added for the new cycle.
Cplas	Yes, we have been certified by ISO 14001 since 2021, and we think it makes a lot of sense because every type of waste we produce is recycled and reincorporated into the processes. We shred plastic waste, and it enters the process again as raw material. We have also implemented solar panels to use Greener energy.
Mesa-Ceramics	Yes, we have solar panels installed for electric energy. Regarding water, we have an internal ETAR that allows us to reuse and clean the water.
Moldart	Yes, this year, we have a big project that consists of integrating solar panels and making the energy 100% renewable. We have been doing a lot of tests on the company’s environment and air quality because we work with a lot of painting, and our employees must wear masks in that section. We are also trying to use more water-based products to decrease the usage of diluents and prevent environmental damage.

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	Answers
Mystic	We do not have a management system that meets certified rules. There are processes to reduce carbon emissions and reduce industrial waste because we are a hospitality and transport company. We try to optimise routes to reduce fuel consumption, changing it to bio combustibles and eliminating everything of single-use paper and plastic. We made some architectural changes by installing some skylights to have natural light to save some energy. We also changed the car fleets to electric cars. We measure what every person wastes on paper and plastic to have better control of production costs.

Most of the responses demonstrate a strong commitment to Sustainability and environmental responsibilities through various initiatives and certifications such as ISO 14001. Companies are implementing a wide range of sustainable practices, including the installation of solar panels for renewable and Greener energy, waste management and recycling programs, changing the car fleet to electric vehicles and utilising Greener gases to minimise carbon emissions. Some companies go even further; for example, Corksupply designed their own efficient cork boiling process, and Mesa-Ceramics developed an internal wastewater treatment plant. This demonstrates a proactive approach to Sustainability and resource management. Mystic tries to optimise routes to reduce fuel consumption and CO2 emissions. The commitment to environmental Sustainability, as mentioned by Fricon, also serves as a competitive advantage in the market.

The third LGS-related question is:

- Do you see benefits in the combined implementation of Lean and Green as a single approach? Would it be conceivable and useful to combine Green-Lean for your company?(Dües et al., 2013)

In Table 20, some opinions about whether there are benefits to combining Lean and Green implementation as a single approach and whether it would be useful for them.

Table 20- Answers given about if companies see benefits with the implementation of lean and green as a single approach.

	Answers
Solidal	In my opinion, it can only work this way. When we consider daily routines and improvement tools, we always integrate environmental issues because otherwise, we would not address them effectively.
Nimco	Yes, because Lean principles are very versatile and can be applied in many different areas, from production to quality and finally to environmental considerations. They are very compatible because Lean can also contribute to reducing energy consumption.
ROQ Laser	It depends. If Lean is well implemented, it leads to Green benefits, but this does not mean that I cannot implement Green without Lean. Many companies only implement Green actions, but Lean most of the time, has Green benefits because if you have less waste, you save some energy. We did, in fact, implement Lean practices and tools looking for Green benefits as well and with the intention of being environmentally sustainable.

	Answers
Mesa-Ceramics	As I was saying, we are talking about the same thing. I do not think they have different goals. From a marketing point of view, we could gain advantages related to the company's image, but both methodologies focus on reducing waste, whether it is production waste or environmental waste.
Colquímica	Many because it's two in one. We are analysing the projects and the benefits of Lean and raising the company's Sustainability. Since the 21st century is the century of Sustainability, we have to incorporate this into our management because there will be natural selection, and those who are not aware of it will be left behind.
Fricon	Yes, of course. If we manage to gain from both of those methods, it is the best of both worlds. Apart from being Green, in my opinion, it is a brand that we should glorify because it brings us more value to our product. In commercial terms, it is quite positive.
Promecel	I believe there are clear benefits in combining Lean and Green as a single approach. It allows us to improve efficiency, reduce waste, and enhance our environmental Sustainability efforts, so I think it could be useful for us.

All the responses recognised the synergy between Lean and Green, highlighting how Lean principles can contribute to environmental Sustainability. ROQ Laser emphasised that “if Lean is well implemented, it leads to Green benefits”, but it does not mean that by implementing Green actions, you can have Lean benefits.

The integration of these two methods as a single approach is viewed as a way to achieve efficiency gains while also improving environmental outcomes, which is advantageous for SMEs seeking to enhance their competitiveness and Sustainability. As Fricon said, “In commercial terms, it is quite positive.” Some companies like Colquímica emphasised the importance and benefits of Lean and Green actions to raise “company Sustainability” and not “be left behind” by the competition.

The fourth question of this questionnaire is:

- The term Sustainability does not only address the environment, but comprises three dimensions, and it is completed through economic (e.g. long-term and sustainable economic growth) and social (e.g. human rights and workers' rights, community engagement) aspects. (Alves & Alves, 2015; Verrier et al., 2014) Does your company address the other two components of Sustainability in any way? If not, why?

In Table 21, some answers given about how companies approach the economic and social pillars of Sustainability are presented.

Table 21- Answers given about how companies approach the economic and social pillars of sustainability.

	Answers
Fricon	Socially, our human resources department is very committed to helping society; for example, last week, we had a fair of clothes to donate to children with needs. Throughout the year, we can also donate things like food and drinks. We participate in many initiatives related to sports and social assistance and maintain a strong connection with our employees and their families. Economically, we are a growing company. We invest in Lean practices to accelerate this process, and it has been very profitable and helpful.
Animar	Generally speaking, I believe that every company aims to maximise profit and be economically sustainable. Our bigger social Sustainability advantage was the decrease in general stress and better organisation. This generates well-being within the company, and everyone knows what to do, when to do it, and how to do it. For example, we established a team solely dedicated to conducting ultrasound exams, ensuring that ultrasounds are always readily available. This saved us much time and ensured quality of service, which made us gain more customers.
Promecel	We invest in the well-being and happiness of our employees. Everyone has access to health insurance, and we offer a variety of activities throughout the year. They also benefit from discounts on gas, books, dentists, and physiotherapy. We have donation initiatives to help those in need, demonstrating a strong commitment to social responsibility both internally and externally. Economically, we implement Lean with the intention of becoming economically sustainable because we believe it helps a lot.
Cplas	Yes, the pillars of Sustainability are addressed in this organisation. The environment pillar is, of course, addressed because we are a plastic-user company. Economically speaking, I think every company wants to be sustainable economically, and that is also why we implemented Lean: to reduce total production costs and increase efficiency. Finally, the social pillar is an important topic, and we have considered, two years in a row now, one of the fifty best companies to work in Portugal. The well-being and safety of our employees and their families are constant worries for us, so we try to provide the best working conditions. We are concerned not only with internal social responsibility but also with external initiatives through promotional campaigns. Additionally, we have an internal library where employees can share books with their children as well.
Lidergraf	In my opinion, Lean addresses all three pillars of Sustainability because it reduces costs, simplifies the process to make it more ergonomic and easier for the employee, and helps the environment by reducing raw material and energy usage. For example, our adoption of less toxic chemical products means we help not only the environment but also the health of our employees and society.

	Answers
Corksupply	At this moment, in everything we do, we are concentrating on improving these 3 pillars of Sustainability, in which we can have a more significant impact. Corksupply invests in its employees and the local community by providing training, ensuring safe working conditions, and fostering a culture of Sustainability. By engaging with local communities and supporting sustainable forestry practices, the company helps to preserve jobs and maintain the ecological balance in cork-producing regions. In 2022, we created Beyond Us, a program designed to centralise and organise our donations and volunteer efforts for charitable organisations that serve the most vulnerable populations and their social needs. By supporting nonprofit organisations that align with our company's values and mission, we can make a significant impact in the community. Corksupply maintains economic viability by optimising production processes to reduce waste and improve efficiency. The company's commitment to Sustainability attracts environmentally conscious customers and opens new markets, enhancing its competitive advantage.
Nimco	The company works on the Sustainability of the company itself and the people who work there. We were able to defeat COVID-related issues without entering layoffs and without putting people in a weaker economic state. At this moment, they are planning the construction of a new factory, and that is only possible if you are economically sustainable. And then, there is a constant worry about providing higher salaries and better working and safety conditions. We have partnerships with stores and services that our employees can enjoy. Before the day of work, we do a little gym and stretch session to prevent injuries. In my opinion, our company stands out for this reason.

The WebQDA software helped identify the most common topics surrounding each pillar of Sustainability mentioned in the answers from each company.

In Figure 12, regarding social Sustainability, the most common topics are “Community Engagement and Employee Well-being” and “Internal and External Responsibilities”. Some companies, such as Fricon and Promecel, are actively involved in social activities like clothing fairs and food donations (as presented in Table 21). Additionally, other companies prioritise employee well-being; for example, Nimco has partnerships with stores and services offering employee discounts. Lidergraf has simplified its processes to make them easier and more ergonomic for its employees. Corksupply and Promecel emphasised that they are both dedicated to internal social responsibility, such as creating safe working conditions and supporting local communities through external initiatives.

Regarding the economic pillar of Sustainability, the most common topics are “Profitability and Growth” and “Resilience and Viability”. All companies mentioned Lean as a tool to help them achieve economic Sustainability by reducing costs and increasing productivity, thereby ensuring economic resilience and long-term viability. For example, Nimco highlighted that they “were able to defeat COVID-related issues without entering layoff and without putting people in a weaker economic state”, all because of their constant worry about being economically sustainable.

## Results and Discussion

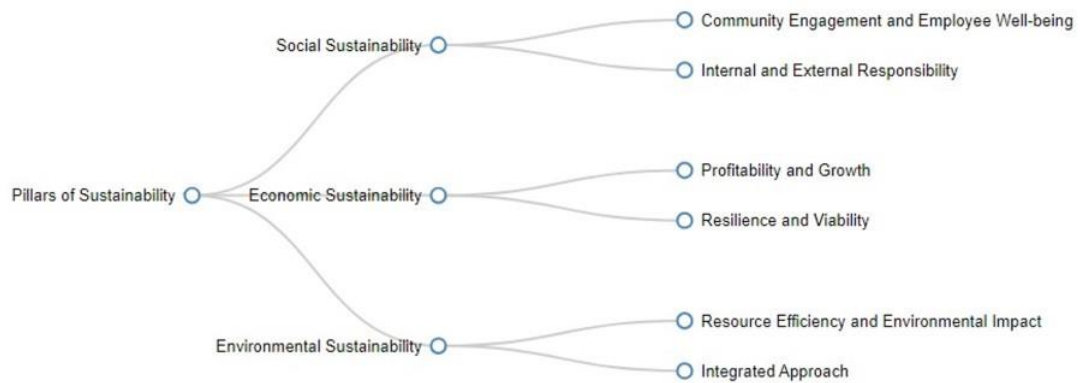


Figure 12- Main topics regarding each pillar of sustainability.

The next and fifth question related to LGS is:

- Finally, Sustainability also implies the ability to sustain Lean (and Green) efforts in the long-term. How does your company intend to achieve this?(Wong & Wong, 2014)

In Table 22, some answers given about companies intending to sustain Lean and Green efforts in the long term to be more sustainable are presented.

Table 22- Answers given about companies intend to sustain lean and green efforts in the long-term.

	Answers
ROQ Laser	Everyone is collectively committed to our daily objectives and routines, as they understand their role in driving improvement for the company. This is why we hold daily Kaizen meetings and implement the 5S and standard process methods at every workstation. After each shift, there is a 10-minute period dedicated to discussing Lean metrics and indicators, as well as cleaning and preparing the workstation for the next shift.
Becri	Our clients' first question nowadays is always about the environment. They want to know if we prioritise Sustainability and only work with companies that have environmental certifications like ISO 14001. Our company aims to maintain ISO 9001 and 14001 certifications and continually work towards a more sustainable future by always bringing that topic to our meetings. This is only beneficial to us because it improves our competitiveness and company image.
CIN	The maintenance/ implementation of Lean Green methodologies should take a top-down approach. Top management should convey the topic's importance to subsequent levels and ensure that the culture is maintained.
Colquímica	The company's Sustainability strategy extends until 2030. This strategy includes several indicators, namely decarbonisation, water consumption reduction, waste reduction, and a decrease in work accidents. A value stream map we created is Lean Green, and it has won two awards. It has all these indicators represented throughout the processes. Consequently, more Sustainability reports are being produced in departmental projects, and more Lean tools, such as A3 thinking, are being applied.
Fricon	Through being dynamic and competitive. We have daily meetings and monthly with all support teams and have our internal audits. We have an internal rule of always giving feedback on every action so people can feel more connected and part of this improvement.

	Answers
Promecel	Focusing on improvement and environmental responsibility ensures the longevity of our efforts. Our company plans to sustain Lean and Green efforts by making them a core part of our culture and operations.

The answers provided by various companies demonstrate a comprehensive and proactive approach to sustaining Lean and Green efforts in the long term.

Many companies, such as ROQ Laser and Fricon, emphasise the importance of incorporating Lean and Green practices into daily routines, meetings, and the overall company culture. This approach ensures that Sustainability efforts are not seen as separate initiatives but as integral parts of everyday operations.

Becri highlighted how customer's expectations are driving companies towards Sustainability by requiring ISO 9001 and ISO 14001 certifications. So, maintaining these certifications not only responds to the demands of the customers but also "improves competitiveness and company's image".

On the other hand, CIN pointed out the importance of a top-down management approach: "Top management should convey the importance of the topic to subsequent levels and ensure that the culture is maintained." This top-down approach helps maintain a strong, consistent culture focused on Sustainability.

Lastly, some companies like Colquímica find it essential to ensure Sustainability efforts like decarbonization, water consumption reduction, and waste reduction to minimize their ecological footprint.

The sixth question of this questionnaire is:

- How important is the topic of Green-Lean and Sustainability for your company? Do you see a need for action? If yes, why? (e.g. Government regulations, climate change, lack of resources) (Daily & Huang, 2001)

In Table 23 there are some answers given about how important LGS is for their company and if there is a need for action.

Table 23- Answers given about how important LGS is for their company and if there is a need for action.

	Answers
CIN	Global competitiveness, fluctuations in resource supply, governmental regulations and other topics have turned Lean Green actions into a priority. The application of measures at business level promotes individual awareness.
Becri	This is very important. Our CEO always wants to be a step ahead of the competition. I think that all employees should feel free to give improvement ideas and feel part of the company's evolution. I think that this mentality is something to strive for.
Solidal	It is very important, even for our position and strategy towards our customers, especially the Nordic market, because they value these issues more. I think it is vital to survive in today's market.

## Results and Discussion

	Answers
Animar	I think that Lean Green and Sustainability are current global topics because they are a way to become more competitive in the market, and they help us upgrade the workplace and retain our employees. The only thing I can think of regarding these subjects, such as Lean and Green, before opening a company or a new clinic is that after opening, it is way more difficult to make changes. So, in my opinion, it should be a requirement to have, for example, an external consultancy assisting and supporting a company when a new structure and company is being built. For example, if I wanted to install solar panels to have Greener energy, it would have been easier if I did it when the clinic was being projected.
Colquímica	Colquímica, by being a chemical industry, is on the front line of the attention of our stakeholders. So, there are a lot of questions and interactions with the customers regarding Sustainability. First, it is important to change society's mentality because we get blocked. We need data from the suppliers because everything works within a value chain, and sometimes, there is a lack of information. Also, in terms of technology, there is much investigation to do, and it is necessary to change technology. The support is very late, the PRR is blocked, and money is not going to the companies. Probably, with the European regulation and taxonomy, this will accelerate. However, until then, it has been slow, and there is no technology available to address this big change.
Promecel	Whoever does not catch the Sustainability boat will stay behind and lose. Lean follows the same path. We are talking about tools that reduce costs and waste and optimise processes and service quality.

These responses underscore the critical importance of integrating Lean and Green practices within a company's strategy to remain competitive in the global market and improve service quality. For example, Solidal finds it “vital to survive in today’s market,” and Promecel points out that “whoever doesn’t catch the Sustainability boat will stay behind and lose.”

Colquímica sees a need for change regarding society's mentality and a necessity to investigate and change technology to invert the lack of information within the value chains. They also emphasised that “supports are very late, the PRR is all blocked, and money isn’t going to the companies,” but this may change “with the European regulation and taxonomy.”

On the other hand, Animar emphasises integrating these practices from the planning stages of a company or new facility, highlighting the challenges of implementing such changes post-establishment. It underscores the importance of proactive planning to streamline the adoption of sustainable technologies and practices, making the transition smoother and more cost-effective.

The last question regarding LGS is:

- In your opinion, what are the obstacles for implementing a sustainable strategy and which aspects need to be addressed in an organization to overcome these? (Zhang & Awasthi, 2014)

In Table 24, some responses given by the companies interviewed regarding the obstacles faced during a sustainable strategy implementation are presented.

Table 24- Answers given about obstacles and aspects that companies face when implementing a sustainable strategy.

	Answers
Artevasi	The main challenge lies in seamlessly integrating sustainability into the organisation's strategic management and defining these aspects hand in hand from the beginning. The benefits and advantages gained from this integration, in terms of market competitiveness and positioning, are significant. An obstacle worth mentioning is the lack of formation about Lean and continuous improvement.
Colquímica	Sometimes, even with strong motivation from the administration, there are many paths and uncertainties about the best strategic approach. However, you must keep trying and learning from mistakes to improve. Defining the necessary steps is challenging, and companies often struggle with the strategy to implement them. The time required for these activities is significant, and not all companies have this available.
Fricon	There are difficulties related to replacing some components, especially those made of plastic because plastic has many recycling challenges. This is our main difficulty. Investment is always a priority because, without funding, we cannot accomplish anything.
Promecel	Being a small company can sometimes make implementing a sustainable strategy difficult. One obstacle is that people still don't effectively see the benefits of implementing sustainable strategies, and sometimes, they don't even understand. There is a lack of awareness and sensibility towards these topics. As long as people can open their taps and water comes out, they won't perceive a problem.
RCM	For me, there are two main obstacles. Firstly, the people. Human beings have always been greatly unsettled by change. For example, here, at the offices, it is way easier to make changes compared to the production floor. Maybe because they are older or less instructed. I do not know, really! Lastly, the initial investment can be very uncomfortable for the financial "lungs" of the company.
Lidergraf	Of course, people's mindset is an obstacle, but also a lack of sustainable raw material alternatives. I know that sometimes it is difficult to find alternatives to certain materials, but it may be a topic to study, and the laws are becoming increasingly rigorous about sustainable supply chains.
ROQ Laser	The strategy to implement a sustainable idea must be top-down. If the top management lacks the motivation and the right mindset, nothing will ever happen. Another obstacle is winning over and convincing the operators who will be using Lean methods every day. This involves persuading them about the advantages that Lean methods will bring to the company, which can be achieved through extensive training and persistence.
Mystic	The main obstacle is the top management. In family companies, they are often more conservative and find it difficult to understand new sustainable ideas and strategies. There is a lack of awareness among top management. Additionally, there is a lack of education, information, and communication. Lastly, there is resistance to change because some people do not understand the need for it. As I mentioned, this is largely a problem of communication and education.

Based on the responses received, companies identified several key obstacles and aspects that need to be addressed in order to implement a sustainable strategy effectively. With the assistance of the WebQDA software, in Figure 13, the six most common topics addressed by the companies interviewed are presented.

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With the same most referenced obstacle as when companies implement Lean methods, “Resistance to change” is also the main obstacle that these companies face when implementing sustainable strategies and changing “people’s mindset”, as Lidergraf noted, reflecting RCM’s observation that “human beings have always been greatly unsettled by change”. Overcoming resistance requires effective change management strategies, including communication, involvement, and incentives.

The second most referenced topic is “Initial investment,” which most companies find challenging to allocate the necessary funds upfront, even if the long-term benefits are substantial. As mentioned by RCM, this “can be very uncomfortable for the financial “lungs” of the company.

The third most common topic is “Uncertain methods”, as “there are many paths and uncertainties about the best strategic approach”, as noted by Colquímica in Table 24. The lack of known alternatives and solutions can also create uncertainty, which can create hesitation and lead to inefficiencies.

“Lack of leadership” is also a topic addressed because, as ROQ Laser mentioned, “if the top management lacks the motivation and the right mindset, nothing will ever happen.” On the other hand, Mystic emphasised that there is a lack of awareness from the top management as they “find it difficult to understand new sustainable ideas and strategies,” and this creates barriers to improvement.

“Lack of training” and general awareness of these topics are obstacles to Mystic and Promecel, for example, because “as long as people can open their taps and water comes out, they won't perceive a problem.”

Lastly, “lack of resources” such as time and human resources can be a barrier to achieving Sustainability goals.



Figure 13- Most common obstacles addressed by the companies interviewed when implementing sustainable strategies.

### 4.3. Sustainable Industry 4.0 and LG-Related Questions

The next two questions aim to investigate the different opinions companies have regarding how digitalisation and Industry 4.0 technologies can influence their Lean, Green, and Sustainability actions and expose some technologies implemented in their companies to monitor and analyse those actions.

The first question regarding industry 4.0 is:

- Do you think digitalization (Industry 4.0 technologies) can help with making your organization Lean and Green and more sustainable?

In Table 25, the companies interviewed gave some answers about how digitalisation makes their organisations Lean, Green, and sustainable.

Table 25- Answers given about how digitalization makes the organizations LG and more sustainable.

	Answers
Fricon	Yes, digitalisation has facilitated our communication with the rest of the world and has shown us that the Greener and more sustainable we are, the more it becomes a part of our brand image. Industry 4.0 is here to help us monitor and automate some processes to reduce errors and improve efficiency. We used to spend much time controlling processes, which nowadays, with digitalisation, is no longer necessary.
Becri	Initially, the records were all manual. Now, every station has a computer that registers everything that is being done and with what material is being made. The idea is to spread across all the processes to be able to monitor and analyse everything that happens on the production floor. To have all the information available at any time and in real-time, we can define better production plans and not overproduce and reflect on possible improvement opportunities. By registering energy and water usage, we can form reports and plans to implement a reduction and be Greener.
ROQ Laser	Absolutely, in every aspect. Industry 4.0 is not just a concept; it is our reality, involving process automation and real-time monitoring of billing and productivity. We can now monitor every aspect of production on the shop floor, significantly easing communication with every department. These advancements help us become more Lean, Green, and sustainable. In my opinion, Industry 5.0 is already around the corner. Within the next five years, we will need to adapt our strategy to incorporate artificial intelligence so as not to lose competitiveness.
Lidergraf	Yes, I think so. It has helped us monitor and analyse process improvements and global performance and made communication between departments and machines much easier.
Cplas	All the projects we have been working on are related to process automation because they make the lives of our operators easier and make monitoring and analysing simpler and less difficult. So, digitalisation was a turning point in terms of communication and follow-up.
Clínica Oftalmológica Sousa Neves	Yes, of course. For instance, we have been serving patients since the clinic opened 22 years ago. Managing all that information on paper rather than digitally would be a significant headache for us. Digitalization has allowed us to save a considerable amount of time in locating client information, enabling us to schedule more appointments per hour. Digitalisation has also made communication between departments way easier.
Promecel	Digitalisation is the present and future of security methods. When things depend on people, there's always a risk of human error. People should not fear being replaced by machines someday because that won't happen.
Colquímica	Digitalisation is mandatory, and we are moving forward to digitise certain processes. This applies to the quality process, which already has tools, but we need more powerful ones. It also applies to Sustainability because of the large amount of data to manage. For example, Colquímica operates three factories in three countries, generating a substantial volume of data. It is essential to digitalise everything; otherwise, managing this data becomes unbearable.

Based on the responses from each company, including those listed in Table 25 and with the assistance of the WebQDA software, a list of the four most referenced topics was extracted and represented in Figure 14.

70% of the companies mentioned that “Process Automation” has helped them the most regarding their Lean, Green and Sustainability actions as it “reduces errors and improves efficiency”, as stated by Fricon. It also makes “the lives of our operators easier and makes monitoring and analysing way simpler and less difficult”, as Cplas said. Process automation is a critical component of digitalisation, transforming how businesses operate by reducing the need for manual intervention in routine tasks. The automation of processes not only saves time but also allows employees to focus on more strategic and creative aspects of their roles.

The topic “Process Monitoring” highlights how digitalisation allows the real-time monitoring of processes, which was mentioned by 50% of the companies. As noted by ROQ Laser, “real-time monitoring of billing and productivity” as digitalisation has this versatile capability that enhances efficiency and transparency across operations. By real-time process monitoring, it is possible to “define better production plans and not overproduce and reflect about possible improvement opportunities” and “by registering energy and water usage, we can form reports and plans to implement a reduction and be Greener”, as emphasised by Becri.

“Communication” represents the role of digitalisation in enhancing communication within and outside the company. Sharing continuous improvement ideas and action plans flows faster and more efficiently through digital communication. Digitalisation allows companies to overcome the problem of a lack of information and participation from everyone within the company. Lidergraf highlighted that digitalisation “made communication between departments and machines way easier.”

“Data Management” is also one of the most referenced topics, as digitalisation aids in managing large volumes of data effectively. Colquímica highlights that “it is essential to digitalise everything; otherwise, managing this data becomes unbearable”. For example, for Clínica Oftalmológica Sousa Neves, this has helped them improve their productivity by allowing them to “save a considerable amount of time in locating client information, enabling us to schedule more appointments per hour”.

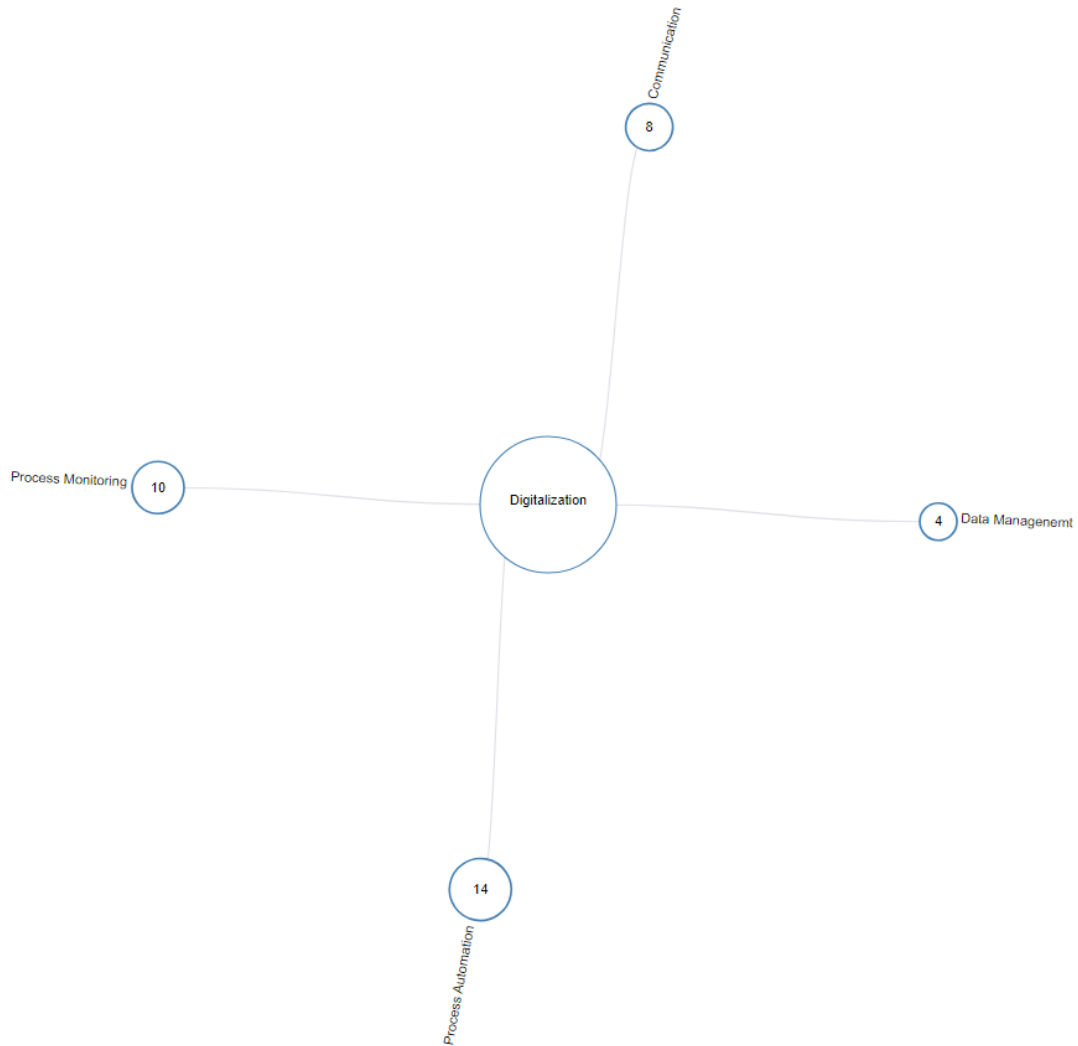


Figure 14- Most common topics regarding digitalization to make organization Lean, Green and sustainable.

The second and final question regarding Industry 4.0 is:

- Have you any examples of using Industry 4.0 (digitalization) to improve your Lean-Green actions?

In Table 26 various examples are presented, provided by companies on how they have utilized Industry 4.0 (digitalization) technologies to enhance their LG actions.

Table 26- Examples of industry 4.0 technologies to improve LG actions.

	Answers
Lidergraf	Yes. We have sensors in all the machines that register the energy, water and material usage just like paper, paint and varnish. We also have collection points and with that we obtain production reports that calculate the efficiency of the processes and many other things.

	Answers
Corksupply	In terms of automation, all our machines generate outputs, and we have a dashboard to monitor them. We use extensive programming to prevent contamination or errors. We aim to implement pneumatic automation for internal transport within the industry. By digitalising all workplaces, we can obtain real-time information about what is happening in the company because all machines are connected online to a program called proGrow. This allows us to understand our efficiency, outputs, and alerts.
Becri	For example, in the cutting process, when the pieces are cut, they must be grouped into different lots: front, back, right sleeve, and left sleeve. Then, they are regrouped into one piece. Previously, there was only one computer for ten stations, so workers could not all register their lots at the same time and had to wait. Now, we have bought a tablet and a small printer for every workstation, significantly reducing waiting times. Before, defects were registered on paper and handed to us. Now, they can be registered on tablets and appear directly in our computer system. We saved time and paper with this application.
Colquímica	Yes, for example, we developed software and installed a robot to handle packaging. Digitalisation not only makes production processes more efficient and communication easier but also addresses the significant issue of a shortage of workers in the industry. Few people want to work in the industry, yet it is the industry that drives the economy. Thus, Industry 4.0 and 5.0 are becoming increasingly important in filling difficult-to-fill positions.
Nimco	Yes, we have examples of aligning machine technology with our processes. We bought scanners that digitise objects so we can work on them in 3D on the computer. Our machines also regulate all variables themselves, which reduces non-quality.
Fricon	We are currently installing large-scale management software to control production. We have also replaced manual label printing with automatic printing, which has resulted in fewer errors and variations and increased productivity. In general, things are much easier now.
Artevasi	For example, we implemented a production system management software and iPick logistics software, which enables us to expedite product reception and order placement. Upon a product's arrival at our company, its quality is determined and controlled through barcode scanning. These systems also facilitate communication and provide access to a cloud-based data repository, ensuring that all necessary information is readily available at any time. Additionally, our IT team developed 'placing orders' software, making bureaucratic tasks much simpler.
Cplas	Yes. We are working on installing a completely automatic production line where the operator is only responsible for the packaging part, and we can achieve that by installing cooperative robots throughout the line. Another example is the installation of an artificial vision system on the injection process to verify and detect defects and avoid rework and waste. All of this is aimed at maximising product quality and reducing customer complaints.

Considering all the answers from the 20 companies interviewed regarding examples of using Industry 4.0 to improve their Lean and Green action, Figure 15 shows the most referenced Industry 4.0 technologies.

50% of the companies gave examples of the “Internet of Things” technology. IoT involves connecting devices and sensors to collect and exchange data over the Internet and enables real-time monitoring. Lidergraf gave the example of having “sensors in all the machines that register the energy, water and material usage just like paper, paint and varnish.” IoT also allows

## Results and Discussion

companies to monitor productivity and waste percentages and analyse and identify continuous improvement opportunities.

50% also gave examples of “Cloud Computing” technology. These companies found that with the digitalisation process, they can access data, applications, and services from any location with an internet connection. This flexibility enables remote work and collaboration among teams of different departments.

“Big Data Analytics” is also shown as one of the most used technologies, as it helps companies process and analyse large volumes of data using advanced analytics techniques. For example, Corksupply stated that “all machines are connected online to a program called proGrow” and “This allows us to understand our efficiency, outputs, and alerts.”

“Robotics and Automation” was also one of the most referenced examples of an Industry 4.0 technology as it results in “fewer errors and variations and increased productivity”, as stated by Fricon.

Nimco gave a “Digital Twin” technology example: They “bought scanners that digitise objects so we can work on them in 3D on the computer.” This allows for simulating and optimising performance in real-time by having a virtual model of a physical asset.

Lastly, “Artificial Intelligence” is used as AI-driven systems can autonomously make decisions and adjust operations based on data analysis. For example, Cplas expressed that they have an “artificial vision system on the injection process to verify and detect defects and avoid rework and waste”.

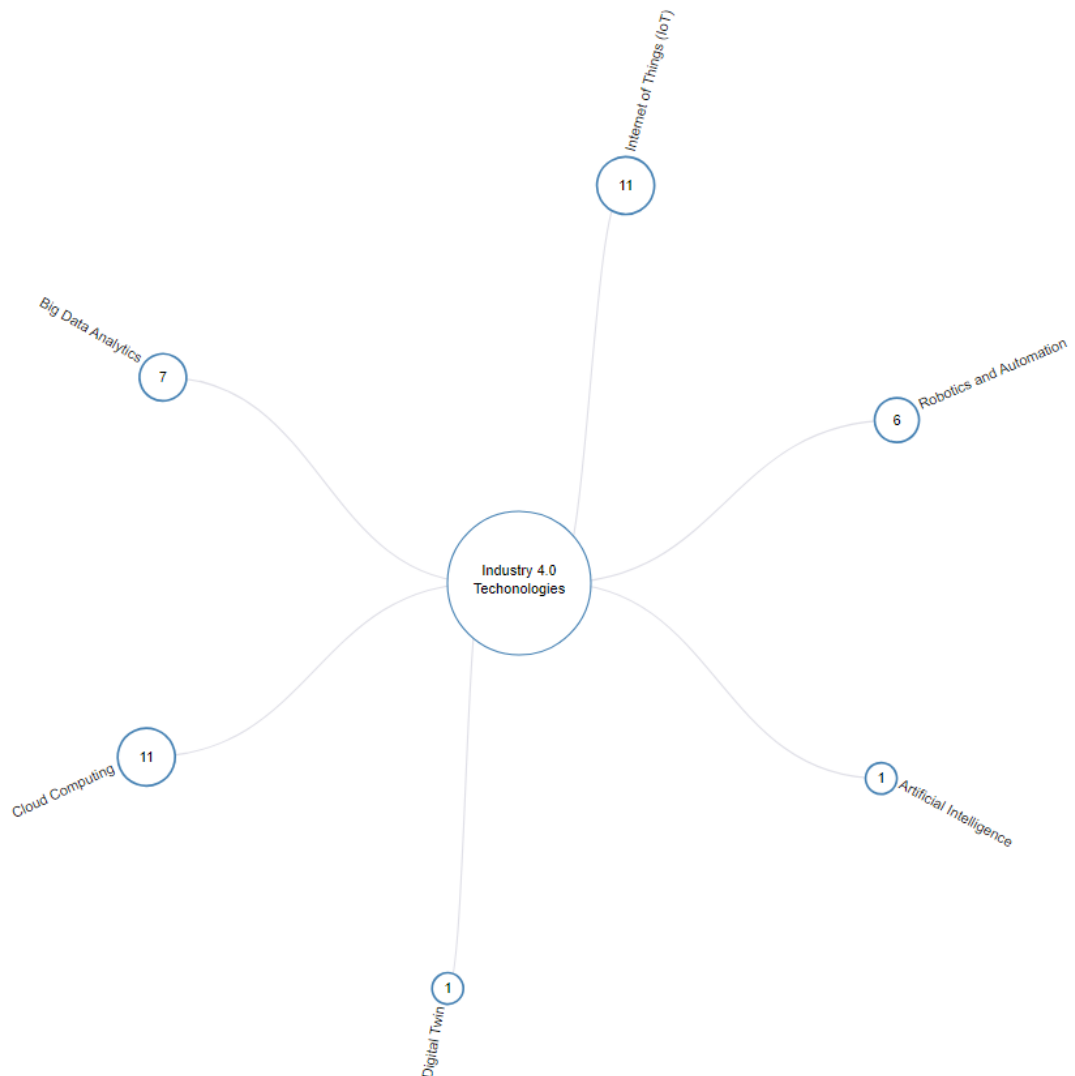


Figure 15- Most common Industry 4.0 technologies.

#### 4.4. Framework Phases and Steps

The goal of this subchapter is to build a framework by analysing insights from the interviews to justify and validate each step. As SMEs find it challenging to implement these methodologies, this framework facilitates and enables them to systematically implement Lean Green and sustainable practices while integrating Industry 4.0 technologies within limited budgets and resources. To ensure long-term success, it aims to improve environmental, economic, and social performance.

The developed framework comprises 4 phases divided into 13 steps, illustrated in Figure 20.

**4.4.1. Phase 1- Preparation**

Phase 1 involves assessing the requirements for implementation and determining the organisation's maturity level and current state to embark on a LGS 4.0 long-term journey. It is essential to evaluate the company’s readiness and ensure resource capabilities to proceed to the next phase and prevent project failures ahead.

**Step 1: Self-analysis and recognize need for change**

As SMEs prepare to implement Lean-Green and sustainable practices, Step 1 is designed to analyse their position on the market and their current situation in order to define targets and objectives and to identify the justification for implementation. A variety of internal and external drivers may drive this need for transformation (Cherrafi et al., 2016). Based on the previous analysis of the strategic goals that the company interviewed specified, the benefits they have achieved from Lean-Green implementation (Figure 9), KPIs defined (Figure 10), and the information gathered from responses to other questions. Table 27 provides a summary of external and internal transformation drivers.

Table 27- Key drivers for integrating Lean, Green and Sustainability.

Internal drivers	External drivers
Cost reduction and profitability	Improve service quality
Performance improvement	Reduce costumer’s complaints
Waste reduction	Market competition
Better working conditions	Improve organization’s image
Boost energy and water usage efficiency	Consumers requirements

**Step 2- Resource and economic capability**

Organisations must also ensure that they have the necessary resources and capabilities to integrate Green-Lean and Sustainability practices. This includes assessing the availability and proficiency of labour skills, the condition of machinery, the quality of materials, and the level of professional expertise. These factors are critical for meeting the requirements of both Lean and Sustainability initiatives (Siegel et al., 2024).

Moreover, economic capability plays a crucial role in the LG integration, encompassing financial resources, budget allocation, cost management strategies, and the ability to invest in sustainable practices and Industry 4.0 technologies.

As seen in Figure 11, “Unavailability of human resources” and “Initial investment” are two of the most common obstacles cited by the companies interviewed. These difficulties were frequently mentioned when providing advice to other businesses considering implementing Lean practices.

**Step 3: Top management commitment and training**

The success of the initiative heavily relies on the commitment and active involvement of top management (Grigg et al., 2020). The implementation of the Lean-Green and sustainable strategies specifically requires active participation by the top management (Yadav et al., 2019).

Managers should strictly follow the implementation by removing barriers, monitoring progress, supporting all the employees involved and demanding results (Cherrafi, Elfezazi, Govindan, et al., 2017).

As mentioned in the interviews with CIN and ROQLaser, respectively, “top management should convey the importance of the topic to subsequent levels and ensure that the culture is maintained” and “If the top management lacks the motivation and the right mindset, nothing will ever happen”. 25% of the companies identified “lack of leadership” as one of the barriers to implementing a sustainable strategy (Figure 13). Cplas also highlighted that a lack of motivation from the administration is an issue that companies need to address.

This implementation should follow a top-down approach, as top managers must have an evolved mindset towards improvement and must motivate their teams to walk in the same direction. As studied by Albliwi et al (2014), if the top management is not committed, engaged, and motivated, the chance of failure is high.

On the other hand, to expand the adoption of LGS throughout the organisation, executives must undergo training in both Lean and Sustainability. This training includes knowledge of Lean-Green tools, sustainable strategies know-how and the philosophy of each paradigm (Siegel et al., 2024). This will empower them to motivate employees and actively participate in implementing the framework. As this framework is designed for SMEs and knowing the characteristics and difficulties of SMEs identified during the interviews, to able to save costs and resources, Cherrafi, Elfezazi, Govindan, et al (2017) emphasised that companies can collaborate with nonprofit organisations, academic institutions and local government to take advantage of funding opportunities, obtain free technical assistance, and develop training courses.

“Lack of training” was identified as an obstacle to implementing both Lean tools and practices (Figure 11) and to implement sustainable strategies (Figure 13) by the companies interviewed.

#### **4.4.2. Phase 2- Planning**

This phase involves thorough planning and careful selection of resources for executing initial projects.

##### **Step 4- Develop company’s mindset and generate motivation**

Developing an LGS 4.0 mindset by integrating it into the company's vision and objectives helps generate employee motivation to embrace LGS 4.0 as a philosophy rather than a single project, and it creates a better understanding within the company of the reason why the organisation is implementing LGS 4.0 measures (Siegel et al., 2024). Everyone in the company should be integrated into the change and know the benefits that the implementation could bring to their work routine and the company. It represents a collective long-term effort supported by top management to promote the growth and development of employees’ potential and motivation by changing attitudes, values, behaviour, and the organisational structure so that the company can best adapt to new situations (Alves & Alves, 2015).

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This is an important step as “Resistance to change” was identified by 15 of the 20 companies interviewed as the main obstacle/barrier to the implementation of Lean, Green and Sustainability practices. Changing the operator’s mindset and work routine is found difficult for SMEs as there is a lack of Sustainability awareness and information about Lean-Green methods, and most of the time, employees do not understand the necessity to change. Figure 16 was obtained through the WebQDA software that identified every company with “Resistance to change” as an obstacle.

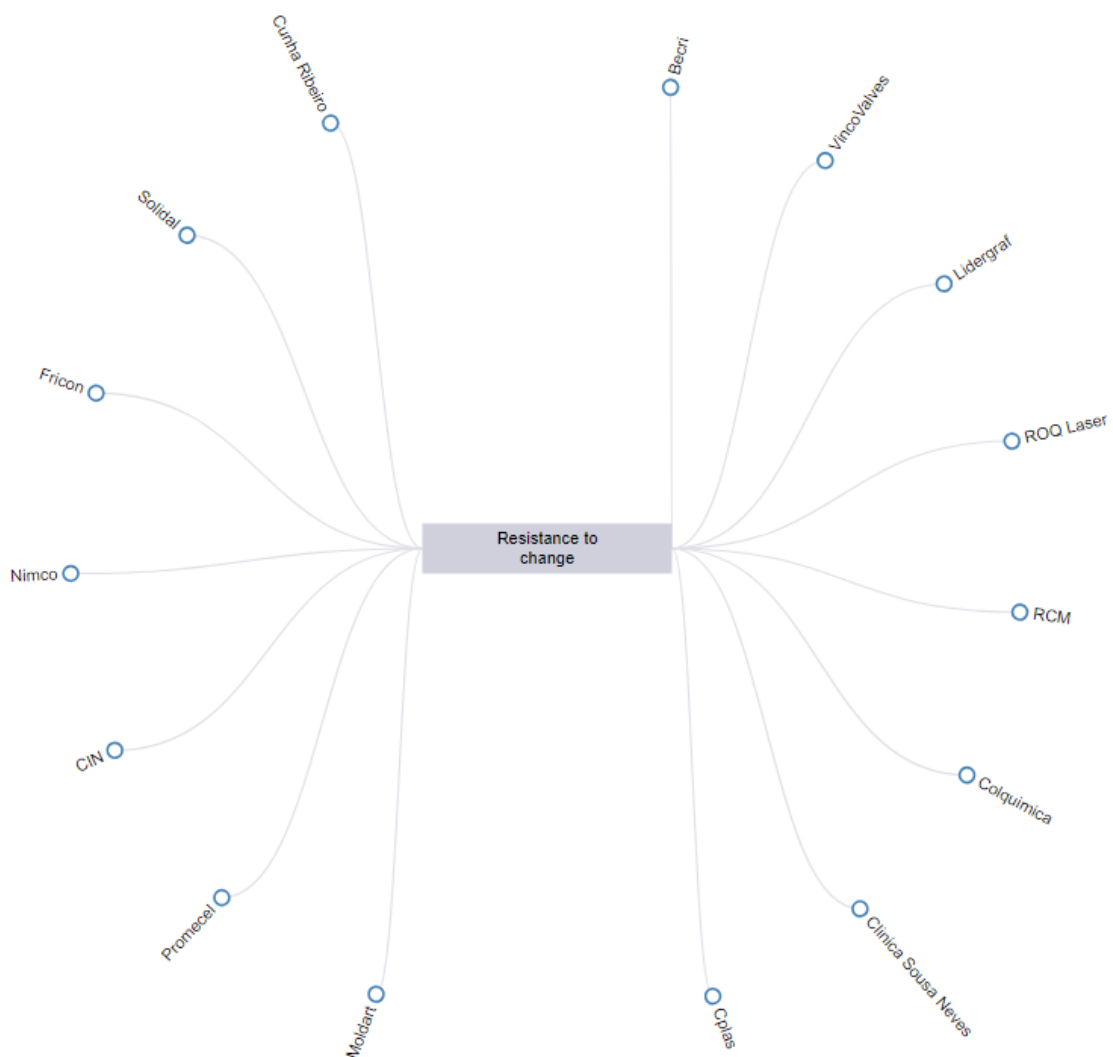


Figure 16- Companies mentioning “Resistance to change” as an obstacle.

Initial training and team meetings regarding quality concepts and Lean-Green and sustainable methods can help to generate understanding and awareness of these topics. According to Alves & Alves (2015), the commitment and acknowledgement of employees are determining factors for the success of LGS implementation.

**Step 5- Select leader and employees for LGS 4.0 team**

A full-time leader with a strong background in Lean manufacturing, sustainable methods and Industry 4.0 technologies should be chosen to lead the implementation process (Alves & Alves, 2015). This person will organise and bring together teams, plan project stages in detail, identify areas to implement tools, conduct training and regularly report on progress. They represent the person connecting the top management to the rest of the company and are responsible for the implementation.

Availability, experience, sense of responsibility, and knowledge regarding these topics should be considered when forming a team, and all employees participating in the implementation should receive all the necessary training and tools to conduct the project.

**Step 6- Choose key performance indicators**

The implementation of LGS 4.0 initiatives requires appropriate metrics to identify and drive improvement. Selecting the right KPIs makes progress towards the target state measurable, verifies if the company is on the right path, and identifies any deviations. To achieve this, it is essential to select Lean and Sustainability KPIs that are relevant to the projects (Siegel et al., 2024).

The indicators chosen should reflect the internal and external drivers identified in Step 1 and be related to the company's strategic goals. With access to the WebQDA software, it was possible to represent in Figure 17, the relationship between the strategic goals that the companies defined and the KPIs used to measure the success of LGS implementation. For example, as seen in Figure 17, when the goal was to reduce costs, companies applied waste percentage, defects, OEE, operational costs, and profitability-related indicators.

All the Lean, Sustainability and Industry 4.0 strategic goals should be measured and documented to monitor and analyse the current performance and compare it to future results.



Figure 17- KPIs defined by the companies according to their strategic goals.

**Step 7- Develop a training program for employees**

Employees should be properly educated on Lean and Green methodologies, the three pillars of Sustainability, and Industry 4.0 technologies to participate in their implementation. Organisations must allocate necessary resources for mass and continual employee training. Training programs should focus not only on the techniques and tools of LGS but also on soft issues such as leadership, team building, communication, and motivation (Cherrafi, Elfezazi, Govindan, et al., 2017).

Only 4 of the 20 companies interviewed had regular weekly/monthly training regarding these concepts, and 30% of the companies did not have any LG-related training. The rest of the companies had only initial training when a new tool or practice was implemented. To help companies sustain LGS 4.0 initiatives and its gains in the long term, a training program accessible to all the employees should be available so that, as mentioned in Colquímica interview, “everyone is working towards the same goal.”

“Lack of training” was also mentioned in both Lean (Figure 11) and sustainable strategy (Figure 13) implementation difficulties as these companies struggle to equip their employees with the

necessary skills and knowledge. Without adequate training, employees may resist changes or be unable to fully leverage the benefits of Lean and sustainable practices, leading to inefficiencies. Mystic emphasised that resistance to change “is largely a problem of communication and education,” and some people do not know the necessity of change, so it slows down the process.

Three companies also had Kaizen Institute, and 2 companies had other external consultancy giving training to their employees. To save costs, these training programs can be conducted internally by the LGS 4.0 team leader or other team member responsible for training and workshops on these concepts. Internal training also provides the flexibility to schedule sessions at convenient times, and it can enhance team cohesion and collaboration as employees work together to develop their skills and knowledge in Lean-Green Sustainability practices. On the other hand, although it may involve higher costs, external training can be more reliable as experts in these areas provide it. These experts can offer specific insights and real-world examples from other companies.

#### **Step 8- Integration of Industry 4.0 technologies**

During the planning phase, it is essential to identify which Industry 4.0 technologies are most suitable for the company's Lean and sustainable goals. This involves evaluating the potential impact of technologies like IoT, AI, robotics and automation, cloud computing, digital twin and big data on operational efficiency and Sustainability (Toktaş-Palut, 2022). Companies must ensure that the selected technologies align with the company's long-term vision, Sustainability objectives defined in steps 1 and 4 and KPIs specified in step 6. While elements of Industry 4.0 technologies should be integrated throughout the next phase of the LGS 4.0 framework, the planning phase is particularly crucial for addressing how these technologies can help achieve Lean and sustainable goals.

With the help of WebQDA software, Figure 18 was developed to illustrate the relationship between each Industry 4.0 technology referred by the companies interviewed and the benefits achieved related to data management, communication, process automation and monitoring. The overall responses from the interviews were positive (Table 25), companies like Lidergraf highlighted that it “made communication between departments and machines way easier.” Fricon noted that it has helped them “monitor and automate some processes to reduce errors and improve efficiency.” Becri emphasised the Green benefits: “By registering energy and water usage, we can form reports and plans to implement a reduction and be Greener.”

Industry 4.0 technologies have helped the companies interviewed improve their Lean and Green actions and assisted the organisations in becoming more sustainable.

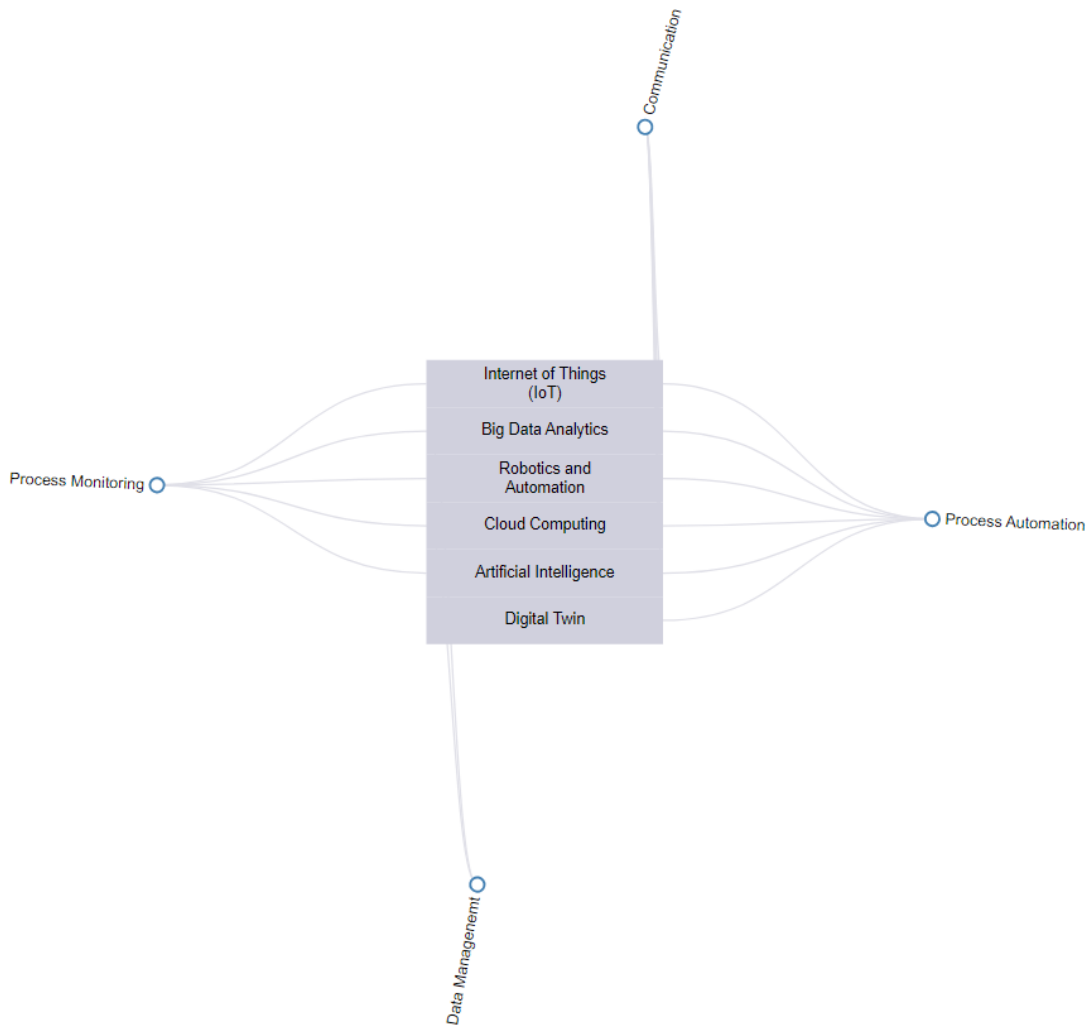


Figure 18- Benefits achieved from the applied Industry 4.0 technologies.

#### 4.4.3. Phase 3- Execution

This phase focuses on the practical implementation of strategies and technologies planned during the initial stages of the framework.

##### Step 9- Implement pilot project

Implementing the right pilot project is a critical step in implementing Lean-Green Sustainability 4.0 within an organisation. A well-chosen pilot project can serve as a proof of concept, demonstrating the benefits of LGS 4.0 initiatives, earning the trust of management and employees and building momentum for broader implementation. The selection and prioritisation of the projects depend on the understanding of the overall processes (Cherrafi, Elfezazi, Govindan et al., 2017). The easy way to understand the current state of the processes and identify opportunities for improvement is by Gemba Walk and developing a VSM. Gemba Walk provides an up-close and detailed view of processes by “understanding by seeing” (Romero et al., 2020), and VSM allows to visualise the entire flow of material and information

and identify points of improvement regarding environmental and material waste (Vinodh et al., 2011). With all this, With the information gathered, selecting and implementing the pilot project becomes easier. However, it should be done carefully, as it is important to present successful projects at the beginning. Otherwise, employees and management might doubt the effectiveness of the entire initiative.

#### **Step 10- Identify improvement opportunities**

This step involves a thorough analysis of existing processes to uncover areas where efficiencies can be gained, waste reduced, and Sustainability practices improved.

During the interviews, several companies highlighted specific opportunities they identified and acted upon. For instance, Colquímica described how robotics and automation have helped streamline their production process by automating repetitive tasks. They not only improved operational efficiency but also reduced human error and waste.

CIN highlighted that by utilising sensors and IoT technology, they were able to track real-time data on production processes and energy consumption. This enabled them to identify inefficiencies and target specific areas for improvement, ultimately enhancing both operational efficiency and Sustainability.

VincoValves emphasised the importance of cloud computing in its operations. By leveraging cloud-based data management systems, it was able to access and analyse data from various sources in real-time. This facilitated better decision-making and helped identify opportunities for process optimisation and resource conservation.

Lastly, Becri improved its ecological footprint by installing solar panels and skylights to save energy, changing its car fleet to electric, and starting waste management and recycling. It provided an example of leveraging data management tools to monitor energy and water usage, forming detailed reports and plans to reduce consumption.

By systematically identifying and addressing improvement opportunities, SMEs can achieve significant gains in efficiency and Sustainability. With the execution of different projects and as data is gathered and key causes are identified, the team can start formulating potential solutions to tackle these root issues and detect improvement opportunities. This often involves conducting a series of brainstorming sessions to generate innovative ideas for reducing or eliminating Sustainability-related and productive waste (Cherrafi, Elfezazi, Govindan, et al., 2017).

#### **4.4.4. Phase 4- Sustain**

In the sustain phase of the LGS 4.0 framework, the focus is on long-term improvement. This phase ensures ongoing process enhancement and consolidates LGS 4.0 as a continuous philosophy and culture, not just a one-time event.

#### **Step 11- Define goals and improve KPIs**

After identifying the KPIs associated with the processes in step 6, this step concerns having overall and general performance indicators. For example, Lidergraf not only defined strategic

goals for the performance indicators of the machines but also implemented global OEE to assess the company's overall performance. As a printing company, they also track and define paper waste as an overall KPI. This generates a comprehensive understanding of an organisation's efficiency and effectiveness. Overall, KPIs serve as high-level metrics that provide insights into the organisation's performance, allowing the detection of trends and patterns over time, which can reveal opportunities for improvement. By setting benchmarks and performance targets that encourage teams to strive for excellence, these KPIs help develop a long-term culture of continuous improvement.

### **Step 12- Regular audits and reviews**

This step involves systematically evaluating processes, practices, and outcomes to ensure they align with the framework's goals and standards. According to Siegel et al (2024), it is important to carry out audits and reviews on a regular basis to update goals and objectives and reassess employees' willingness to change.

For example, ROQ Laser, as presented in Table 22, after every shift, a 10-minute Kaizen meeting is held to discuss Lean metrics and indicators such as 5'S. This Lean-oriented effort aligns all the employees towards the same intended mindset.

Fricon also conducts daily meetings and performs internal audits to ensure long-term Lean and Green success and achieve the company's vision and Sustainability goals.

### **Step 13- Develop LGS 4.0 culture**

The final and most important step of this framework is to cultivate a culture that embodies the principles of LGS 4.0.

Table 22 provides insights into how these companies that were interviewed plan to maintain their Lean and Green efforts to sustain sustainable strategies and actions in the long term. Figure 19 provides an overview of the key topics that companies emphasise to sustain their LGS efforts.

"Employee Engagement" and "Communication and Awareness" were the most referenced topics in actively involving employees in the LGS 4.0 journey. This was done through suggestion schemes and feedback actions, similar to Fricon's approach, so that "people can feel more connected and part of the improvement". Additionally, maintaining open channels of communication about the goals, progress, and benefits of LGS helps keep everyone informed and aligned with the company's vision. For example, Mesa-Ceramics conducts weekly meetings regarding Lean methods and Green benefits.

"Regular audits," as said in step 12, help monitor progress and identify areas for improvement. This ensures that the LGS practices are effectively integrated and maintained.

"Environmental actions" were found important to sustain Green and sustainable efforts. Colquímica implemented a sustainable strategy extending until 2030, where decarbonisation, water consumption reduction, waste reduction, and a decrease in work accidents are the main goals. On the other hand, Promecel emphasised that by focusing on environmental Sustainability, they can ensure long-lasting efforts.

“Investment” and “Better work conditions” were also mentioned as important in sustaining LGS efforts.



Figure 19- Referenced topics regarding sustain LG and sustainable efforts.

Lastly, “Continuous Training” was also one of the most referenced topics ( Figure 19), and it is essential to ensure that the workforce remains skilled and knowledgeable, which is necessary to sustain LGS 4.0 efforts. Regular training sessions reinforce key concepts and practices. Repeatedly exposing employees to LGS principles helps them remember and adopt these practices, embedding them into the company's culture. In Table 28, it is presented the percentage of employees who are Lean trained in each company and whether Lean is applied only to production processes or across all businesses.

Table 28- Percentage of employees lean trained and lean application area from every company interviewed.

Company	Employees lean trained (%)			Lean application area	
	<=20%	>20 and <=80%	100%	Only Production	Across all business
Moldart			x	x	
RCM	x			x	
VincoValves			x	x	
Cplas		x		x	
Lidergraf			x		x
Clínica Veterinário Animar	x			x	
Clínica Oftalmológica Sousa Neves	x			x	
ROQ Laser			x		x
Artevasi			x	x	
Cunha Ribeiro	x				x
Solidal			x	x	
Colquímica			x		x
Becri			x	x	
Mesa-Ceramics	x			x	
Corksupply			x		x
Nimco	x			x	
Promecel		x		x	
CIN			x	x	
Fricon			x		x
Mystic			x	x	
<b>Total (%)</b>	30% (6)	10% (2)	60% (12)	70% (14)	30% (6)

The data revealed that 30% of the companies have less than 20% of their employees Lean trained. These companies lack the widespread knowledge and skills needed to implement and sustain Lean practices effectively. A limited number of trained employees can hinder the overall adoption and integration of Lean methodologies, and when more employees are trained, they can identify inefficiencies and suggest improvements. To build a robust LGS 4.0 culture, these companies must increase the percentage of LGS 4.0-trained employees significantly. Colquímica highlighted that by having 100% of the employees Lean trained, “everyone is working towards the same goal”.

From the 20 companies interviewed, 70% only applied Lean principles to the production floor. This limited application suggests that these organisations are not fully leveraging the potential of Lean practices and missing out on significant opportunities to improve efficiency and reduce waste across all business areas, such as administration, customer service, finance, human

resources, etc. Applying LGS 4.0 methods and practices across all areas also ensures the development of an LGS 4.0 culture.

According to Siegel et al. (2024), “the generated environmental, social and economic benefits should be widely reported to increase commitment and enthusiasm around the Sustainability initiative”. This makes the employee’s motivation towards improvement increase and make them part of the change.

## 4.5. Discussion

By developing a comprehensive framework, this study shortens the deficiency in understanding and implementing LGS 4.0 practices and methods among SMEs. This study considers the characteristics and challenges mentioned by interviewed SMEs, such as lack of financial resources, leadership, training, unavailability of specialized personnel, resistance to change, uncertainty about how to carry out processes, and much more. The overall LGS 4.0 culture, structure and resources differ significantly from those of larger companies. With this in mind, this dissertation proposes a step-by-step practical guide to simplify the LGS 4.0 implementation in SMEs with limited budget and resources, aiming to ensure a long-term success by enhancing environmental, social and economic performance. Since SMEs often emphasise short term objectives to achieve quick results, the framework also incorporates methods to sustain the two strategies in the long term.

The face-to-face interviews with Portuguese SMEs was an effective method to gather and provide different real-world insights that quantitative methods might miss and to validate the theoretical findings from the literature review. This qualitative approach ensures that the framework was developed regarding the real-world challenges that these SMEs face. The diversity in the type of industries that participated, ranging from manufacturing to healthcare clinics also provided a comprehensive view how different sectors approach LGS practices. During this phase, the main difficulty was scheduling and conducting interviews due to the geographical spread and time constraints. The sample size was limited to 20 because these interviews were time-consuming in order to have deeper detail. A notable gap during this phase was the lack of prior studies focuses on LGS implementation within the Industry 4.0 context and the lack of structured frameworks tailored to the unique needs and constraints of SMEs. Thus, the results from the interviews were used to fill these gaps and develop a structured framework that addresses the practical needs of SMEs, something that was lacking in the existing literature.

With the emphasis on the integration of Industry 4.0 technologies with LG practices and by incorporating the three pillars of Sustainability, this study has developed a guidance to enhance operational efficiency while aiming to balance profitability with social responsibility, reduce the ecological footprint and being more competitive in the global market.

This study also validates the theoretical findings with qualitative data from interviews, adding depth and context to the practical LGS 4.0 framework developed.

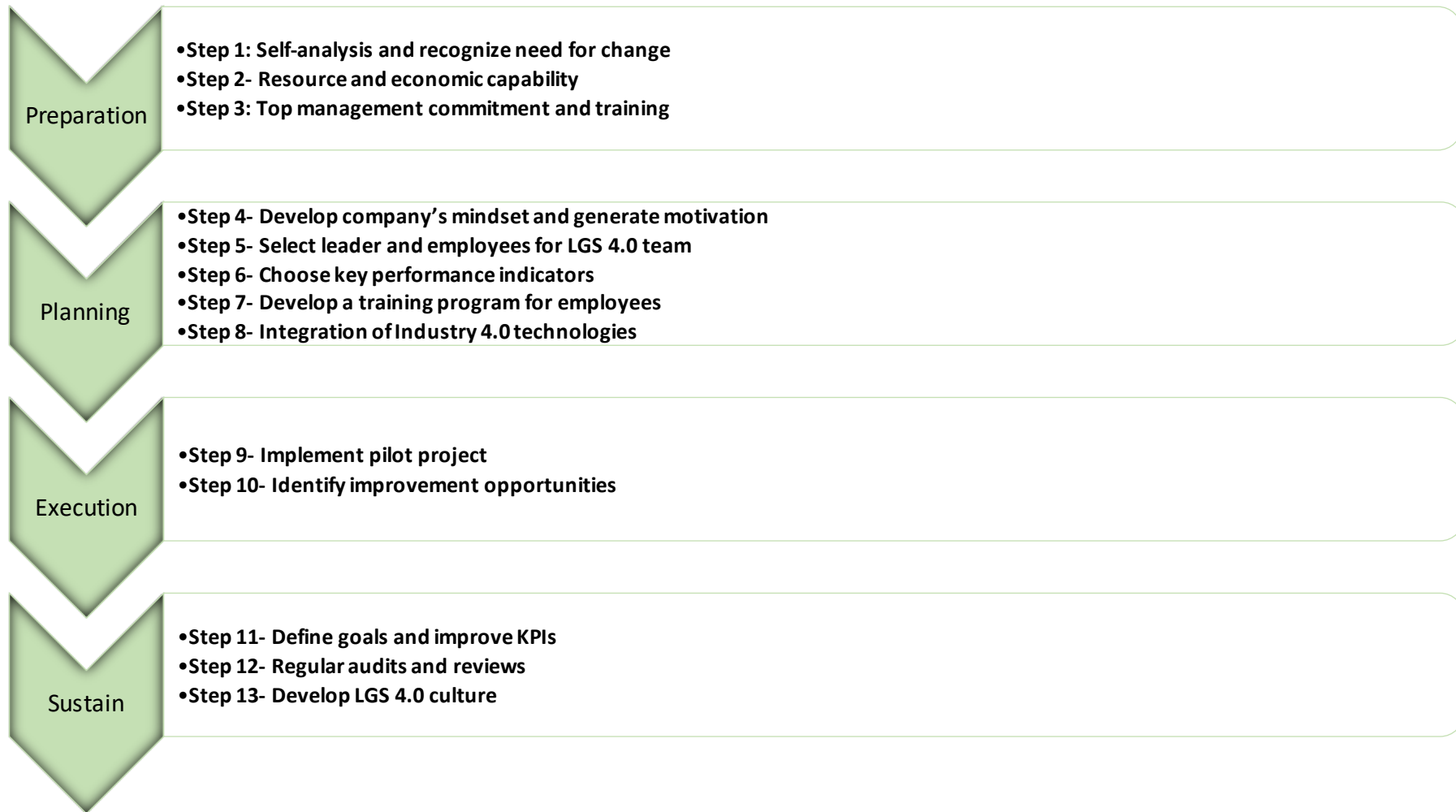


Figure 20- Structure of the LGS 4.0 framework.

## 5. Conclusion

This chapter summarises the building process of the LGS 4.0 framework and presents the critical findings of this dissertation. Additionally, proposals regarding possible future work/research are also presented.

### 5.1. Final Conclusions

A model for LGS 4.0 was developed to fill the gap of a lack of guidance and frameworks specifically tailored to the characteristics and constraints of SMEs. This model was specifically for LG implementation and enhanced the synergetic benefits of LS to achieve long-term environmental, economic, and social Sustainability within the context of Industry 4.0. The LGS 4.0 framework consists of five phases subdivided into thirteen steps. It aims to help SMEs of different sectors implement LGS 4.0 methods effectively in a practical, structured form.

To gather information and build a reliable foundation to validate the proposed framework, twenty Portuguese companies were interviewed, most of which were SMEs. All the companies were asked the same twenty questions: three general questions, eight Lean-related questions, seven LGS questions and two Industry 4.0-related questions. It identified particular challenges that SMEs face, such as limited financial resources, resistance to change, lack of commitment from top management and absence of expert people in both Lean and Green practices. The framework was mostly built around the most mentioned obstacles and considering the specific needs and limitations of SMEs.

Despite these challenges, the interviews also revealed how companies are approaching LGS initiatives, revealed different opinions about the synergy between Lean and Green, the benefits of implementing these methodologies as a single approach, and the role that Industry 4.0 technologies play in these efforts.

Comparing to Siegel et al. (2024)'s article, this study extends the research by adding Industry 4.0-related questions. It explores how Industry 4.0 technologies influence each dimension of Sustainability and helps to understand how different companies approach digital transformation to impact Lean and Lean-Green practices.

The findings from these face-to-face interviews and the thorough analysis were found crucial for developing a structured approach to implementing LGS 4.0 methods in SMEs. The designed framework offers an uncomplicated and smooth step-by-step guide to explore the benefits of implementing LGS 4.0, including reducing water, energy and raw material consumption,

## Conclusion

improving work conditions, boosting economic aspects and productivity, and upgrading service quality.

## **5.2. Limitations and Future Work Proposal**

Although this study's main objective has been achieved, some limitations remain that need to be addressed.

Although the sample size of twenty Portuguese companies provides valuable insights, it can be recognised as a limitation as it might not fully represent all SMEs. Additionally, as this study was focused on Portuguese SMEs, the specific socio-economic state and cultural context of Portugal may influence the challenges that SMEs face, which can differ from those of SMEs in other countries.

As future work proposals, it is important to test and validate the framework in a real industrial setting to strengthen the results of this study and evaluate it. By applying it to different sectorial SMEs and verifying the suitability of the proposed framework, this study can ensure its applicability across various contexts and industries.

Another way to validate the framework is by having LGS experts give feedback and advice to improve and clarify the steps.

For example, to expand this study and the framework, there can also be an incorporation and implementation of Six Sigma methods and practices.

## Conclusion

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# Declaration of Integrity

I declare that I conducted this academic work with integrity. I did not plagiarize or apply any form of misuse of information or falsification of results throughout the process that led to its preparation.

I declare that the work presented in this document is original and my own and has not previously been used for any other purpose.

I further declare that I am fully aware of the Code of Ethical Conduct of P.PORTO.

NAME: Diogo Marques Vilaça

ISEP, Porto, 10<sup>th</sup> of June, 2024

## Declaration of Integrity

# Appendix A

No.	Question
<b>General Questions</b>	
-	What is your position in this company?
-	How long have you worked for this company and how long have you and the organization worked with Lean methods?
-	What is your role or responsibility regarding the Lean operations in your company?
<b>Questions about Lean</b>	
1	What is your understanding of the term “Lean” and how do you define it from your own perspective?
2	What are the strategic goals of Lean for the current management (Zhang & Awasthi, 2014)?
3	What are your company’s current operational, strategic and tactical benefits? (Zhang & Awasthi, 2014)
4	How much of investment has your company allocated to continuous improvement methods? (Zhang & Awasthi, 2014) In your view, what is the ratio of investment on Lean to benefits achieved from Lean implementation (on a scale of 1:1 to 1:10)?
5	What percentage of the employees have been trained on Lean Production System and how many days of training have they received? (Daily & Huang, 2001)
6	How many Lean projects on average have employees executed per year?(Cherrafi, Elfezazi, Chiarini, et al., 2017) Have the projects been carried out in production setting or have you deployed Lean across the whole business? If so, where else you have applied Lean within the business (e.g. Lean in HR, Lean in Finance? Lean in Product design and development)? (Piercy & Rich, 2015)
7	How do you measure the success of Lean implementation? (Aguado et al., 2013)
8	What are the key lessons learned from the implementation of Lean? What are the difficulties of implementation and what should other businesses look out for when considering implementing Lean? (Aguado et al., 2013)
<b>Questions about Lean-Green and Sustainability</b>	
9	The term Green-Lean addresses the combination of Lean efforts with environmental management to increase resource efficiency and reduce costs. Do you see a synergy with these two approaches, or are they competing with each other?(Dües et al., 2013)

## Glossary

10	Does your company deploy any environmental management systems, or does it address the environment with other methods such as energy or water management, reduced CO2 emissions, etc.? If not, why? (Garza-Reyes et al., 2014)
11	Do you see benefits in the combined implementation of Lean and Green as a single approach? Would it be conceivable and useful to combine Green-Lean for your company?(Dües et al., 2013)
12	The term Sustainability does not only address the environment, but comprises three dimensions, and it is completed through economic (e.g. long-term and sustainable economic growth) and social (e.g. human rights and workers' rights, community engagement) aspects. (Alves & Alves, 2015; Verrier et al., 2014) Does your company address the other two components of Sustainability in any way? If not, why?
13	Finally, Sustainability also implies the ability to sustain Lean (and Green) efforts in the long-term. How does your company intend to achieve this?(Wong & Wong, 2014)
14	How important is the topic of Green-Lean and Sustainability for your company? Do you see a need for action? If yes, why? (e.g. Government regulations, climate change, lack of resources) (Daily & Huang, 2001)
15	In your opinion, what are the obstacles for implementing a sustainable strategy and which aspects need to be addressed in an organization to overcome these? (Zhang & Awasthi, 2014)
<b>Questions about Sustainable Industry 4.0 and Lean Green</b>	
16	Do you think digitalization (Industry 4.0 technologies) can help with making your organization Lean and Green and more sustainable?
17	Have you any examples of using Industry 4.0 (digitalization) to improve your Lean-Green actions?