CRANFIELD UNIVERSITY

IMPROVING THE SUSTAINABILITY OF MANUFACTURING SYSTEMS THROUGH GREEN LEAN MANUFACTURING PRACTICES

WADHAH AHMED ABUALFARAA

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING
PhD in Manufaturing

PhD
Academic Year: 2015 - 2019

Supervisor: Prof. Konstantinos Salonitis
Associate Supervisor: Dr. Ahmed Al-Ashaab
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ABSTRACT

In the current worldwide scenario, manufacturers are urged to improve their sustainability performance, in terms of keeping the balance among economic, environmental and social performances. Nevertheless, top managers and company leaders tend to complain that it is not possible to become greener without large investments. In particular, they argue that green practices require expensive technology, the environmental regulations are strict and the compliance cost is high. In recent years, the well-known lean manufacturing approach, mainly focused in waste reduction, has become to be viewed with a renewed interest towards improving not only economic but also environmental and social aspects. Although promising results have been published in the literature showing that lean practices can lead to some environmental and social improvements, most of the researchers in the field agree that lean manufacturing has not obtained the maturity level required to ensure sustainability yet. In this context, the idea of combining both lean and green manufacturing has arised. Unfortunately, while there is no doubt that lean manufacturing increases productivity, efficiency, quality and costumers' satisfaction by reducing wastes, there is a lack of research about the benefits of lean practices in relation to green ones. On one hand, there are researchers that argue that the lean continuous improvement culture favours the development of green strategies. On the other hand, there are the ones that argue that green objectives are in conflict with lean ones, since lean practices are mainly focus on adding value resources, whereas green practices can limit production, design and services for the sake of taking care of environmental issues. In this conflicting context, there is a lack of lean-green strategies in the literature as well as little to no evidence of successful implementation cases. In this thesis, the gap between applying lean and green practices is studied, evaluating the actual possibility of combining them towards providing strategical solutions for the sake of sustainability, in terms of economic, environmental and social performances. Results obtained from three extensive literature reviews regarding the current trends in lean, green and lean-green manufacturing show that although lean and green practices do differ in their main objectives, they can efficiently be implemented together since they have the same structure and they are synergetic, in the sense that they can enhance each others' strenghs and mitigate each others' weaknesses. Based on the literature reviews' findings a novel theoretical manufacturing framework capable of combining the lean and green approaches within a synergetic environment is developed in this thesis. In order to test the proposed framework within the real manufacturing scenario, a survey is conducted in different Saudi manufacturing companies. The results of this survey show that Saudi employees are becoming aware of the several business opportunities that lean and green practices can lead. In particular, the quantitative results have shown that Saudi employees expect lean and green practices to improve the operational and environmental performances of the companies. Moreover, they also show that Saudi employees agree that the combination of lean and green practices can lead to further improvements in the sustainability performance. Nevertheless, the qualitative results show that, in order to achieve these benefits, Saudi companies are urged to develop effective systems at individual, institutional and community levels capable of creating a suitable framework for implementing the required cultural and structural changes. On one hand, institutional change involves changing rules and norms in the organisations, while individual change involves employee training and motivation. On the other hand, both employees and institutions should be the main actors influencing the broader social change, regulating the impact on the communities' sustainability and how this impact can return in terms of social investment works towards increasing the companies' profit. In this context, Saudi employees suggest that companies should reduce the number (and complexity) of the currently used manufacturing processes; simplify the productive and administrative procedures making them more efficient; promote educational programs for employees, in terms of preparing them for the change and training them towards adopting innovative manufacturing techniques; and improve employees' working conditions, in terms of safety, health and salary, so that they can be more engaged and willing to learn new strategies and implement them. Finally, Saudi employees highlight that none of this can be actually be achieved whitout a stronger leadership, a higher top management and stakeholder involvement, and a more supportive government.

Keywords: Lean Manufacturing, Green Manufacturing, Lean-Green Manufacturing, Sustainability, Operational Performance, Value-added Activities, Productivity, Continuous Improvement, Financial Performance, Environmental Performance, Social Performance.

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May God grant the above cited personalities the success and honour in their life.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ABREVIATIONS AND ACRONYMS

3

3R · Reduction-Reuse-Recovery

5

5S · Sorting, Straightening (Set in Order), Shine and Sweeping, Standardising, and Sustaining

C

CM · *Cellular Manufacturing*

D

DfE · Design for Environment, Design for Environment

E

EDM · Electric Discharge Machining
EMS · Environmental Management System
EOL · End-of-Life
EPR · Extended Producer Responsibility

G

GLTQ · Green Lean Total Quality
GMPPSS · Process Planning Support System for Green Manufacturing
GRI · Global Reporting Initiative
GSCM · Green Supply Chain Management

H

HRM · Human Resources Management

I

IF · Impact Factor

J

JIT · *Just in Time*

L

LCA · Life Cycle Assessment

M

MCDM · Multi-criteria Model for Decision-Making
MSE · Medium and Small Enterprise

P

PCA · Principal Component Analysis

R

RoHS · (Restriction of Hazardous Substances
ROI · Return on Investment

S

SJR · SCImago Journal Rank
SLM · Systematic Literature Matrix
SLR · *Systematic Literature Review*
SMED · Single Minute Exchange of Die
SPSS · *Statistical Package for Social Sciences*
STS · Socio-Technical System

T

TEI · *Total Employee Involvement*
TPM · *Total Preventive Maintenance*
TPS · Toyota Production System
TQM · *Total Quality Management*
TRIZ · Theory of Inventive Problem-Solving tools

V

VSM · *Value Stream Mapping*

W

WCED · World Commission on Environment and Development
WEEE · Waste Electrical and Electronic Equipment
WIP · Work-in-Process
WRT · Waste Reducing Techniques

1 INTRODUCTION

1.1 Background

Lean manufacturing, which principles derive from the Toyota Production System (TPS) philosophy (Monden, 1998), has been largely considered in the literature to be one of the most influential manufacturing paradigms (Monden, 1998), (Holweg, 2007). Although there is no definite definition of lean manufacturing, since it is in constant development, it is essentially based on the idea of increasing value to customers while reducing the resource and time consumptions via waste elimination. In (Herron and Hicks, 2008), lean manufacturing is defined as "*making more with less*", while in (Womack et al., 1990) it is defined as the practice of reducing waste in all areas and all forms following the well-known Japanese manufacturing philosophies like TPS.

Since it was introduced for the automotive industry in Japan, lean manufacturing has become very popular, since it provides organisations the tools to improve their competitiveness based on increasing the productivity, efficiency, quality and costumers' satisfaction by reducing the waste in all aspects. Nevertheless, in last decades, the growing market demand for environmentally friendly solutions has led companies to be concerned not only about their usual financial objectives but also about how to manage their production processes to become environmentally efficient. In this context, lean manufacturing has been considered with a renewed interest as a starting point for "greener" approaches capable not only of minimising wastes (Smith and Hawkins, 2004), but also of reducing, by extending, modifying and updating lean methodologies, the environmental and social negative impacts of the traditionally used industrial practices (Sundar et al., 2014). In the same line, the concept of green manufacturing has recently been introduced (Garza Reyes, 2015a), (Paul et al., 2014). The green manufacturing concept extends the "waste reduction" idea proposed by lean manufacturing, proposing to reduce waste and pollution as well as to optimise the use of raw material and energy in order to minimise the environmental and health risks. As in the case of lean manufacturing, no definite green manufacturing definition can be found in the literature, since it involves different techniques and objectives that are continuously updated based on new research publications as well as specific communities' needs (Dilip Maruthi and Rashmi, 2015). Nevertheless, a widely accepted definition of the green manufacturing idea states that green manufacturing is aimed at meeting the current needs of the people while minimising the environmental impact, so that the future needs will also be possible to be met (Deif, 2011).

In today's society, where the threat of the climate change has already shown to be here to stay, there exists an increased awareness of how manufacturing practices negatively impact the environment. This has made the environmental responsibility to become a crucial task, compelling companies to consider environmental and social aspects beside the economic ones. In this context, companies are urged to adopt green initiatives (Mendler et al., 2005) like decreasing hazardous emissions, eliminating the consumption of wasteful resources, and recycling (Digalwar et al., 2013), in order to survive in the current market. In this worldwide situation, where several countries are facing serious economic difficulties, the raw materials and the transportation costs are rising, and the credit market is getting tougher, the need for an eco-oriented approach focused on optimising the use of the available resources, from the environmental as well as economic points of view, seems to increase day after day. Nevertheless, to actually implement green manufacturing is not always straightforward. In particular, although becoming greener would result in several benefits, reducing not only the environmental risks, but also the health risks, having safer, healthier and cleaner companies, improving product quality and even the companies' public image (Deif, 2011), many industry owners consider environmental regulations as a burden for production and achieving profits. In order to comply with the environmental regulations, as well as to remain competitive, companies need to be creative and propose new strategies to move towards a greener industry while keeping it profitable (Ahemad and Shrivastava, 2013). In this line, several manufacturers that were already implementing lean manufacturing have realised that becoming "green lean" would be a natural progression, allowing them to create cleaner production methods based on lean principles so that the environmental aspects of the processes could be improved, while the benefits (particularly the economic ones) that they have already achieved by the former applied lean practices could be kept (Karp, 2005).

In recent years, it has been shown that lean tools do have the potential to be used to reduce wastes from a green perspective. In this line, the idea of combining lean and green initiatives in order to achieve improvements in the operational as well as environmental aspects has gained popularity (Fercoq et al., 2013). Different approaches have been proposed to evaluate and implement the combination of both practices. For instance, (Garza Reyes, 2015a) presented a method to evaluate the correlation between lean practices and environmental performance applied to a case study in a metal cutting industry; while (Sawhney, 2007) proposed a green and lean model for a production cell. Nevertheless, although research about the individual implementation of lean and green approaches abounds in the literature, as numerous literature reviews, such as the ones in

(Pampanelli et al., 2014) and (Sundar et al., 2014), demonstrates, there is still much research to be conducted regarding their integration into a single approach (Paul et al., 2014). In particular, the actual impact that the application of lean principles supposes to a system's green performance is an open question under continuous discussion, and so, needs to be further investigated (Garza Reyes, 2015a). Moreover, in a recent literature review by (Garza Reyes, 2015a), conflicting results have been reported regarding whether green and lean practices are suitable to work together or they rather have to be implemented separately. On one hand, there are the ones who favour the integration of both approaches (Garza Reyes, 2015b), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012) arguing that lean and green practices are able to generate sequential or reciprocal interdependencies between them, so they can support each other whenever implemented together. On the other hand, there are the ones that argue that lean and green approaches differ in their main objectives, so they could have different impacts on the overall performance, making it not always a good choice to combine them (Galeazzo et al., 2014), (Mollenkopf et al., 2010).

Although the green lean approach seems to be promising, the conflicting results found in the literature make it necessary to further investigate the actual possibilities of their integration, the potential of the combined approach, and its influence in different aspects of the system's performance, such as economic, environmental and social ones. In addition, although both practices are related with the concept of sustainability, precisions regarding in which way they are related are difficult to find in the literature. In (Kleindorfer et al., 2005), sustainability has been defined as fulfilling the needs of the current generation without compromising the needs of the future generations. Nevertheless, although researchers seem to agree regarding the importance of the sustainable development, there is not the same agreement regarding its definition (WCED, 1987), (Dixon and Fallon, 1989), (Gray, 2010). In fact, different implementations and interpretations within different areas, such as, social responsibility (Glavic and Lukman, 2007), (Montiel, 2018), environmental management (Wheeler et al., 2003), or business sustainability (Goosen, 2012), can be found in the literature.

In this research, the actual impact of combining lean and green practices in the system's performance is evaluated in order to propose a novel combination approach for the sake of sustainability, *i.e*, to keep balance economically, environmentally and socially within a manufacturing field. The similarities and contradictions between both green and lean approaches are studied and a new strategy is proposed to enhance the former and mitigate the later, so that the synergy between them could be maximised with respect to three of the main aspects of the system, *viz.*, the economic, the environmental and the social ones.

In particular, developing the economy and improving the environmental and social sustainability in Saudi manufacturing companies will be the aimed case study in this research. According to a recent report by Mordor Intelligence[1], Saudi Arabia is currently one of the world's fastest growing countries in the manufacturing sector, with 7.5% average growth every year (Rennie, 2008). In addition, the recent slump in oil prices has emphasised the focus on other Saudi business sectors, being manufacturing at the top of the list in terms of potential. The current scenario implies a big challenge for Saudi companies requiring to moving towards a market-based approach more in line with other modern economies. In this context, any Saudi company that aims to be competitive in the global marketplace should be able to produce with the least possible costs and minimising the environmental effects in order to achieve excellence in price, quality and social reputation. In other words, in order to compete in the international market, Saudi companies are urged to apply lean and green practices. Unfortunately, these practices have not been as widely spread in Middle East as they have been in America and Western Europe. In fact, it was not until recent years that Saudi companies have considered them, being their implementation currently in its early stages as the empirical study in (Intelligence, 2019) demonstrates. Then, it is intended that the lean-green combined manufacturing framework proposed in this thesis could help Saudi companies to move towards implementing successful manufacturing procedures, in order to be able to simultaneously improve their economic, environmental and social performances.

This chapter is organised as follows. In Section 1.2, the motivation for the research conducted within the context of this thesis is presented. In Section 1.3, the main aim and objectives of the research are introduced. Section 1.4 is devoted to highlight the contributions to the field resulting from the research conducted during this thesis. In Section 1.5, an outline of the thesis is provided. Finally, in Section 1.6, the chapter summary is provided.

1.2 Motivation

For several years, the main leitmotiv in the field of manufacturing has been to satisfy or create needs, while keeping competitiveness in terms of product quality, time to market and innovation. Nevertheless, in recent years, it has been highlighted that manufacturing philosophies based on customers' demand, together with the improved people living's standards, have led to a growing product demand, fulfilled by a huge amount of produced

[1] https://www.mordorintelligence.com

goods, ending up in an increasing generation of pollution and wastes. In this context, companies are compelled to move towards more sustainable manufacturing practices, keeping the balance among economic, environmental and social performances simultaneously. Although some promising results have been obtained either by adapting lean practices to address green objectives (Saja et al., 2015), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), or by improving green practices in terms of economic efficiency (Siti Norhafizan Hibadullah, 2013), (Sezen and Cankaya, 2013), (Acharya et al., 2014), (Trivedi and Sharma, 2017), (Dangelico et al., 2016), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008), researchers agree that neither lean nor green practices can fulfil the current sustainable requirements when implemented individually (Xu et al., 2008), (Rajive et al., 2014), (Peto, 2012), (Hayani et al., 2016). Unfortunately, to combine both manufacturing approaches into a single one is a very complex and challenging task (Marhani et al., 2013), (Garza Reyes, 2015b), (Kurdve et al., 2014), (Garza Reyes et al., 2014). In addition, there is a lack in the literature of suitable integration and combination strategies as well as of successful empirical evidence of their practical implementation (Hayani et al., 2016). In this context, the main motivation of the conducted research is to fill the research gaps regarding the actual lean-green combined approach implementation in order to provide researchers and practitioners creative tools towards achieving the currently required levels of sustainability keeping the balance among economic, environmental and social performances.

1.3 Main Aim and Objectives

As discussed in Section 1.2, in recent years, companies have realised that, for the sake of surviving, they have to move towards manufacturing practices that can maintain a healthy balance among the main aspects of sustainability, *viz.*, economic, environmental and social ones. In this context, the lean-green manufacturing approach, which combines lean practices focused on customers’ demand, and green practices focused on reducing the business’ environmental impact, has gained popularity. Nevertheless, several research gaps, such as the lack of practical combination strategies and successful evidence of their implementation, have been identified in the literature (Kurdve et al., 2014). The main aim of this thesis is to develop a novel manufacturing framework to combine lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and mitigating their weaknesses. In this way, it is intended to provide researchers and practitioners an innovative lean-green manufacturing tool capable of achieving the currently required level of sustainability, in terms of improving economic, environmental and social aspects simultaneously.In order to do so, the following objectives are pursued:

1. Provide a deep insight into the current trends in lean and green approaches, analysing their main tools, techniques and methods as well as their main benefits, operational barriers and limitations, making special focus in their link with the sustainability aspects of the companies.
2. Analyse lean and green main similarities, differences, compatibilities and conflict of interest in order to evaluate whether they can be integrated into a single combined approach.
3. Identify the most relevant currently available lean-green combination strategies in the literature, highlighting their main gaps, benefits and limitations.
4. Evaluate the capability of the lean-green combined approach of fulfilling the current sustainability requirements in terms of improving economic, environmental and social performances simultaneously.
5. Identify critical success factors to improve sustainable results based on the lean-green approach.
6. Develop a novel manufacturing framework for integrating lean, green and lean-green approaches within a synergetic environment capable of taking advantage of their strengths while mitigating their weaknesses.
7. Validate the proposed manufacturing framework conducting a survey in different Saudi manufacturing companies.

1.4 Contributions to Knowledge

The lean-green manufacturing is still a relatively new practice, lacking of a clear and structured research definition, and of significant evidence of successful cases in the practice. In addition, due to the lack of widely used and standard sustainability metrics, the research gap becomes deeper when evaluating the lean-green approach performance in terms of sustainability improvements. In this thesis, a novel lean-green manufacturing framework is developed in order to improve the sustainability performance of the companies. The contributions of the research conducted within the context of this thesis are as follows:

1. Provide a deep insight into the current situation of lean and green practices, regarding not only their adoption but also their development, the perceived benefits and encountered conflict of interest and limitations in the real manufacturing scenario. This is addressed in Chapters 2 and 3 by conducting a Systematic Literature Review (SLR) on lean and green practices, respectively.

2. Evaluate the actual possibility of integrating lean and green practices into a single combined approach, proving that synergic effects can be obtained enhancing their strengths while mitigating their weaknesses. This is addressed in the Chapter 4 by conducting a SLR on the current trends on the lean-green approach.
3. Provide practitioners and researchers innovative tools towards achieving a superior level of sustainability by improving economic, environmental and social performances simultaneously by developing a novel theoretical framework capable of integrating lean, green and lean-green practices. The proposed lean-green manufacturing framework is presented in Chapter 6. In particular, it is developed based on the SLRs conducted in Chapters 2, 3 and 4, following the research methodology described in Chapter 5. In addition, the proposed manufacturing framework is validated based on a survey conducted in different Saudi companies focused on different business areas, including close-ended as well as open-ended questions, as described in Chapter 7. The results of the survey are analysed in Chapter 8 mainly based on a qualitative approach and supported by a complementary quantitative approach.

1.5 Thesis Structure

The remaining of the thesis is organised as follows. In order to propose, design and develop an innovative manufacturing framework capable of combining lean, green and lean-green approaches, it is crucial to fully understand the state of the art of each one of them. Chapters 1, 2 and 3 are devoted to study lean, green and lean-green concepts, respectively. In recent years, due to the highly competitive marketplace, lean practices, which have traditionally account for improving quality and productivity based on waste elimination, have started to be considered with a renewed interest (Kurdve et al., 2014). In this context, it is crucial to understand not only the lean concepts but also the current trends in the field. In Chapter 2, lean concepts are introduced and the most popular lean practices as well as the main tools and techniques associated with them are described. In addition, in order to give an in-depth insight into the current trends in the lean manufacturing field, an exhaustive literature review is carried out. In particular, special emphasis is done towards analysing the link between lean practices and the whole sustainability of the companies in terms not only of economic aspects but also of social and environmental ones. In general, researchers agree that, in order to achieve a higher sustainability level, not only lean but also green practices should be adopted. In Chapter 3, a complete theoretical background about green manufacturing is provided. In particular, the need for implementing green practices within the current manufacturing scenario is highlighted and the most popularly adopted green techniques and tools are described. Here, also an exhaustive literature review is carried out in order to give an in-depth insight into the current trends in green manufacturing, making special focus on the sustainability benefits green practices can lead not only in terms of environment improvements but also improving social and economic performances. In Chapter 4, the need for integrating lean and green practices towards achieving a superior level of sustainability capable of keeping the balance among economic, environmental and social aspects is discussed. In this line, the actual possibility of combining lean and green practices as well as how to practically implement this combination in a synergetic environment enhancing their strengths and disguising their weaknesses is evaluated. In Chapter 5, the research methodology used to conduct the present research is introduced, and its selection is theoretically justified. Each of the research steps involved in the selected research process is described in detail. In addition, each one of the different research decisions made in this context towards achieving the research objectives and successfully answering the research questions, are explained. In Chapter 6, the proposed theoretical manufacturing framework integrating lean, green and lean-green practices towards achieving a superior level of sustainability capable of keeping the balance among economic, environmental and social performances is presented. In particular, each of the design decision, such as, the supporting modelling theories, the inclusion and selection of the construct variables, and the formulation of the supporting hypotheses are deeply evaluated. In Chapter 7, the survey conducted within the Saudi manufacturing scenario is described. In Chapter 8, the survey results are analysed mainly based on a qualitatively approach conducted based on the well-known NVIVO tool. In addition, in order to complement the qualitative findings, a supporting quantitative analisys, based on the widely used Statistical Package for the Social Sciences (SPSS) tool, is also conducted in Chapter 8. Finally, in Chapter 9, the thesis conclusions are presented and discussed. In addition, some recommendations towards improving the achieved results are also discussed, and future research directions are suggested.

1.6 Chapter Summary

In recent years, companies have recognised that moving towards a superior level of sustainability is a must in order to keep being competitive and be potential leaders of the current and future markets. In this context, companies are urged to implement new manufacturing strategies towards keeping the balance among economic, environmental and social aspects. In this line, several researchers have proposed either to modify already adopted lean practices or incorporate promising green ones in order to be able to achieve the required sustainability improvements. Nevertheless, despite obtaining some promising results, researchers have concluded that neither lean nor green practices are enough to ensure the required balance among the different aspects of sustainability when implemented individually, suggesting to combine them. Since such integration have demonstrated to be a complex and challenging task, the present thesis is aimed at filling the research gaps regarding the actual possibility of combining lean and green approaches in order to provide researchers and practitioners creative tools towards achieving the currently required levels of sustainability keeping the balance among economic, environmental and social performances.

The main step towards being able to propose a new manufacturing strategy is to fully understand the current manufacturing scenario. In this line, a complete theoretical background about lean manufacturing and its main tools and techniques is provided in Chapter 2. In addition, based on an exhaustive literature review, particular focused is done on the current trends in lean practices as well as on their link with different sustainability aspects, *viz.*, economic, environmental and social ones.

2 LEAN MANUFACTURING: LITERATURE REVIEW

2.1 Introduction

The lean concept, which is based on the well-known TPS philosophy (Sundar et al., 2014), promotes the waste reduction (ideally, elimination) in all the organizations' aspects (Monden, 1998), being waste understood as any non-value added activity. During the post-World War II period, Japanese manufacturers were unable to compete with American ones due to the lack of resources, either material, financial or human. In order to make a move towards improvement, the then Japanese leaders proposed a new process-oriented approach, focused on the reduction of waste, rather than adopting the American popular mass production approach. In this way, they introduced a new management paradigm, which would be later known as TPS, and set the basis for lean manufacturing (Womack et al., 1990).

Since it was first introduced in Japan, the idea of improving quality and productivity based on waste elimination has gradually been embraced not only by car manufacturers but also by many other industries all over the world. During the 1980s, many product markets in the US as well as in Europe began to feel pressured by foreign manufacturers who brought higher quality and lower priced products to the market (Herron and Hicks, 2008). In such a situation, lean manufacturing, as it is known since the 1990s, provided the affected markets the tools to reduce waste in order to achieve add value to their products based specifically on what the customers were actually requiring, *i.e.*, higher quality, and willing to pay for, *i.e.*, lower price (Hobbs, 2004). In addition, lean manufacturing principles have shown to be suitable to be transferred and applied not only to within the manufacturing field, but also to the service field, being applied in many diverse industries, ranging from the steel (Herron and Hicks, 2008) to the food and beverage industry (Soni et al., 2013), including health care services like hospitals (Borges Lopes et al., 2015) and emergency departments (Hobbs, 2004).

In recent years, due to the rapidly changing and highly competitive marketplace, companies have faced new challenges. As a result, lean practices have started to be considered with a renewed interest (Dickson et al., 2009b). In this context, it is crucial to fully understand lean main concepts as well as the main techniques and tools used for implementing them, in order to be able to update them and implement the required modifications to fulfil the new needs in the manufacturing field. In this line, it is also crucial to be aware of the current trends in the field, in order to identify and study the most popular approaches as well as to highlight the research gaps so that novel approaches can be proposed and future research directions can be suggested. In this chapter, the main concepts regarding lean practices are introduced, the most popular techniques and tools used for their implementation are described, and the current trends in the field are analysed. Finally, today's global environment companies are compelled to seek sustainability for the sake of surviving. Then, the actual impact of applying lean practices to the organisation sustainability, in terms of economic, environmental and social aspects, is specially discussed.

The remaining of the chapter is organised as follows. In Section 2.2, the lean manufacturing concept is introduced. In Section 2.3, the most popular lean techniques applied within the real manufacturing scenario are described. In Section 2.4, an exhaustive literature review is conducted in order to analyse the current trends in the lean manufacturing field. In Section 2.5, the actual link between lean practices and sustainability aspects are discussed. In Section 2.6, the main findings and gaps identified in the SLR are summarised. Finally, in Section 2.7 the chapter summary is provided.

2.2 What is Lean Manufacturing?

Lean manufacturing is aimed at increasing the value delivered to customers by eliminating waste, that is to say, by eliminating any non-value added activity (Sundar et al., 2014). One of the key aspects that differentiate lean manufacturing from traditional manufacturing approaches, such as mass production, is the fact that lean manufacturing is a highly customer-oriented approach, where the product value is mainly defined based on the customer needs. In this sense, the production operations can be divided, in terms of lean practices, into three different categories, *viz.*, value-added activities, which are aimed at producing the product accurately following the customer requirements; non value-added activities, which are not necessary to produce such a product; and necessary non value-added activities, which do not actually add value from the customer's point of view but are still necessary to produce the expected product.

Different definitions of lean manufacturing can be found in the literature. In (Womack et al., 1990), the lean concept is seen as a manufacturing way of thinking that is able to decrease the time from customer order to the time when the product is already finished and shipped by reducing any waste. In (Liker and Lamb, 2000), lean is defined as a system aimed at eliminating waste based on the concurrent reduction or minimisation of supplier, costumer, and internal variabilities; while according to (Shah and Ward, 2007), lean manufacturing can be seen as another term for referring to a systematic approach that recognises and gets rid of waste from activities that add no value by improving and tracing products from the time they are drawn to focus on perfection.

Generally speaking, the lean concept can be described from two different points of view, namely, the philosophical and the practical ones. The former refers to a set of guiding principles and goals, while the latter consists in a set of practical tools, methods and techniques (Czarnecki and Loyd). Indeed, lean philosophy does not actually propose novel techniques regarding production, but promotes to change the way in which manufacturing is addressed. In this way, the successful implementation of lean manufacturing mainly depends on the fully understanding of the lean thinking principles introduced by (Shah and Ward, 2007), which are commonly defined within the following five areas, as it is shown in Figure 2.1.

- Specifying values for a certain product from customer's perspective.
- Finding the value stream for individual products and services.
- Making value flow without any disruptions.
- Allowing consumers to pull value from companies and companies from their suppliers.
- Focusing on perfection.

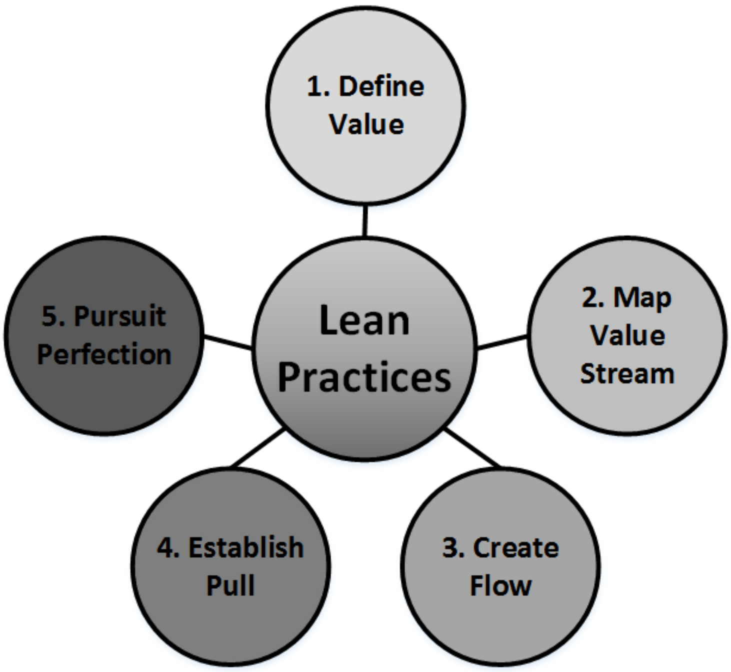

Figure 2.1: The 5 lean principles[2].

In addition, in (Womack and Jones, 1996)(Womack and Jones, 1996)(Womack and Jones, 1996)(Womack and Jones, 1996)[62](Womack and Jones, 1996) seven wastes that should be taken into account when implementing lean manufacturing are introduced.

[2] Source: Based on graph available at: https://www.indiamart.com/proddetail/lean-methodology-2832244688.html

These seven wastes, illustrated in Figure 2.2, constitute the basis of the current lean manufacturing implementations and are listed as follows (Choudharya, et al., 2018):

- Overproduction: Producing more than the clients' demand or before the required time.
- Inventory: Materials or finished products that are held in stock, waiting to be processed, to be transported or to be inspected, etc.
- Over-processing: Any excessive work performed in production process than required by the customer.
- Motion: Unnecessary motion of people not adding any value to products.
- Waiting: People waiting for information, for machines to finish their automatic cycles, for other people, for materials, etc., which extends the production or delivery cycle.
- Defects: Producing products with defects, requiring rework and leading to many associated costs such as cost of materials, labour cost, machine cost, etc.
- Transportation: Unnecessary movements and repeated handling of the same materials or finished product.

Figure 2.2: The 7 wastes of lean manufacturing[3].

[3] Source: Based on the scheme available at https://www.leanteamsusa.com/5s-training/7-wastes/

Lean manufacturing practices are conceptually different from the ones corresponding to traditional manufacturing (Womack et al., 1990). In Table 2-1, a comparison between traditional and lean manufacturing approaches is shown in order to summarise the main differences between them. From Table 2-1, it can be seen that several improvements regarding cost, inventory, and time, among others, can be achieved by applying the lean approach. In fact, although companies changing from a traditional practice, such as mass production, to a lean one could experiment cultural issues and, at the beginning, resistance to change, it has been largely demonstrated that embracing the lean practices yields substantial cost and quality advantages (Singh and Sharma, 2009). Finally, although it was first introduced for the automotive industry (Singh and Sharma, 2009), any type of organisations, businesses, manufacturers, processing, distributing, development of software, or even accounting or health care services can benefit from adopting lean practices (Holweg, 2007), as numerous examples found in the literature demonstrate (Herron and Hicks, 2008), (Soni et al., 2013), (Borges Lopes et al., 2015), (Hobbs, 2004).

Table 2-1: Traditional vs. Lean manufacturing[4].

Manufacturing Methods	Traditional	Lean
Production schedules	Push method.	Pull method.
Manufacturing	As products are manufactured the inventory is replenished.	Products are manufactured in order to fill customer orders.
Production cycle times	Weeks/month	Hours/days
Manufacturing lot size	Large	Small
Plant and equipment layout	By department function.	By product flow.
Workers assignation	Each employee has a particular machine assigned to him.	One employee can be assigned to a group of machines.
Workers empowerment	Low involvement of workers regarding how operations and processes work.	High involvement of workers, being encouraged to identify issues and suggest improvements.
Inventory level	High.	Low.
Inventory turns	Low (6-9 turns per year or less)	High (more than 20 turns per year)
Flexibility in changing manufacturing schedules	Manufacturing schedules are not flexible, being it difficult to modify them.	Manufacturing schedules are highly flexible, being easy to modify and implement.
Manufacturing costs	High and difficult to control.	Stable and under control.

2.3 Lean Manufacturing: Tools and Techniques

Several techniques have been proposed in the literature within the framework of lean manufacturing in order to address costs reduction as well as productivity and quality improvements in order to fulfil customers' needs (Dickson et al., 2009b). Among them, Just-in-time (JIT) (Ahuja and Khamba, 2008a), Cellular Manufacturing (CM) (Humphreys, 2011), (Wemmerlov and Hyer, 1987), Standardisation of Work, Workplace Organisation-The Five S (5S) (Olivella and Gavilan, 2008), Value Stream Mapping (VSM) (Gapp et al.,

[4] Source: Based on the table available at: http://www.dynamicbiz.us/366/article-leanmanufacturing.html

2008), Total Preventive Maintenance (TPM) (Rother and Shook, 2003), Visual Management (Ahuja and Khamba, 2008b), Production Smoothing (Leveling) (Parry and Turner, 2006), and Quality at the Source or Do it Right the First Time, are the most popular. In (Marksberry et al., 2011), a recent and detailed review on such techniques can be found.

2.3.1 Just in Time

JIT is an inventory management aimed at providing every process, one part at a time, exactly when that part is needed. As a result, it is intended to reduce lot and buffer sizes as well as lead times (Sundara et al., 2014). Then, a successful implementation of JIT would lead to high quality products based exclusively on customer demand. In addition, it would ensure the inventory levels remain low and a strong relationship with suppliers. To achieve this, JIT implements a pull system, where both internal customers, *i.e.*, individuals or employees who purchase the product of the company being part of it, as well as external customers, *i.e.*, individuals who do not belong to the company or are the end user of the product, demand before starting the first sign of production (Karlsson and Ahlstrom, 1996). The entire process is organised according to the Kanban system which uses visual signs as the main communication tool for pull-based production and material replacement (Monden, 1998). A conceptual diagram of such a system is shown in Figure 2.3.

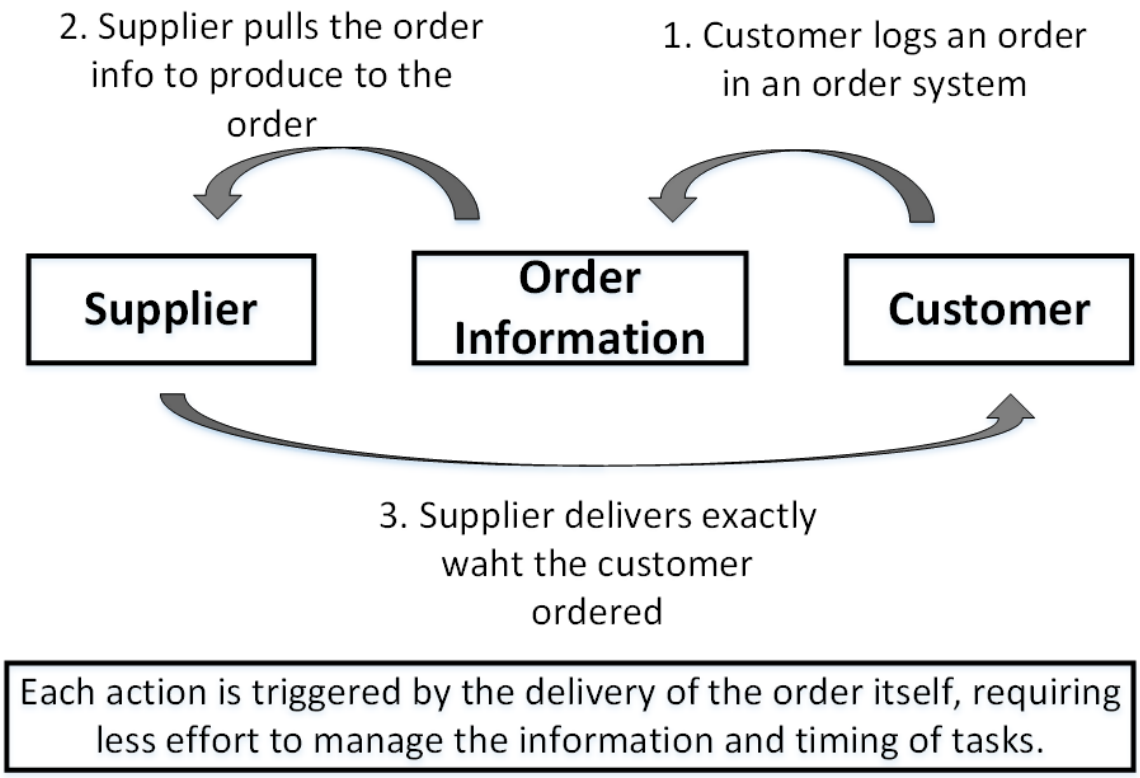

Figure 2.3: Kanban System[5].

2.3.2 Cellular Manufacturing

CM is based on arranging products, machine, tools, storage, equipment, workers, and materials into cells in such a way that a smooth workflow is allowed across the whole productive process (Abdullah, 2003). Figure 2.4 shows the benefits of applying CM to a production process. One of the advantages of this approach is the possibility of handle a high variety of products and a fast delivery rate by dividing products according to their characteristics and putting the similar ones into groups in order to process them on the same cell. The largest benefit from CM is reflected in the designing phase of the manufacturing cells, provided JIT, Total Employee Involvement (TEI), and Total Quality Management (TQM) are accomplished. Manufacturing cells become successful when they are properly addressed in the design, operations, selection, and control aspects.

The use of the cellular approach could imply less energy consumed in the storage, design and operation processes due to the reduction of the time spent in each one of these stages. In this way, the cellular approach would be a good alternative when trying to achieve greener results (by means of a reduction in the energy consumption).

[5] Source: Based on the scheme available at https://www.slideshare.net/BrentBrewington/kanban-explained

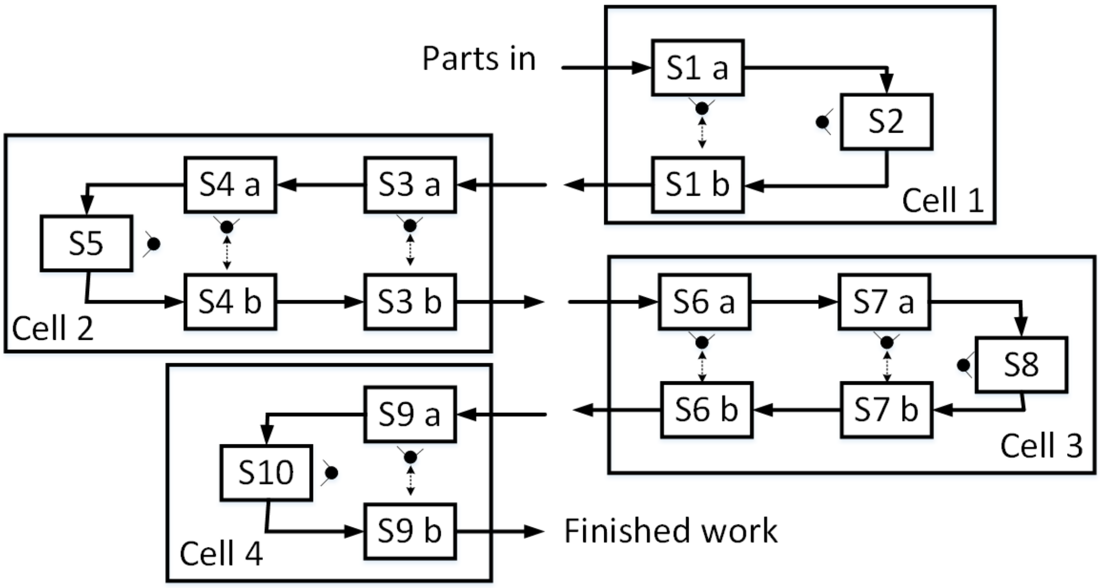

Figure 2.4: CM concept[6].

2.3.3 Standardization of Work

The standardisation of employee tasks is a key aspect for waste removal. In general, standardised work is defined as each job being organised and finished in the best means (Joachim Metternich et al., 2013). Figure 2.5 shows the three main components of the standardisation of work, *viz.*, *takt*[7] time, correct and efficient sequence, and standard in-process materials.

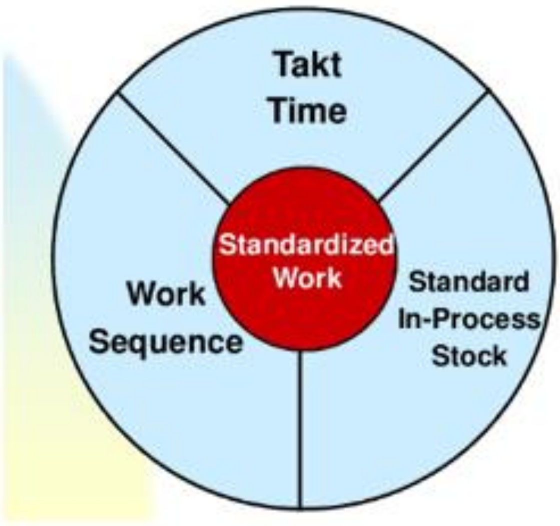

Figure 2.5: The three pillars of standardisation of work[8].

[6] Source: Based on the scheme available at https://www.latestquality.com/cellular-manufacturing/
[7] A German term for beat or rhythm.
[8] Source: https://www.onlineclothingstudy.com/2016/09/importance-of-standardization-in.html

Takt time is defined as the standard timing corresponding to the frequency in which only one piece is produced. Takt time is specified by customer demand and used to control the process rate that occurs at different production stages. In addition, it has been shown that utilising takt time means dealing with less energy form a green perspective. Takt time can be computed as follows: $T=T_a/D$,

where T is the Takt time, *i.e.* the work time between two consecutive product units, T_a is the net time available to work, *i.e.* the work time per period, and D is the customer demand, *i.e.* the number of products required per period.

- The work sequence is focused in reaching a smooth layout, where each operator performs the corresponding task at the corresponding machine within the corresponding takt time.
- The standard in-process stock is necessary to be ensured in order to keep a smooth workflow. That is, it is necessary to the right amount of work available in order to be able to perform the required tasks.

2.3.4 Workplace Organization-The Five S

The well-known "5S" is a group of five Japanese words, as shown in Figure 2.6, design a method that improves the total production performance (Alavala, 2008). The 5S are defined as follows:

- Sorting: The first S consists in identifying, separating and removing all the things that are unnecessary in the daily work. Removing the unnecessary materials will allow generating an inventory of the materials, tools and equipment necessary for the job.
- Straightening (Set in Order): The second S is based on the idea that there is a place for everything and everything should be in its place. In this phase, the materials, tools and equipment are placed in specific locations according to their frequency of use, shape, weight, accessibility and ergonomics, so that they can be easily visualised and identified, avoiding downtime and displacements in unnecessary searches.
- Shine and Sweeping: The third S considers that a dirty workplace decreases motivation, produce environmental and occupational hazards, gets a negative company's image and negatively affects the quality of production. In this line, the this phase proposes identifying the main centers where the dirt is produced, such as broken bulbs, spills and leaks and minimise them as much as possible.

- Standardising: The fourth S consists in standardising and marking the location, stock levels and operating ranges of previously identified materials in order to easily detect any anomaly that may affect the normal workflow. Marks and signals are usually visual elements, such as reminder cards and electronic indicators, among others.
- Sustaining: The fifth S consists in conducting a series of audits in order to maintain the benefits achieved by implementing the previous 4S, ensuring a continuous improvement.

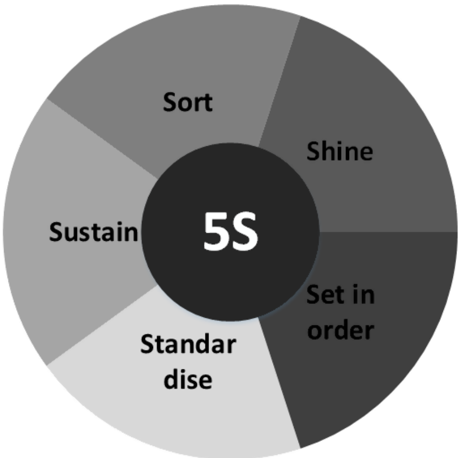

Figure 2.6: The 5S[9].

2.3.5 Value Stream Mapping

VSM is a technique that aims at visualising the process of production, information, and flow of material to improve the productive process by recognising waste and the sources causing it. VSM is developed by using a set of icons, that are known as the language during the production process that enables a better decision-making to increase value stream (Scott, 2011). Figure 2.7 shows a typical VSM diagram.

VSM are essentially blueprints used to implement the concepts of lean manufacturing by designing the way in how flow and materials should be operated. The map is usually split into a big picture and the details. The first step consists in creating an outline of the main feature of the processes, in order to be able to go deeper into the detailed mapping later on. This overview should help to understand the flow, identify the waste occurrence, design principles of lean manufacturing, illustrate who should be part of each implementation team, and introduce the relationship between the physical flow and the information. Being aware of the flow, allows recognising when, where, and how the data and the product flows can impact the organisation (Tompkins et al., 1996).

[9] Source: Based on the scheme available at https://www.5stoday.com/what-is-5s/

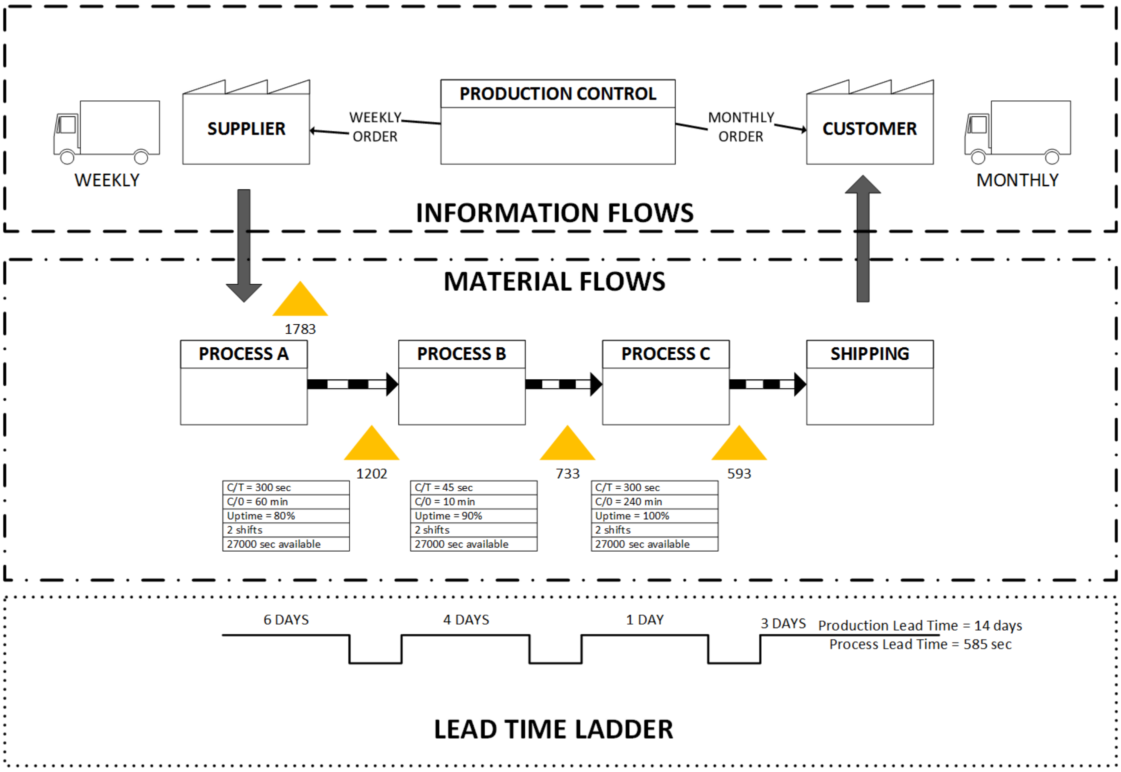

Figure 2.7: VSM typical diagram[10].

2.3.6 Total Preventive Maintenance

TPM assigns production workers jobs that include inspecting, cleaning, tightening, and calibrating equipment, in particular the machines at the shop floor, in order to avoid production breakdowns and unnecessary delays. (Tompkins et al., 1996). In this way, TPM gives employees a sense of responsibility and awareness of the equipment they use, reducing the abuse and misuse of the equipment, as operators who are also in charge of the maintenance of equipments are more careful about their use. In Figure 2.8 the eight pillars of TPM are shown.

[10] Source: Based on the VSM example available at https://www.graphicproducts.com/articles/value-stream-mapping-vsm/

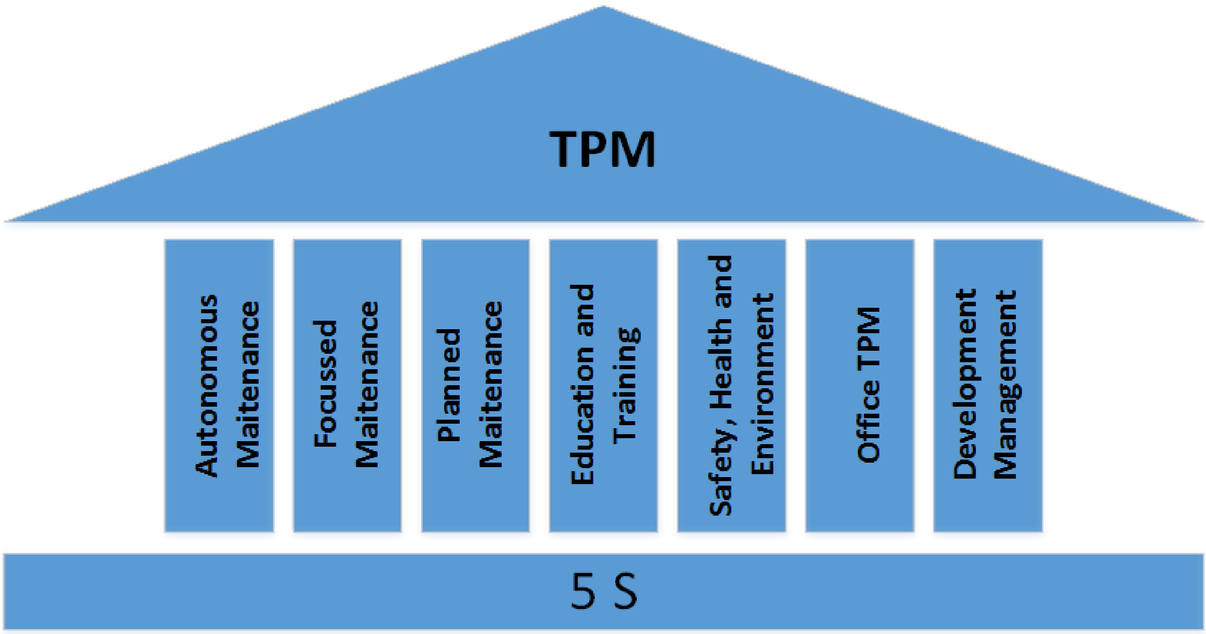

Figure 2.8: The eight pillars of TPM[11].

2.3.7 Production Smoothing (Levelling)

Levelling of production is focused on reducing waste by reducing unevenness. The main aim of levelling is evening the amount of production and product mix over time in order to provide stability to the internal production processes. In this way, intermediate goods are produced at a constant rate allowing the further processing to be carried out at a constant and predictable rate too. In order to handle customer demand fluctuations, two different levelling approaches are usually used, namely, production levelling and demand levelling. The production levelling can be performed by levelling volume or products. In the case of volume levelling, companies should manufacture at the long-term average demand and carry an inventory proportional to the variability of demand, stability of the production process and the frequency of shipments. In this way, the production is smoothened throughout the whole process, reducing process inventories and simplifying operations. In the case of product levelling, the demand for components should be levelled for the upstream sub-processes so that the lead time and total inventories can be reduced along the entire value stream. This type of levelling is usually implemented resorting to visual scheduling boards known as heijunka boxes. Finally, in the case of the demand levelling, the levelling should be performed by manipulating the product offering, influencing the ordering process and revealing the demand amplification induced variability of ordering patterns. Figure 2.9 illustrates how levelling helps to smooth the process. In return, the company will be able to operate at an increased average capacity (García Hernández et al., 2012).

[11] Source: Based on the TPM scheme presented in (Haddad, 2012).

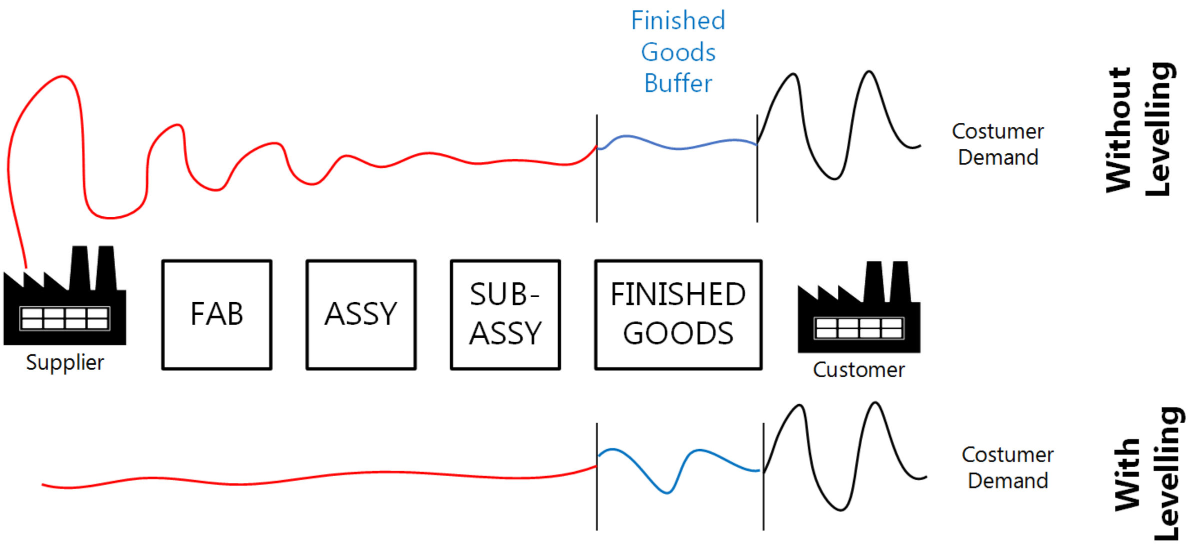

Figure 2.9: Levelling vs. non-levelling effects on the internal process[12].

2.3.8 Visual Management

Visual management can be thought as the link between people and information, improving the effectiveness of communication and reaction. It has largely been shown that more effective means of communication are achieved by using large visual displays on the shop floor rather than just written reports and guidelines. In addition, teams also communicate better using visual presentations. Then, visual management is aimed at making it easy to get the right information to the right destiny wherever and whenever it is required. Figure 2.10 shows the elements of visual management. Some common types of Visual Management in the workplace are:

- And/On lights
- Stock Controls and Signals
- Cross-Training Matrix for Employees
- 5S (signs, tape, labels, color coding, etc)
- Control Plans
- Production / Quality / Delivery / Service Metrics
- Glass Wall Metrics
- Failure Mode Analysis and Effects (FMEA)
- Auditing Boards
- Spare Parts Availability (flow racks)
- Standard Operating Procedures or Standard Work
- SPC on production floor

[12] Source: Based on the scheme available at https://3.bp.blogspot.com/_eMKj04WreR0/SNz8DW2v09I/AAAAAAAAAGo/CqIqtBeL5Ts/s400

- Preventive Maintenance Boards
- Shadow Boards

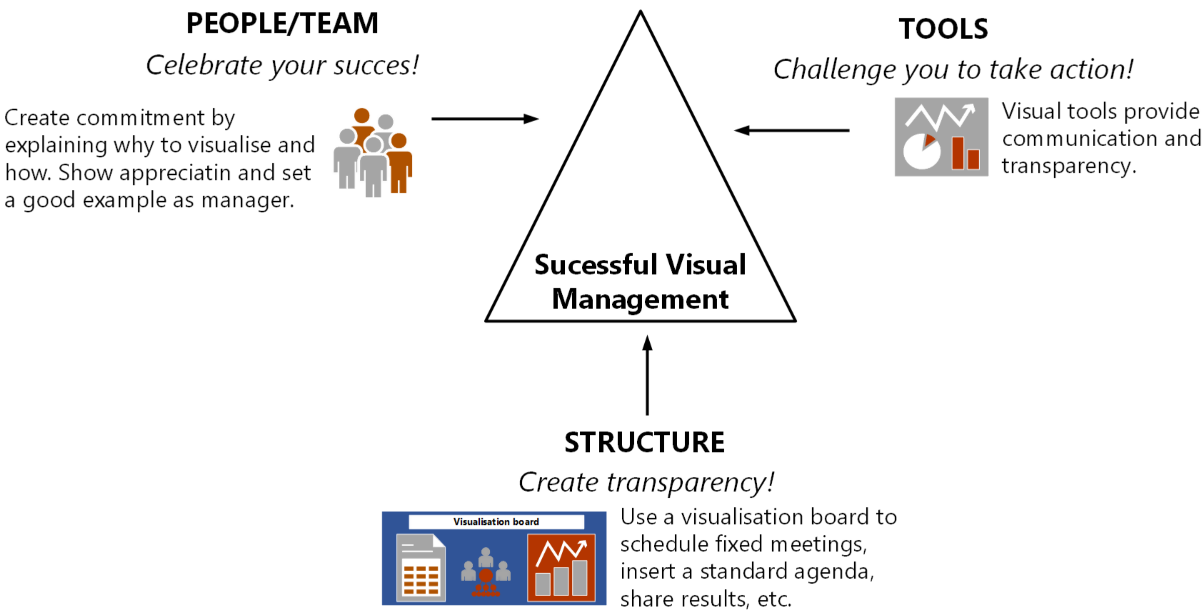

Figure 2.10: Visual management elements[13].

2.3.9 Quality at the Source or Do it Right the First Time

"*Do it right the first time"* is another term to be used when stating quality at the source. This is defined as quality being built within the production processes where defects are tried to be avoid from the very beginning and, in case they appear, they are immediately detected (Liker and Lamb, 2000). The quality at the source concept, illustrated in Figure 2.11, involves a cultural shift, including:

- Employee understanding of the customers and their requirements.
- Internal quality audits.
- Employee awareness of quality standards and benchmarks.
- Employee understanding of the customer's intended use of the product or service.
- Skilled and well-trained workforce.
- Technology capable of identifying quality flaws and rectifying them in an efficient manner.
- Proper data collection and tracking of quality faults.
- Open communication of standards, performance and processes.

[13] Source: Based on the scheme available at: https://www.tnpvisualworkplace.com/discover-inspire/visual-management-blog/5s-workplace-organisation/the-three-steps-of-successful-visual-management

Provided the above changes are successfully implemented, quality at the source can lead to different improvements including better informed employees, cultural awareness of the importance of quality to the customer, reduction in rework expenses and reduction in production waste, among many others.

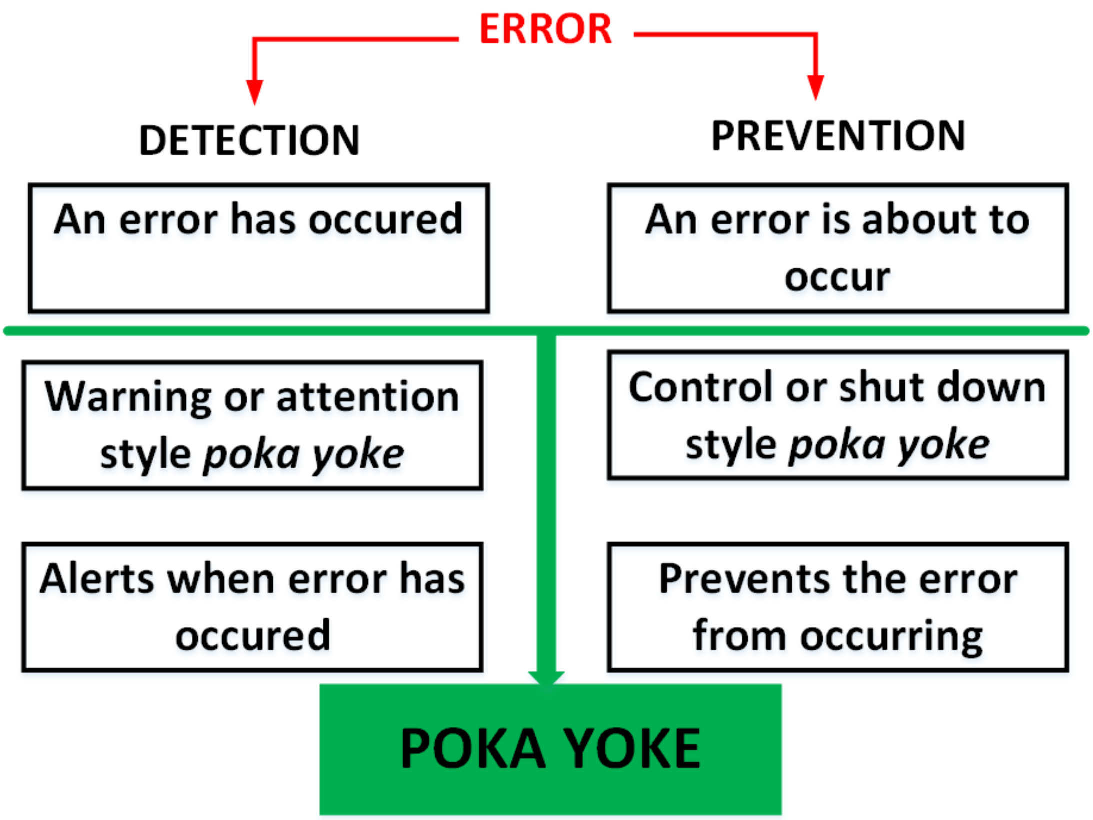

Figure 2.11: Quality at the source[14].

2.4 Current Trends in Lean Manufacturing

Lean practices have been in constant development since they were first introduced in 1950s. In this context, the previous theoretical background can be seen as a starting point for understanding the lean concepts and principles as well as the most popular techniques associated with them, being necessary to complement this knowledge with further research regarding the current trends in the field. In order to do so, an exhaustive literature review, based on the Systematic Literature Review principles, is carried out on this section.

Generally speaking, a well conducted literature review should be able to give researchers in the field a clear picture regarding the main issues of the area in order to identify the current gaps in the literature and close the related subjects where plethora of research

[14] Source: Based on the scheme included in https://www.slideshare.net/ROBERTSTAPP1/quality-at-source-poka-yoke-80624441

has already been reached (Paneru, 2011). In this section, the SLR is conducted following the steps introduced in (Webster and Watson, 2002). First of all, the research questions that are intended to be answered by the SLR are formulated in Section 2.4.1. In a second step, the different contributions are located and selected in order to be evaluated and summarised in Section 2.4.2. Finally, in Section 2.4.3 the analysis of all the selected contributions is carried out in order to draw the corresponding conclusions and propose further research directions based on them.

2.4.1 Research Questions and Search Methodology

The aim of the present SLR is to give an insight into the current trends for lean practices making special focus on their effects on the companies' sustainability. To do so, the conducted literature review should be able to answer the following questions:

1. Which are the best current lean practices and their applications?
2. What is the actual impact of applying these practices in the companies' sustainability performance?

In particular, the first research question will be addressed in Section 2.4.3, while the second one will be addressed in Section 2.5.

The search for the relevant contributions related to these research questions has been carried out on the basis of the online access of the University as well as the library resources. Books and peer-reviewed articles from International Journals as well as from Proceedings of International Conferences have mainly been considered since they tend to be the most reliable sources for performing a SLR (Denyer and Tranfield, 2009). In particular, the following subjects have been selected as initial research points:

- Lean practices and their main applications.
- Lean practices and their contribution towards economy, environment and social performance.
- Lean practices and their impact on the sustainability performance.

Finally, in order to focus the attention on the most recent developments and the current trends for lean practices, only articles published in the last two decades are considered in this SLR.

2.4.2 Thematic Synthesis

Applying the search criteria described in Section 2.4.1 resulted in a total of 73 selected contributions to the field. Among them, 53 (72.6%) are from International Journals, while 5 (6.8%) are from books, and 15 (20.5%) are from Proceedings of International

Conferences. This clearly shows that International Journals are currently the preferred option by researchers to divulgate their research findings. This is probably due to the widely accepted idea that such type of publications enjoy a higher status than, for instance, the conference proceedings (Saunders et al., 2012). The most recurrent journals in the conducted search are the J. of Production Economics[15] (Impact Factor (IF) 2018: 4.998, SCImago Journal Rank (SJR) 2018: 2.475), with 9 (12.3%) contributions among the selected ones, and the J. of Cleaner Production[16] (IF 2018: 6.395, SJR 2018: 1.620) and J. of Manufacturing Systems[17] (IF 2018: 3.642, SJR 2018: 1.592) with 4 (5.4%) and 3 (4.1%) contributions, respectively. This allows some observations. On one hand, the high IF and SJR indices of these journals validates the relevancy of the selected articles and suggests that researchers tend to publish their contributions in specialised journals, which is in line with the findings in(Freyne et al., 2010). On the other hand, two of the most cited journals are directly associated with a traditional production concept (J. of Production Economics and J. of Manufacturing Systems) summing 12 (16.4%) contributions, while the other journal, which is associated with the cleaner production concept only provides 4 (5.4%) contributions. This suggests that the lean concept remains being mainly associated with the economic aspects of the production, rather than with the cleaner ones. Finally, among the conference contributions, the Procedia series, which is a collection of high quality conference proceedings, seems to be the most popular one, being 14 of the 15 conference papers published in this series. These articles belong to different issues, such as, CIRP (6), Engineering (3), Computer Science (3), Economic (1) and Social (1).

Different approaches have been proposed in the literature to synthesise the results obtained by the SLR (Garza Reyes, 2015b). In this chapter, a thematic synthesis is performed in order to identify, classify and analyse the most important subjects addressed by the selected articles. A Systematic Literature Matrix (SLM) (Garza Reyes, 2015b) is shown in Table 2-2. In this table, the 73 selected articles are thematically categorised in order to summarise the gathered information through the SLR in terms of their main subjects. The present literature review aims to identify the best currently applied lean practices and their actual impact on the companies' performance, doing special focus on sustainability aspects. In this line, the 73 selected articles are divided into different thematic categories aimed to better understand the collected contributions. The proposed thematic categories are:

[15] https://www.journals.elsevier.com/international-journal-of-production-economics
[16] https://www.journals.elsevier.com/journal-of-cleaner-production
[17] https://www.journals.elsevier.com/journal-of-manufacturing-systems

- Conceptual Analysis: Articles in this category address lean concepts from a theoretical perspective. In general, these kinds of analyses are found in books, since articles published in conference proceedings and journals address lean concept from more practical perspectives.
- Literature Review: Literature reviews focus on collecting and discussing the main and most recent contributions to the field.
- Research Application: This category includes articles where authors propose different models and approaches to implement lean practices. In particular, these proposed models are validated either using data from benchmark (ideally publicly available) databases or by simulation.
- Case Study/Empirical Study: These types of studies are held within the companies' context. Some of them resort to surveys to collect information regarding the different lean practices implemented and their results, some others perform experimental tests.
- Lean Techniques: Articles classified in this category study a particular lean technique or a subset of them from a methodological perspective.
- Supply Chain: The supply chain represents all the necessary activities to produce the product from the suppliers and get them to the customers. To include this category within the thematic synthesis helps to understand to which extent articles in the field of lean manufacturing address the different steps involved in the supply chain management.
- Operation/Process: This category refers to the productive sector of the company. It is expected that many of the selected articles would be included in this category.
- Human Resources: This category is included in order to analyse whether the human resource aspect of the lean practices is addresses in the literature or not.
- Performance Measurement: In order to evaluate the improvements achieved by applying lean practices, it is necessary to have a systematic, standard and widely accepted framework to measure these improvements. Researchers in the field agree that there is a lack in the literature for such formal frameworks. To include this category helps to analyse the different efforts that researchers are making towards proposing new metrics to fill this gap in the literature.
- Impact on Performance: This category shows which are researchers' main concerns regarding the different aspects of the companies' performance.
- Sustainability: To include this category allows analysing whether the sustainability aspect of lean practices has properly been addressed in the literature and which are the main findings regarding their relationship.

Table 2-2: SLM for lean practices.

Nº	Paper	Concept. Anal.	Lit. Review	Research Applic.	Case Study/ Empiral Appl.	Lean Techniques /Tools	Operation/ Process	Supply Chain	Human Resources	Perform. Measure	Impact on Perform.	Sustaina bility
1	Rahman, N.A.A., Sariwati, M.S., Mashitah, M.E. "Lean Manufacturing Case Study with Kanban System Implementation". Proc Econom. Finance 7 (2013): 174-180				X	x	x					
2	Riezebos, J., Warse, K. "Advancing lean manufacturing, the role of IT." Comput. in Industry 60(4) (2009): 235-236			x		x	x					
3	Manotas Duque, D.F., Rivera Cadavid, L. "Lean manufacturing measurement: the relationship between lean activities and lean metrics." Estudios Gerenciales 23.105 (2007): 69-83.			x			x			X	x	
4	Martínez-Jurado, P.J., Moyano-Fuentes, J. "Lean management, Supply chain management and sustainability: a literature review." J. of Cleaner Prod. 85 (2014): 134-150.		x					x			x	X

5	Taylor, D., Brunt, D., Manufacturing Operations and Supply Chain Management: The lean approach, Thomson (2001)	**x**					**x**	**x**				
6	Eroglu, C., Hofer, C. "Lean, leaner, too lean? The inventory-performance link revisited." J. of Operat. Manag. 29.4 (2011): 356-369.	**x**			**x**		**x**				**x**	
7	M Dieste, M. ; Panizzolo, R., On the Relationship between Lean Practices and Environmental Performance, IOP Conference Series: Earth and Environmental Science 151 (2018)		**x**				**x**				**x**	
8	Peto, O., Lean in the Aspect of Sustainability, Club of Economics in Miskolc TMP 8(1) (2012):54-58	**x**				**x**	**x**			**X**	**x**	**X**
9	Sundar, R., Balaji, A.N., Kumar, S. "A Review on Lean Manufacturing Implementation Techniques." Procedia Engineer. 97 (2014): 1875-1885.	**x**				**x**	**x**					
10	Chunguang B., Ahmet S. Sarkis, J., Investing in lean manufacturing practices: an environmental and			**x**			**x**				**x**	

	operational perspective, Int. J. Prod. Research (2018)											
11	Bortolotti, T., Boscari, S. and Danese, P. "Successful lean implementation: Organizational culture and soft lean practices." Int. J. Prod. Econom. 160 (2015): 182-201.			**x**					**X**		**x**	
12	Abdulmalek, F.A., Rajgopal, J. "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study." Int. J. Prod. Econom. 107.1 (2007): 223-236.			**x**	**x**	**x**	**x**				**x**	
13	Karim, M.A. et al. "Implementation of Lean Manufacturing in Saudi Manufacturing Organisations: An Empirical Study." Advanced Materials Research. Vol. 339. 2011.				**X**		**x**					
14	Fliedner, G., Majeske, K. "Sustainability: The new lean frontier", J. Prod. Invent. Manag. 46 (2010):6–13	**x**		**x**			**x**	**x**			**x**	**X**

15	Melton, T. "The benefits of lean manufacturing: what lean thinking has to offer the process industries:" Chemical Engineer. Research and Design 83.6 (2005): 662-673.	**x**					**x**				**x**	
16	Khanchanapong, T., et al. "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance." Int. J. Prod. Econom. 153 (2014): 191-203.				**X**		**x**				**x**	
17	Resta, B., et al. "Towards a framework for lean operations in product-oriented product service systems." CIRP J. Manufact. Scie. and Technol. (2015).			**x**			**x**					
18	Seifermann, S. et al. "Evaluation of Work Measurement Concepts for a Cellular Manufacturing Reference Line to Enable Low Cost Automation for Lean Machining." Procedia CIRP 17 (2014): 588-593.			**x**		**x**	**x**					

19	Kull, T.J., et al. The moderation of lean manufacturing effectiveness by dimensions of national culture: Testing practice-culture congruence hypotheses. Int. J. Prod. Econom. 153 (2014):1-12.			**x**					**X**		**x**	
20	Torgeir, W., Ringen, G. "Investigating Lean Development Practices in SE Companies: A Comparative Study Between Sectors." Procedia Comput. Scie. 44 (2015): 234-243.				**X**		**x**	**x**	**X**		**x**	
21	Sullivan, W.G., McDonald, T., Van Aken, E.M.. "Equipment replacement decisions and lean manufacturing." Robot. and Comput.-Integrated Manufact. 18.3 (2002): 255-265.			**x**			**x**					
22	Fliedner, G. Sustainability: A new lean principle (2008)			**x**								**x**
23	Vinodh, S., Arvind, K.R. & Somanaathan, Tools and techniques for enabling sustainability through lean initiatives, M. Clean Techn Environ Policy (2011) 13:			**x**		**x**	**x**					**X**

	469											
24	Smart, Nigel J. Lean biomanufacturing: Creating value through innovative bioprocessing approaches. Elsevier, 2013.			**x**			**x**					
25	Jabbour, Charbel José Chiappetta, et al. "Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing." J. Cleaner Prod.				**X**		**x**		**X**		**x**	
26	Meade, D.J., Kumar, S. and Abdolazim Houshyar. "Financial analysis of a theoretical lean manufacturing implementation using hybrid simulation modeling." J. Manufact. Sys. 25.2 (2006)137-152.			**x**			**x**				**x**	
27	McCarthy, D., Rich, N. "Lean TPM: a blueprint for change". Butterworth-Heinemann (2015)			**x**		**x**	**x**					

28	Kreimeier, D., et al. "Holistic Learning Factories–A Concept to Train Lean Management, Resource Efficiency as Well as Management and Organization Improvement Skills." Procedia CIRP 17 (2014): 184-188.	**x**										
29	Dora, Manoj, et al. "Operational performance and critical success factors of lean manufacturing in European food processing SMEs." Trends in Food Scie. & Technol. 31.2 (2013): 156-164.				**X**		**x**				**x**	
30	Cagliano, R., Caniato, F., Spina, G. "Lean, agile and traditional supply: how do they impact manufacturing performance?." J. Purchasing and Supply Managem. 10.4 (2004): 151-164.			**x**				**x**			**x**	
31	Rubio, S., Corominas, A. "Optimal manufacturing–remanufacturing policies in a lean production environment." Comput. & Ind. Engineer. 55.1 (2008): 234-242.			**x**			**x**					

32	Abdollahi, M, Meysam Arvan, Jafar Razmi. "An integrated approach for supplier portfolio selection: Lean or agile?." Expert Sys. with Appl. 42.1 (2015): 679-690.			**x**				**x**				
33	Powell, D., et al. "A New Set of Principles for Pursuing the Lean Ideal in Engineer-to-order Manufacturers." Procedia CIRP 17 (2014): 571-576.	**x**		**x**			**x**					
34	Tyagi, S., et al. "Lean tools and methods to support efficient knowledge creation." Int. J. Inf. Manag. 35.2 (2015): 204-214.			**x**		**x**						
35	Behrouzi, F., Kuan Yew Wong. "Lean performance evaluation of manufacturing systems: A dynamic and innovative approach." Procedia Comput. Scie. 3 (2011): 388-395.			**x**			**x**			**X**	**x**	
36	Demeter, K., Zsolt M.. "The impact of lean practices on inventory turnover." Int. J. Prod. Econom. 133.1 (2011): 154-163.			**x**			**x**				**x**	
37	Doolen, T.L., Hacker. M. "A review of lean assessment in organizations: an				**X**		**x**					

	exploratory study of lean practices by electronics manufacturers." J. Manufact. Sys. 24.1 (2005): 55-67.											
38	ElMaraghy, H., Deif, A. "Dynamic modelling of impact of lean policies on production levelling feasibility." CIRP Annals-Manufact. Technol. 63.1 (2014): 389-392.			**x**		**x**	**x**				**x**	
39	Dombrowski, U., T. Mielke. "Lean Leadership–Fundamental Principles and their Application." Procedia CIRP 7 (2013): 569-574.	**x**							**X**			
40	Marhani, M. A., et al. "Sustainability Through Lean Construction Approach: A Literature Review." Procedia-Social and Behavioral Scie. 101 (2013): 90-99.		**x**								**x**	**X**
41	Villa, A., Taurino, T. "From JIT to Seru, for a Production as Lean as Possible." Procedia Engineer. 63 (2013): 956-965.			**x**		**x**	**x**					
42	Bhasin, S. "Performance of Lean in large organisations." J. Manufact. Sys. 31.3 (2012): 349-357.			**x**			**x**				**x**	

43	De Haan, J., F. Naus, M. Overboom. "Creative tension in a lean work environment: Implications for logistics firms and workers." Int. J. Prod. Econom. 137.1 (2012): 157-164.			x				x	X			
44	Matt, D. T., and E. Rauch. "Implementation of Lean production in small sized enterprises." Procedia CIRP 12 (2013): 420-425.			x	X		x					
45	Goss, R., et al. "Leveraging new SEMI standard to reduce waste and improve flow for semicoductor manufacturing." Robot. and Comput.-Integrated Manufact. 26.6 (2010): 658-664.			x		x	x					
46	Martin, L.D., et al. "Process improvement in the operating room using Toyota (Lean) methods." Revista Colombiana de Anestesiología 42.3 (2014): 220-228.				X		x					
47	Deif, A.M., ElMaraghy, H. "Cost performance dynamics in lean production leveling." J. Manufact. Sys 33.4 (2014): 613-623.			x		x	x				x	

48	Panizzolo, R. "Applying the lessons learned from 27 lean manufacturers.: The relevance of relationships management." Int. J. Prod. Econom. 55.3 (1998): 223-240.				X		x		X			
49	Wong, Wai Peng, and Kuan Yew Wong. "Synergizing an ecosphere of lean for sustainable operations." J. Cleaner Prod. 85 (2014): 51-66.			x			x		X			
50	Stenholm, D, Mathiesen, H., Bergsjo, D. "Knowledge Based Development in Automotive Industry Guided by Lean Enablers for System Engineering." Procedia Comput. Scie. 44 (2015): 244-253.			x			x					
51	Scherrer-Rathje, Maike, Boyle, T., Deflorin, P. "Lean, take two! Reflections from the second attempt at lean implementation." Business Horizons 52.1 (2009): 79-88.	x					x					
52	Chavez, R., et al. Internal lean practices and performance: The role of technological turbulence. Int. J. Prod. Econom. 160			x				x			x	

	(2015): 157-171.											
53	Olhager, J., Prajogo, D. The impact of manufacturing and supply chain improvement initiatives: A survey comparing make-to-order and make-to-stock firms.Omega 40.2 (2012): 159-165.			**x**			**x**	**x**			**x**	
54	Ruhland, M.Making the case for lean manufacturing: Streamlining operations can help finishers improve product quality and trim costs at the same time.Metal Finishing 106.12 (2008): 15-18.			**x**			**x**				**x**	
55	Holtskog, H. "Continuous improvement beyond the lean understanding." Procedia CIRP 7 (2013): 575-579.	**x**			**X**		**x**					
56	Durkee, J.Just what is ‘lean manufacturing’ anyway?. Metal Finishing 106.12 (2008): 44-46.	**x**					**x**					
57	Gracanin, D., Buchmeister, B., Lalic, B., Using Cost-time Profile for Value Stream Optimization, Procedia Engineer.			**x**		**x**	**x**					

	69 (2014): 1225-1231.											
58	Standard, C., Dale D. Running today's factory: a proven strategy for lean manufacturing. Hanser Gardner Pub., 1999.			**x**			**x**					
59	Davidson, D., MacKay, K. "Meeting the lean deburring challenge." Metal Finishing 107.5 (2009): 18-21.	**x**					**x**					
60	Venkataraman, K., et al. "Application of Value Stream Mapping for Reduction of Cycle Time in a Machining Process." Procedia Mat. Scie. 6 (2014): 1187-1196.				**X**	**x**	**x**					
61	Marlow, P.B., Paixao, A. "Measuring lean ports performance." Int. J. Transport Manag. 1.4 (2003): 189-202.				**X**					**x**	**x**	
62	Chapter 9 - What are the measures of lean success? Reinventing Lean, 2007, Pages 271-286 Gerhard Plenert	**x**									**x**	
63	Conner, G. Don't let wasteful tasks slow you down:Lean manufacturing eliminates meaningless	**x**					**x**					

	activities from the shop floor while boosting productivity and efficiency. Metal finishing 104.3 (2006): 13-15.											
64	Kister, T.C., B. Hawkins. Governing principles and concepts of lean maintenance. Mainten. Plann. and Sched. (2006)42-62.	**x**										
65	Bruun, P., Mefford, R. Lean production and the Internet. Int. J. Prod. Econom. 89.3 (2004): 247-260.				**X**		**x**					
66	Alves Pinto Junior, M.J., Veiga Mendes, J., Operational Practices of Lean Manufacturing: Potentiating Environmental Improvements, J. Ind. Engineer. Manag. (2017)		**x**				**x**				**x**	
67	Siti Norhafizan Hibadullah, et. Al. Lean Manufacturing Practices and Environmental Performance in Malaysian Automotive Industry. Asian J. Finance & Accounting 5 (2013)				**X**		**x**				**x**	
68	Haddach, A., et. al. Role of Lean, Environmental and Social Practices to Increasing Firm's			**x**			**x**		**X**		**x**	**X**

	Overall Performance, J. Mater. Environ. Sci. 7 (2) (2016): 505-514											
69	M. Shabeena Begam, et. al., Current Trends on Lean Management – A review, Int. J. Lean Thinking 4, (2013)	**x**	**x**									
70	Bhamu, J., Sangwan, K.S."Lean manufacturing: literature review and research issues", Int. J. Op. & Prod. Manag. 34(7):(2014)	**x**	**x**				**x**					
71	Danese, P., Manfe, V., Romano, P. "A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions" Int. J. Manag. Rev.(2017)	**x**	**x**									
72	Govindana, K., Azevedo, S.G., Carvalho, H., Cruz Machado, V., Impact of supply chain management practices on sustainability, J. Cleaner Prod. 85 (2014): 212-225			**x**				**x**			**x**	**X**
73	Sahoo, A.K., Singh, N.K., Shankar, R. et al. Lean philosophy: implementation in a forging company, Int J Adv Manuf Technol 36 (2008)				**X**		**x**					

2.4.3 Findings for the Current Trends in the Lean Manufacturing

The articles selected in the SLR shows that there has been plenty of research in the lean area, as the 7 (9.5%) literature reviews in the SLM demonstrate (Kloppe et al., 2007), (Martinez Jurado and Moyano Fuentes, 2014), (Dieste and Panizzolo, 2018), (Marhani, 2013), (Alves Pinto Junior and Veiga Mendes, 2017), (Shabeena Begam et al., 2013), (Bhamu and Sangwan, 2014). In addition, up to 50 (68.5%) of the selected articles have been published in the 2010s. This shows that, although lean practices have been implemented for several decades, the dynamically changing needs of the current marketplace have indeed renewed the interest in them. In addition, from the collected articles, it can be seen that researchers in the field tend to study the lean approach from a practical point of view. In particular, only 19 (26%) articles study the lean approach from a conceptual point of view, while the rest address it in a more practical way, rather by proposing different research applications (37 (50.6%)) or by presenting a case study or conducting empirical research (19 (26%)).

As mentioned in Section 2.2, the lean concept can be described from the philosophical and the practical points of view. In addition, the practical ones are usually divided into lean manufacturing and lean management. Among the 73 selected articles, there are 56 (76.7%) articles that address lean practices from a manufacturing point of view, while 20 (27.4%) and 14 (19.1%) do so from a management and philosophic points of view, respectively. This last category seems to overlap with the management one, being 10 out of the 14 articles about lean philosophy and management simultaneously. On the other hand, it seems that articles addressing lean manufacturing do not include explicit treatments for lean management or philosophy, being mentioned together in 8 and 4 articles, respectively. Here, it is important to highlight that, although, in this thesis, the main focus is done on manufacturing issues, it is crucial to consider different aspects of the lean initiatives in order to reach improvements in an organisation as a whole. Then, all the aspects of the company have to be considered when implementing lean techniques. Finally, from the selected articles, it can be seen that most of them (55 (75.3%)) focus mainly (or exclusively) in the processing and operational aspects, while only 10 (13.7%) address supply chain issues. Even less articles (9 (12.3%)) talk about lean practices from a human resource's point of view.

Throughout years, large companies have shown to be more willing to implement lean practices than smaller ones. Moreover, it is generally agreed that large companies have a greater capability of principle formalisation, making it easier the implementation of new strategies of manufacturing and management, as well as to obtain performance improvements through their implementation (Danese et al., 2017), (Bhasin, 2012). In general, although research regarding successful lean implementations in large companies abounds (Doolen and Hacker, 2005), (Bhasin, 2012), less examples can be found regarding lean implementations in Medium and Small Enterprises (MSEs) (Karim, 2011). In addition, SMEs, which play an important role in regional economics, have faced several issues when trying to implement lean principles, making it hard to be able to achieve performance improvements. In this regard, authors in (Bhamu and Sangwan, 2014) suggest that it is necessary to develop a new framework for implementing lean practices in SMEs since it has already been demonstrated that the translation of lean techniques from large to SMEs organisations is not straightforward. In the present SLR, only 3 (4.1%) articles report to have conducted the research not only in large companies but also in MSEs (Belhadi et al., 2016), (Bhasin, 2012), (Karim, 2011), while in (Rahman et al., 2013) and (Doraa et al., 2013) lean practices for SMEs and small companies, respectively, are exclusively addressed. This shows that there still exists a gap in the literature regarding the study of lean practices implementation within the SME and small companies' environment. In addition, since they were first introduced in Japan, lean practices have been embraced by organisations all over the world (Matt and Rauch, 2013), starting from the US and Europe, and being recently followed by Asian and South American countries. In this line, the selected articles in the SLR report studies in companies from US (Herron and Hicks, 2008), (Eroglu and Hofer, 2011), (Doolen and Hacker, 2005), Australia (Martin et al., 2014), and European countries, such as Norway (Olhager and Prajogo, 2012), (Chunguang et al., 2018), Denmark (Torgeir and Ringen, 2015), Britain (Jørgensen et al., 2007), Italy (Bhasin, 2012), Republic of Ireland (Matt and Rauch, 2013), and Portugal (Chavez et al., 2015), as well as from Asian countries, such as Malasya (Govindan et al., 2014), (Rahman et al., 2013), Saudi Arabia (Marhani et al., 2013), Thailand (Karim, 2011), and India (Khanchanapong et al., 2014), and South American countries, such as Brazil (Venkataraman et al., 2014).

As it has also been mentioned in Section 2.1, lean practices have been successfully adapted to a wide range of organisations beyond the automotive industry. In addition, not only manufacturing companies enjoy the benefits of implementing lean practices but also the construction and service areas do. In the present SLR, applications within the framework of the manufacturing companies not only limited to the automotive industry, but also to electronics (Chiappetta Jabbour et al., 2013), (Doolen and Hacker, 2005), (Goss, 2010), food (Alves Pinto Junior and Veiga Mendes, 2017), and forging (Doraa et al., 2013) manufacturing have been proposed. Articles addressing the implementation of lean practices in the healthcare area (Sahoo et al., 2008), port services (Martin et al., 2014), system engineering (Marlow and Paixao Casaca, 2003), (Torgeir and Ringen, 2015), and construction (Torgeir and Ringen, 2015), are also included in the SLR.

Nowadays, there exist plenty of reasons why companies are moving towards leaner practices. Among them, improving productivity, efficiency, product quality and costumers' satisfaction can be mentioned. The articles selected in the present SLR confirm that researchers are interested on the impact of implementing lean practices regarding different aspects of a company, being 26 (35.6%) articles devoted to explicitly analyse such impacts on the economic (6), sustainability (6), operational (5), environmental (5), overall (3), product/service quality (2), social (2), organizational culture (1), business (1), inventory (1) and inventory turnover (1) areas. Nevertheless, although being aware of the impact that lean practices do have on the company performance is crucial, according to (Marhani et al., 2013) there is a lack in the literature for standard and widely accepted performance measurements associated with the different lean practices, making it difficult for researchers in the field to systematically evaluate lean performance. The observations that can be done from the present SLR agree with this, since only 4 (5.4%) of the selected articles provide a formal framework for lean performance evaluation (Manotas Duque, 2007), (Manotas Duque, 2007), (Eroglu and Hofer, 2011), (Behrouzi and Wong, 2011). In (Marlow and Paixao Casaca, 2003), an interesting summary of the most widely used metrics in the literature is presented, concluding that, in general, a priori assumptions about the obtained improvements in different aspects of the organisation when applying lean techniques should be accurate. In (Manotas Duque, 2007), a new approach to measure the inventory leanness is proposed, arguing that there is little research regarding whether lean inventory practices leads to improvements. Results in (Eroglu and Hofer, 2011) obtained from analysing 54 US manufacturing industries, indicate that there exists an ideal inventory level, which organisations should achieve in order to maximise their benefits. In (Eroglu and Hofer, 2011), a novel and systematic lean manufacturing measure based on fuzzy membership functions is proposed, resulting in a flexible, dynamic and easy to use integrated unit-less score. Finally, in (Behrouzi and Wong, 2011), a new set of performance measurements is introduced for port quality services.

The current changing business environment has forced companies to resort to new strategies for the sake of surviving. Since lean manufacturing very beginning, several lean techniques have been proposed being many of them currently well stablished and widely used. According to (Marlow and Paixao Casaca, 2003), most of the existing literature addresses lean techniques individually, nevertheless, authors in (Sundar et al., 2014) highlight the fact that, for the sake of success, these techniques should be properly integrated. In this line, they propose a route map to effectively implement lean techniques together. In the SLR conducted here, although all of the articles address lean techniques, there are 27 (36.9%) of them that focus exclusively in the study, development or implementation of a particular lean technique. Table 2-3 shows a summary of the techniques and tools proposed in the selected articles, together with the proposals' objectives and, when available, their resulting findings. According to the recent literature review by (Sundar et al., 2014), the most popular lean techniques are JIT, Scheduling, Employee Perceptions, VSM, Takt time, Flow Manufacturing, Bottleneck Process, Group Technology, CM, U-line Manufacturing System, Line Balancing, Quick Changeover/Single Minute Exchange of Die (SMED), Quality at Source, Small Lot size/Batch, Inventory, Kanban, Pull System with One-Piece Flow, Production Levelling, Continuous Improvement (CI), and Standardised Work. From the analyses of the selected articles in the SLR, it can be confirmed that these are indeed the most widely used techniques in the field, being employed in a wide range of applications as it can be seen from Table 2-3 (Sundar et al., 2014), (Seifermann et al., 2014), (El Maraghy and Deif, 2014), (Abdulmalek and Rajgopal, 2007), (Sullivan et al., 2002), (Rahman et al., 2013), (Peto, 2012), (Torgeir and Ringen, 2015), (Martin et al., 2014), (Stenholm et al., 2015), (Chavez et al., 2015), (Olhager and Prajogo, 2012), (Holtskog, 2013), (Gracanin et al., 2014), (Davidson and MacKay, 2009), (Siti Norhafizan Hibadullah, 2013), (Govindan et al., 2014).

Table 2-3: Techniques and tools proposed for implementing lean practices in the selected articles in the SLR, together with their applications and corresponding findings.

Nº	Article	Proposed Technique/Tool	Objective	Findings
1	(Sahoo et al., 2008)	Kanban	Determine to what extent Malaysian manufacturing companies has been able to implement Kanban activities.	Successful lean implementation depends on: • Commitment of top management • Inventory control • Quality improvement
2	(Rahman et al., 2013)	Variants of Kanban, Kaizen, SMED, and 5S	Propose variants of different well-known lean techniques, such as Kanban, SMED, 5S and Kaizen based on IT.	IT can be used to support companies to implement lean practices complementing each other.
3	(Riezebos and Warse, 2009)	• Elimination of Waste • CI • Continuous Flow and Pull Driven Systems • Multifunctional Teams • Information Systems	Integrate a set of metrics in order to build a consistent metric for each different stage during the implementation of lean practices.	In general, the a priori assumptions about the advantages of applying lean practices should be accurate.
8	(Manotas Duque, 2007)	5S	Evaluate the impact of applying 5S in the organisation sustainability.	Lean practices can help companies to move towards sustainability providing a good communication flow is ensured.
9	(Peto, 2012)	• Scheduling • Employee perceptions • VSM • Takt time • Bottleneck process • Group Technology • CM • U-line manufacturing system • Line balancing • Flow Manufacturing • Quick Changeover/SMED • Small Lot size/ Batch • Inventory • Pull System with, One-Piece Flow • Kanban • Production Levelling • Quality, at source • CI	Literature review.	A unified framework for implementation of lean practices is proposed.

		• Standardised Work		
10	(Sundar et al., 2014),	• Customer Value • Knowledge Transfer • CI • Standardisation • Stabilisation • Culture	Propose a new framework to combine six lean practices, including Customer Value, Knowledge Transfer, CI, Standardisation, Stabilisation and Culture, for product development in the context of System Engineering.	Although there exist a significant difference between the perceived lean performance in System Engineering and other sectors, System Engineering has the potential to improve the organisational learning management towards CI.
11	(Chunguang et al., 2018).	Soft lean practices	Evaluate the relation between successful lean manufacturing implementation and the organisational culture profile, doing special focus on the adoption of soft lean practices.	The organisational culture profile of successful lean companies shows a high cooperation, due to a low level of assertiveness.
12	(Bortolotti et al., 2015)	VSM	Propose a novel Multi-criteria Model for Decision-Making (MCDM) in the context of lean manufacturing.	The before and after scenarios are shown in detailed by the simulation model, and illustrates the potential benefits of lean practices, such as lead-time and inventory reduction.
18	(Abdulmalek and Rajgopal, 2007)	CM	Develope a low cost lean automation capable of adapting to individual tasks.	The proposed approach proved to be viable and useful to set the basis for further extensions to other CM lines
20	(Seifermann et al., 2014)	• Costumer Value • Knowledge Transfer • CI • Standardisation	Compare System Engineering companies to companies in other industrial sectors, with respect to lean success.	Project characteristics seem to be the aspect to explain the differences between companies from different sectors.
21	(Torgeir and Ringen, 2015)	VSM	Equipment replacement decision.	The use of VSM allows making better equipment replacement decisions based on the mapping of the current state of the production line.
27	(Torgeir and Ringen, 2015)	TPM	Conceptual analysis.	

38/47	(McCarthy and Rich, 2015) (El Maraghy and Deif, 2014)	CM	Propose a lean cell model based on systems dynamics to identify and capture lean tools that can influence production levelling.	The developed model provides lean practitioners a useful framework that should allow them to better decide about the implementation of production levelling techniques, and about the production lot sizes.
41	(Deif, 2011)	JIT	Give an insight into the evolution from JIT towards Seru Seisan.	Seru main advantages: high flexibility, short lead time, low inventory, and good morale. Seru main disadvantages: finite ductility on the size of a Seru, huge investment on training, increase in variable production cost, pressure on workers.
43	(Villa and Taurino, 2013)	Creative Tension Concept	Recognise the need for added value as well as the role of cost control in logistics based on the "creative tension" concept.	To challenge workers to use their skills in a creative way will actually lead to positive results.
46	(De Haan et al., 2012)	CPI	Implement lean methods in operative services at healthcare centre.	Lean tools have been successfully adapted in the operative services, reaching real and sustainable improvements in clinical outcomes.
50	(Martin et al., 2014)	Lean enablers for knowledge-based development	Evaluate the differences, similarities and synergies between the traditional System Engineering, Program and Lean Management.	Although creating knowledge, when truly understanding the problem, has shown to be successful and satisfactory, there is still a lack of standardisation.
52	(Stenholm et al., 2015)	Internal lean practices	Evaluate the impact of internal lean practices on operational, organisational and supply chain performances. In particular, in the presence of technological turbulence.	Internal lean practices are positively associated with supply chain, operational and organisational performance.
53	(Chavez et al., 2015)	Supplier rationalisation and integration	• Analyse the impact of lean practices and supplier rationalisation and integration on business performance. • Evaluate differences between make-to-order and make-to-stock companies.	Make-to-order: • Significant impact of supplier integration • No impact of supplier rationalisation Make-to-stock: • Significant impact of supplier rationalisation • No impact of supplier integration

55	(Olhager and Prajogo, 2012)	CI	Draw a historical line of continuous improvement in Norwegian automotive industries.	Although CI is felt like a natural part of the tasks in daily work, the actual notion of CI has a cultural foundation, and workers involvement is crucial for achieving improvements at the factory floor.
57	(Holtskog, 2013)	• Value stream costing • Cost-time profile	Propose a new value stream optimisation approach based on the combination of value stream costing and cost-time profile.	In order to achieve better results, companies need to be focused on the value.
59	(Gracanin et al., 2014)	Centrifugal finishing	Study the synergy among lean thinking and acculturation and the appropriate technology deployment.	Based on lean practices, it is possible to standardise edge and surface finish expectations to a degree not possibly achieved with manual methods.
67	(Davidson and MacKay, 2009)	• Supplier management • Employee involvement • JIT • Customer focus • Statistical process control to monitor quality	Study the correlation between lean practices and environmental performance in Malaysian automotive industries.	Lean manufacturing correlate positively with the environmental performance.
72	(Siti Norhafizan Hibadullah, 2013)	• Waste elimination • Supply chain risk management • Cleaner production • Flexible transportation and sourcing • Reverse logistics • ISO 14001 certification	Evaluate the impact of lean, resilient and green practices on the supply chain sustainability.	Techniques such as waste elimination, supply chain risk management and cleaner production correlate positively with supply chain sustainability.
73	(Govindan et al., 2014)	VSM	Implement VSM within the context of a forging company.	Improvements regarding set-up time and Work-in-Process (WIP) inventory have been shown.

In addition, from the different contributions in the SLR, it can be observed that, in recent years, there has been a tendency to see traditionally used lean techniques with a renewed interest. In this line, different novel approaches have been recently proposed in the literature (Sahoo et al., 2008), (Riezebos and Warse, 2009), (Chunguang et al., 2018). Some of them, introduce new variants of already well-known techniques, as in the case of (Bortolotti et al., 2015), where different variations of lean techniques, such as Kanban, Kaizen, SMED, and 5S are proposed based on IT, arguing that IT is a powerful tool that can help companies to implement lean practices since they can complement each other. Some others, propose new strategies to combine lean techniques in order to take advantages from their synergy, as in the case of (Riezebos and Warse, 2009), where a new framework to combine six lean practices, including Customer Value, Knowledge Transfer, CI, Standardisation, Stabilisation and Culture, for product development in the context of System Engineering is proposed. Finally, although most of the current literature is focused in hard lean practices, such as practical techniques and tools, soft lean practices have recently called the attention of some researchers, as in the case of (Chunguang et al., 2018), where the relationship between successful lean manufacturing implementation and the organisational culture profile is studied, doing special focus on the adoption of soft lean practices. In (Bortolotti et al., 2015), it is stated that soft lean practices are crucial for the lean production to be successful, and authors in (Bortolotti et al., 2015) encourage companies to implement hard and soft lean practices in a synergetic environment in order to maximise the lean benefits.

Finally, Figure 2.12 summarises the information gathered from the SLR and discussed above, showing the main techniques and tools that have been proposed, the different applications in which lean practices have been studied, and the main performance implications that have been addressed in the selected articles.

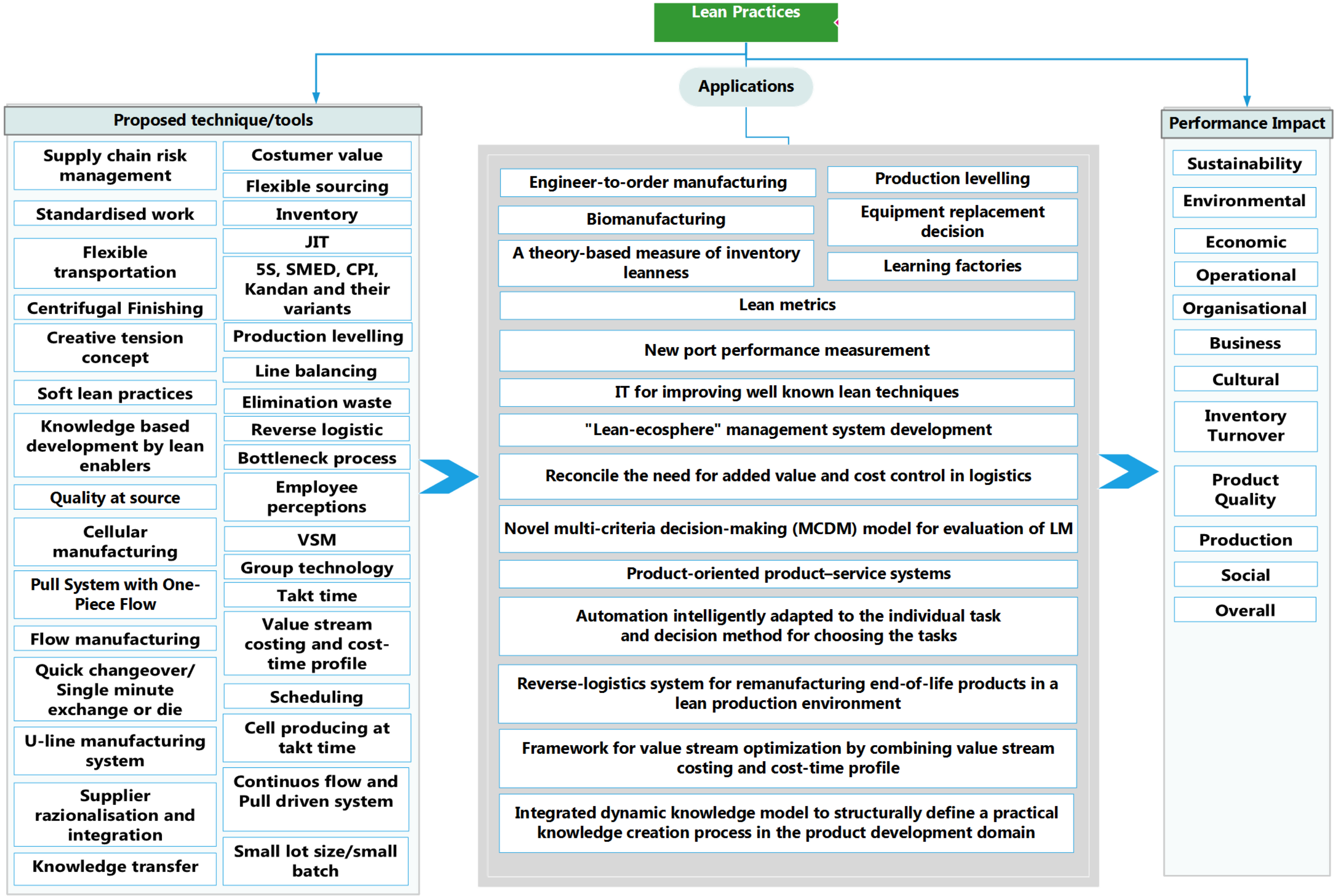

Figure 2.12: Summary of the lean practices in the SLR: Proposed techniques, applications and their performance impact.

2.5 Lean Manufacturing and its Link with Sustainability

The well-known Triple-Bottom-Line (TBL) sustainability conceptualisation shown in Figure 2.13 is adopted within the context of this thesis. In particular, the TBL sustainability model, first introduced in (Bortolotti et al., 2015), suggests that a firm would be able to achieve sustainable results provided it is capable of improving environmental, social and economic performances simultaneously. Then, in order to analyse lean practices and its link with sustainability, it is necessary to analyse to what extent companies currently implementing lean practices are concerning not only economic but also environmental and social aspects.

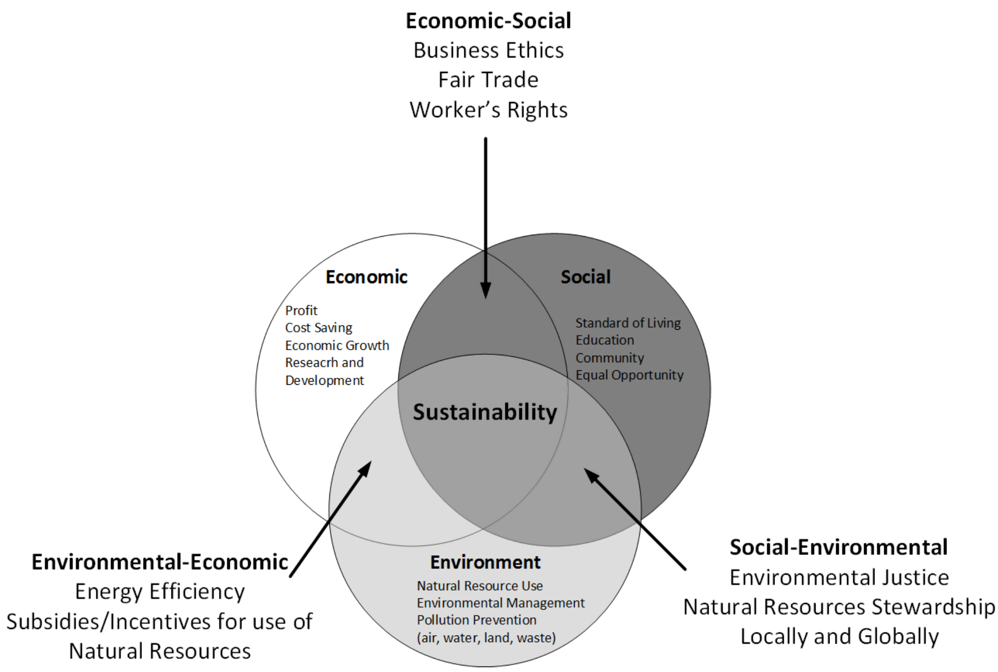

Figure 2.13: The three pillars of sustainability performance defined in (Elkington, 1998)[18].

In order to fulfil today's society demands for sustainable solutions, lean manufacturing has become to be considered with a renewed interest as a starting point for becoming "greener" by extending, modifying and updating lean methodologies, in the sense of improving economic aspects by reducing cost and increasing the profit; environmental aspects by reducing waste and optimising resource usage; and social aspects by improving the working environment and occupant health. This lean approach towards sustainability can be seen in Figure 2.14.

[18] Source: Based on the scheme included in http://css.umich.edu/sites/default/files/css_doc/CSS02-04.pdf

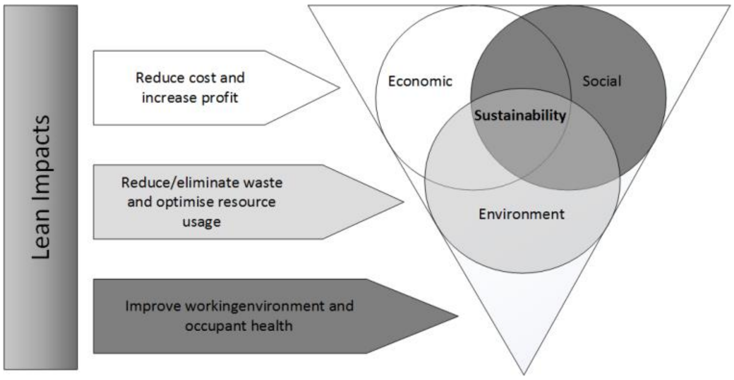

Figure 2.14: Lean contributions towards sustainability[19].

Several studies have demonstrated that lean practices can actually yield sustainability improvements, even if they have not been particularly aimed at doing so (Elkington, 1998). In Table 2-4 the main lean techniques used in the literature as well as their benefits towards sustainability are shown.

Table 2-4: Main lean techniques and their impact on sustainability (Fliedner, 2008)[20].

Lean Technique/Tool	Perceived Sustainable Benefits
Kaizen	Different activities that are likely to generate waste can be eliminated by Kaizen practices.
VSM	The overall wastage can further be reduced by implementing VSM techniques, since it they allow reducing the defect occurrence and the energy consumption across the whole system.
5S	• The need for lightning can be reduced by keeping windows clean. In this sense, the energy consumption is reduced. • Keeping the equipment, components and materials organised helps to reduce the material consumption.
CM	Since CM allows decreasing the set-up times and the product changeovers, the energy and resource requirements can be reduced.
Pull Approach	The inventory is reduced, and then several kinds of wastes can be avoided. In addition, the need for floor space is reduced, and so it is the need for energy.
TPM	Increasing the equipment lifespan leads to decrease the need for equipment replacement, reducing the environmental footprint.
Six Sigma	• To minimise the number of defects yields improvements regarding the energy and resources consumption. • The solid and hazardous wastes are reduced since Six Sigma techniques provide an accident-free workplace. • The product lifespan, which is a crucial aspect of sustainability, can be increased by improving its durability and reliability.
Pre-production Planning	• Using equipment that is right sized lead to reduce the material and energy requirements. • A simpler product design process would allow using fewer materials and parts. In addition, product would be easier to recycle, a fundamental task for sustainability
Lean Supplier Networks	Magnify the benefits already achieved by other lean practices.

[19] Source: Based on the scheme presented in (Nahmens, 2012).

[20] Source: Based on the table presented in (Fliedner, 2008).

Although lean practices have long been associated with economical and operational aspects, in recent years researchers have begun to look at them from new points of view. In this line, the SLM of Table 2-2 includes 13 (17.8%) articles that address lean practices from an environmental, social or sustainable perspective. From these articles, 3 (4.1%) have been published in the J. of Cleaner Production, while the others have been published in the J. of Materials and Environmental Science, Magazine of Clean Technologies and Environmental Policy, Procedia-Social and Behavioral Sciences, IOP Conf. Series: Earth and Environmental Science, Club of Economics in Miskolc, Int. J. of Production Research, Advances in Production Management Systems (International Federation for Information Processing), J. of Production Economics, J. of Industrial Engineering and Management, Asian J. of Finance & Accounting, and J. of Production Inventory Management. This shows that researchers tend to publish articles regarding sustainability in specialised journals devoted to environmental issues rather than economic ones.

Among the above mentioned 13 articles, 7 (9.6%) are exclusively devoted to analyse the relationship between lean practices and sustainability (Fliedner, 2008), (Peto, 2012), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Vinodh et al., 2011), (Marhani et al., 2013), (Haddach et al., 2016), while the other ones talk about social (Govindan et al., 2014), (Haddach et al., 2016), and environmental (Chiappetta Jabbour et al., 2013), (Dieste and Panizzolo, 2018), (Chunguang et al., 2018), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013) issues.

Only one of the 13 selected articles has been published before 2010, confirming the current tendency in the literature to make focus on the sustainable aspects of lean practices. Nevertheless, according to (Haddach et al., 2016), there is still a lack of real life case studies in the literature. On the contrary, in a recent literature review regarding the sustainable benefits of applying lean practices presented in (Peto, 2012), many empirical evidences are collected and analysed. In addition, in (Dieste and Panizzolo, 2018) it is shown that companies applying lean practices achieve greener results. Moreover, it is also highlighted that most of the researchers in the field agree that lean practices yield environmental performance improvements, since lean practices favour a cultural background that allows waste reduction and pollution prevention, which are crucial factors for environmental performance. Many of the articles selected in the SLR conducted in Section 2.4 agrees with this observation (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). In (Chiappetta Jabbour et al., 2013), it is argued that sustainability is an evolution of lean practices stating that, although lean initiatives have historically been internally focused, sustainability makes them to be externally focused, spanning the entire value chain. In addition, different successful lean sustainable initiatives within the framework of different areas, such as product, process, design or environmental managements are studied in order to analyse and report their achieved benefits. In the same line, it is highlighted that, even when lean practices were not initially aimed at environmental issues, companies have found that lean practices indeed yielded improvements in the environmental performance. In this context, organizations should explicitly consider lean practices' environmental impact as well as their potential regarding sustainability, understanding sustainability as a new lean concept.

In general, the selected articles in SLR shown in Table 2-2 address the link between the lean concepts and sustainability based on a qualitative approach. This is probably due to the fact that there is a lack in the literature of a unified criterion and a widely accepted metric to evaluate to which extent lean practices do have impact on sustainability. Nevertheless, there are some studies among the selected ones in the SLR that offer a more detailed study (Fliedner and Majeske, 2010), (Alves Pinto Junior and Veiga Mendes, 2017), (Dieste and Panizzolo, 2018), (Haddach et al., 2016). In (Govindan et al., 2014), a case study in an electronics company is conducted in order to analyse the correlation between the environmental performance and different lean techniques, such as Kaizen, PDCA (Plan, Do, Check, Act), Ishikawa Diagram, Poka-Yoke, and Standardised Work. In this case, a positive correlation between the environmental performance and each one of the studied lean techniques is reported. In (Alves Pinto Junior and Veiga Mendes, 2017), green indicators are evaluated in terms of lean practices. The reported results show that energy use and solid waste are among the best performing factors. In addition, air emissions have also resulted to perform well, although this contradicts previous observations in, for instance, (Dieste and Panizzolo, 2018), where it is stated that lean practices do not improve this indicator. In this regard, authors argue that companies should pay special attention on JIT applications since they are one of the causes of air emissions increments (Venkat and Wakeland, 2006). In (Rothenberg et al., 2001), the impact of lean as well as some other practices like green ones on supply chain sustainability is analysed based on several case studies of Portuguese automotive industries. Results show that waste elimination, supply chain management and cleaner production positively correlated with supply chain sustainability in economic, social and environmental terms. Finally, in (Govindan et al., 2014), a combination of lean, environmental and social practices is proposed in order to reach improvements in the sustainability of the organisation, demonstrating that the combined approach outperform each of the practices being implemented individually.

Although most of the articles in the SLM of Table 2-2 agree that lean practices have already demonstrated to be able to reach sustainability improvements in terms of economic, social and environmental balance, there are some other articles within the ones selected in the SLR conducted in Section 2.4 that do not report benefits regarding sustainability when applying lean practices (Haddach et al., 2016), (Peto, 2012). For instance, in (Marhani et al., 2013), an study of lean practices in terms of sustainability requirements is held, concluding that lean practices have not yet reach the required level for achieving sustainability; while in (Peto, 2012), the implementation of lean practices in a Malaysian construction industry is analysed, concluding that a more holistic approach, including health, safety and Six Sigma is required in order to ensure sustainability. In general, the articles that agree that lean practices, as they are currently implemented, are not enough to reach sustainability, find similar barriers. In (Marhani et al., 2013), some of them, such as, human attitude, financial, managerial and technical issues, and lack of government support, are particularly addressed for the case of lean construction. Finally, in (Marhani et al., 2013), it is highlighted that, although most of the reported efforts towards sustainability have been fruitful, there is still a need for a higher costumer and suppliers involvement in order to improve the already reached levels of sustainability.

2.6 Main Findings and Research Gaps from the Lean Manufacturing SLR

The main findings and research gaps identified in the SLR conducted in this chapter are summarised in Table 2-5 and Table 2-6, respectively.

Table 2-5: Summary of the main finding identified in the Lean Manufacturing SLR.

Findings	Sources
• **Large companies have a greater capability of principle formalisation, making it easier the implementation of lean manufacturing than in the case of SMEs.** • **The translation of lean techniques from large to SMEs organisations is not straightforward.**	(Danese et al., 2017), (Bhasin, 2012), (Bhamu and Sangwan, 2014)
Most of the works in the literature evaluate the performance of lean practices qualitatively.	(Marhani et al., 2013)
The most popular lean techniques are JIT, Scheduling, Employee Perceptions, VSM, Takt time, Flow Manufacturing,	(Sundar et al., 2014), (Seifermann et al., 2014), (El

Bottleneck Process, Group Technology, CM, U-line Manufacturing System, Line Balancing, Quick Changeover/SMED, Quality at Source, Small Lot size/Batch, Inventory, Kanban, Pull System with One-Piece Flow, Production Levelling, CI, and Standardised Work.	Maraghy and Deif, 2014), (Abdulmalek and Rajgopal, 2007), (Sullivan et al., 2002), (Rahman et al., 2013), (Peto, 2012), (Torgeir and Ringen, 2015), (Martin et al., 2014), (Stenholm et al., 2015), (Chavez et al., 2015), (Olhager and Prajogo, 2012), (Holtskog, 2013), (Gracanin et al., 2014), (Davidson and MacKay, 2009), (Siti Norhafizan Hibadullah, 2013), (Govindan et al., 2014).
Lean practices favour a cultural background that allows waste reduction and pollution prevention, which are crucial factors for environmental performance	(Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013)
Environmental aspects can be improved by reducing waste and optimising resource usage. In particular, promising results have been reported in the literature regarding: • **energy use** • **solid waste**	(Venkat and Wakeland, 2006), (Bashkite and Karaulova, 2012)
Lean tools like 5S can improve social aspects by improving the working environment.	(Dües et al., 2012), (King and Lenox, 2001)
JIT applications cause air emissions increments.	(Venkat and Wakeland, 2006)
The main barriers reported when applying lean practices are: • **human attitude** • **financial issues** • **managerial issues** • **technical issues** • **lack of government support**	(Marhani et al., 2013)

Table 2-6: Summary of the main research gaps identified in the Lean Manufacturing SLR.

Research Gaps	Sources
There is a need for developing new manufacturing	(Danese et al., 2017), (Bhasin, 2012), (Bhamu

frameworks supporting the implementation of lean practices in SMEs.	and Sangwan, 2014)
There is a lack for standard and widely accepted performance measurements associated with the different lean tools and practices.	(Marhani et al., 2013)
There is a lack of real life case studies evaluating the lean influence in the companies' sustainability performance.	(Haddach et al., 2016)
It is still not clear in the to what extent and how lean tools are able to help towards reducing manufacturing environmental impacts when it seems to be a conflict of interests between environmental performance and cost, quality, and time performances.	(Venkat and Wakeland, 2006), (Bashkite and Karaulova, 2012)
A more holistic approach, including health, safety and Six Sigma is required in order to ensure sustainability	(Peto, 2012)
There is a need for a higher costumer and suppliers involvement.	(Marhani et al., 2013)

2.7 Chapter Summary

In recent years, due to the rapidly changing and highly competitive marketplace, companies have faced new challenges. In this context, lean practices, which have traditionally account for improving quality and productivity based on waste elimination, have started to be considered with a renewed interest (Dieste and Panizzolo, 2018). In particular, special emphasis has been done towards analysing to what extent these practices are able to lead not only to economic improvements but also to environmental and social ones. In order to give some insight into this issue, a SLR has been conducted in this chapter regarding the current trends in the field, doing special focus on the link between lean manufacturing and the different sustainability aspects. According to the SLR, most of the researchers agree that lean practices have the advantage of being not only well-documented but also widely used and practically adopted. In addition, although, by nature, they are not designed to do so, they can positively influence not only economic performance but also environmental and social ones (Sundar et al., 2014), (Bhamu and Sangwan, 2014).

It is important to highlight that, despite the promising greener results obtained by lean practices (Danese et al., 2017), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018), it is possible that the achieved benefits in other aspects than the economic one would be not enough to meet the current sustainability requirements. In this line, researchers agree that, in order to achieve a higher sustainability level, green practices should also be adopted. In Chapter 3 a complete theoretical background about green manufacturing is provided and its main techniques are described. In addition, particular emphasis is done on the current trends in green practices as well as on their link with sustainability, in terms of economic, environmental and social aspects.

3 GREEN MANUFACTURING: LITERATURE REVIEW

3.1 Introduction

In the today's society, the increased global awareness of how manufacturers could risk the environment have resulted in a new green movement aimed at shaping customer needs in the different areas that depend on ethical issues towards the environment. In this context, there are many reasons why manufacturers should be willing to reduce their impact on the environment, ranging from keep being competitive to improving their social reputation, not to mention the government and stakeholders pressure (Bortolotti et al., 2015), (Klebnikoff, 1996), (Ciocci and Pecht, 2006), (Mohnty and Deshmukh, 1998).

The concept of green manufacturing was first introduced in Germany in the early 1990s to fulfil the market's greener expectations by extending the "waste reduction" idea proposed by lean manufacturing, in the sense of reducing waste and pollution as well as optimising the use of raw material and energy in order to minimise the environmental and health risks (Ahemad and Shrivastava, 2013), (Paul et al., 2014). Although the literature about green manufacturing is not as vast as in the case of the lean manufacturing, different definitions of green manufacturing can be found. In (Dilip Maruthi and Rashmi, 2015), green manufacturing is defined as a sustainable approach that makes special focus on product development and operations to decrease the impact on the environment. In (Atlas and Florida, 1998), this definition is extended by presenting green manufacturing as a set of practices aimed at integrating the different companies' tasks within different productive areas, such as, designing, manufacturing and planning in such a way that the flow of environmental waste can be identified, quantified, assessed, and managed so that the environmental impact can be reduced.

Green manufacturing becomes a reality when there is an economical understanding of its importance and efficiency (Melnyk et al., 2001). Unfortunately, despite the several successful cases within the academic as well as the industrial fields (Deif, 2011), (Rao, 2004), (Karp, 2005), (Hoffman, 2000), there has long existed a miscommunication between researchers and managers regarding how important it is to invest in green technology and change. Managers should understand that investing in green manufacturing practices will be reimbursed through costs that are saved through a more efficient system, resulting in a positive impact on the Return on Investment (ROI) (Mohnty and Deshmukh, 1998). In recent years, in order to encourage industries to move towards greener solutions, almost every governments from Asia, EU, South America and the US, have focused on improving and impending new regulations, obligations, and tax benefits to companies becoming greener or eco-friendly in different stages of manufacturing (Paul et al., 2014), (Chan, 2005). In this line, the United Nations has introduced the UNIDO Cleaner Production Programme[21] promoting the use of green manufacturing as it will improve competition and productivity of the enterprises.

In this context, where companies are urged to adopt green initiatives, such as, optimising the use of resources and energy, as well as developing and using renewable materials, it becomes crucial to fully understand green manufacturing main concepts, methods, techniques, and tools in order to be able to fulfil the green needs of both organisations and costumers. In addition, it is also important to investigate the current trends in the field, in order to identify and analyse the most popular approaches as well as to highlight the research gaps so that novel approaches can be proposed and future research directions can be suggested. In this chapter, the main concepts regarding green practices are introduced, the most popular methods and tools used for their implementation are described, and the current trends in the field are analysed. Finally, the actual relationship between green practices and the companies' sustainability, in terms of economic, environmental and social aspects, is discussed.

The remaining of the chapter is organised as follows. In Section 3.2, a theoretical background of green manufacturing is provided. In Section 3.3, the most popular green tools and techniques are described. In Section 3.4, an exhaustive literature review is conducted in order to analyse the current trends regarding green practices. In Section 3.5, the actual link between green practices and sustainability aspects are discussed. In Section 3.6, the main findings and gaps identified in the SLR are summarised. Finally, in Section 3.7 the chapter summary is provided.

3.2 What is Green Manufacturing?

For several years, the main leitmotiv in the field of manufacturing has been to satisfy or create needs, while keeping competitiveness by enhancing the product quality, reducing the time to market, and being innovative. In recent years, this manufacturing philosophy, together with the improved people living's standards, has led to a growing product demand, fulfilled by a huge amount of produced goods, which ended up generating pollution and wastes. In this context, the concept of green manufacturing emerges based on the principles shown in Figure 3.1 (Thomas, 2010), in an attempt to give companies useful tools towards taking into account environmental aspects within the manufacturing procedure to reduce or prevent hazardous emissions, get rid of the consumption of wasteful resources, recycle, and minimise health risks (Yusuff et al., 2012) throughout the entire manufacturing process, by minimising the environmental footprint during the whole

[21] https://web.archive.org/web/20060528092455/http://www.unido.org/doc/4460

product life cycle. In particular, as in the case of lean manufacturing, green manufacturing also defines a series of green wastes that should be taken into account (Choudharya, et al., 2018):

- Energy: Overuse of power from things such as lighting, motors, and electronic equipment
- Water: Overuse of fresh water, *i.e.* paying to use more water than needed and paying again to have it taken away and cleaned.
- Material: Designing virgin raw materials into products that would end up in the landfill or designing resource expensive non-recyclable product for short life time. Garbage: Paying for something that will be thrown away, *i.e.* something that has caused negative environmental impact to produce, and then paying again for disposal.
- Transportation: Unnecessary transportation of materials, goods, and people.
- Emissions: Unnecessary paying to create and discharge pollutants on-site, and then being subject to the fines and levies associated with doing this.
- Biodiversity: Either directly impacting flora and fauna negatively or overharvesting resources faster than they can regenerate themselves.

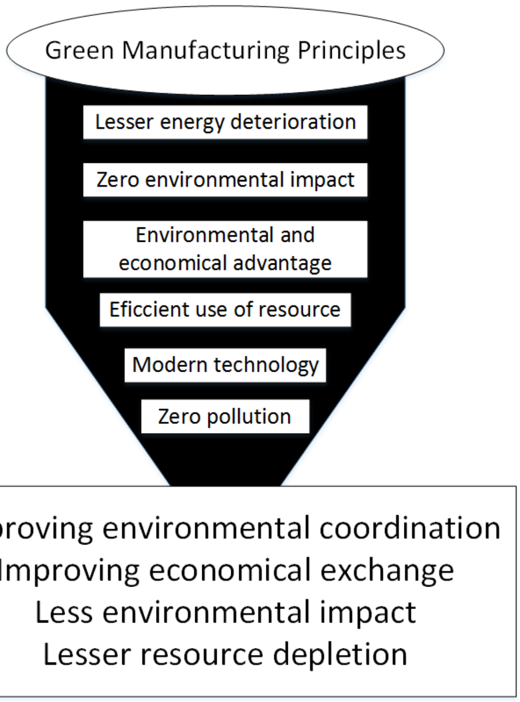

Figure 3.1: Green manufacturing principles[22].

The key idea introduced by the green thinking is the idea that companies should be responsible for the environmental impact of their products throughout their entire life

[22] Source: Based on the diagram presented in (Yusuff, 2012).

cycle. In this line, in (Deif, 2011) the Extended Producer Responsibility (EPR) is defined as the extension of the manufacturers' responsibility to different stages of the whole product life cycle, making special focus in the final disposal of the product. Then, the EPR urges companies to "close the loop", that is, to extend the concept of product life cycle not only by taking care of the product and its environmental impact through the traditional linear product life cycle (shown in Figure 3.2), but also by considering the product End-of-Life (EOL) stage, which is the point where the product is no longer able to work as it is supposed to work (Lindqhvist, 2000), as a new stage in a circular (greener) product life cycle (shown in Figure 3.3).

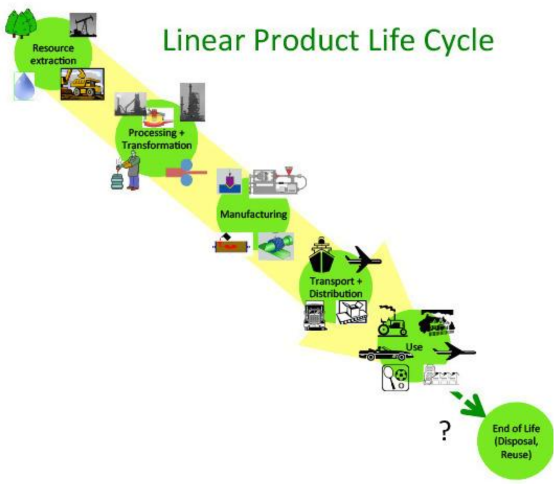

Figure 3.2: Linear Product Life Cycle (Rose et al., 2000) [23].

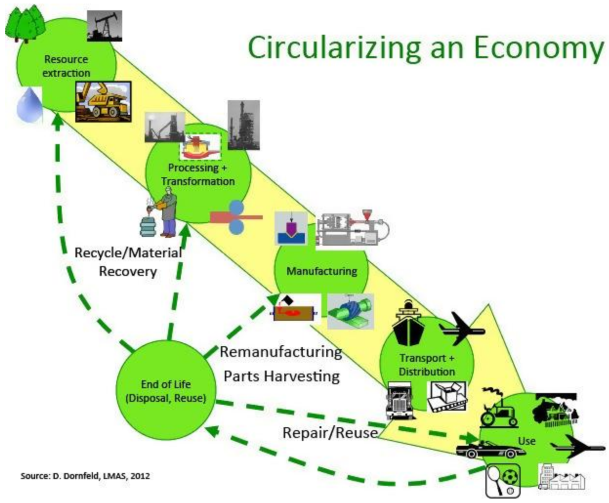

Figure 3.3: Circular Product Life Cycle (Dornfeld, 2014) [24].

Figure 3.4 shows an example of a green product life cycle based on the closed loop life cycle idea which includes product EOL as a new stage in the product life cycle. Although the actual implementation of the green product life cycle as well as the strategies applied at each stage would depend on different factors, such as the company culture and local regulations, they generally address the design, material selection and resource extraction, processing and transportation, manufacturing, packaging, distribution and transportation, use, and EOL of a product (Dornfeld, 2014). In addition, although the particular objectives of each stage could differ in order to satisfy different requirements or regulations, they mainly agree in the following objectives:

[23] Source: Based on the figure presented in (Dornfeld, 2014).
[24] Source: Based on the figure presented in (Dornfeld, 2014).

- Design: The design stage is based in the Design for Environment (DfE) principles, consisting in a set of guidelines to consider the environmental impact of a product from the very beginning of the production process, *i.e*, from its design. This technique includes minimising the resource consumption, reducing the use of toxic substances, rapid prototyping and planning the product for recyclability, among others.
- Procure: The procurement stage is focused on making the supply chain as green as possible. The supplier engagement with the green principles has to be ensured in order to acquire resources and materials that are in agreement with international environmental standards and governmental regulations.
- Manufacture: The manufacturing process should be resource efficient regarding energy, water and materials consumption, while minimising hazardous emissions and wastes.
- Packaging and Distribution: The packaging should be returnable, reusable or recyclable, while the distribution should be based on the green principles.
- Costumer use: One of the main concerns of the green manufacturing is to produce a green product which is reliable until its EOL. In addition, the green product usage should imply low energy consumption as well as be emission free.
- EOL: The EOL product strategy is a decision making strategy to deal with a product at its EOL, and constitutes one of the crucial phases towards green manufacturing. In fact, the actual success in reducing the environmental footprint of a product strongly depends on the selected EOL strategy. EOL strategies include reuse, remanufacturing, and recycling (Yusuff et al., 2012). Finally, it is important to highlight that the EOL stage is tightly related with the rest of the stages in the product life cycle. In particular, the design phase is crucial for the EOL strategy success, since in order to be able to handle products at their EOL, manufacturers should design their products to be easy to disassemble, allowing reuse of their components and recycling.

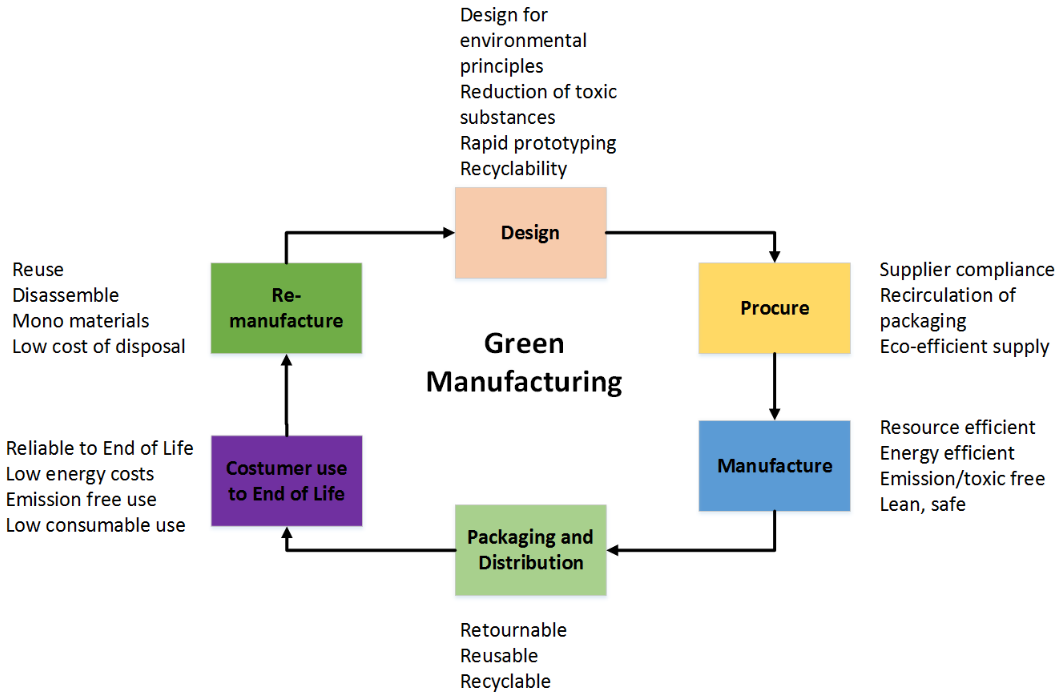

Figure 3.4: Green manufacturing cycle[25].

Finally, as in the case of lean manufacturing, the waste reduction is also a crucial aspect for green manufacturing. In addition, in the particular case of the green manufacturing, a further interpretation of waste is introduced, considering wastes not only any non-value added activity, but also any activity that can generate any kind of wastage (resource, material, energy, etc.). In (Toffel, 2002), authors analysed several case studies where different techniques were applied to reduce waste, showing the importance of reducing wastes as a pillar of green manufacturing. In fact, in (Mohanty and Deshmukh, 2005) green productivity is defined as any event that focus on reducing waste. Authors in a recent literature review (Naderi, 1996) also agree with the waste interpretation introduced in (Rehman, 2013) and (Mohanty and Deshmukh, 2005), stating that most of the green practices proposed in the literature are mainly focused on reducing sources that involve any action that could generate considerable amount of waste and recycling, reusing or using wastes as elements during the processes, either substituting a product, or even as raw material feedstock. In this line, Figure 3.5 illustrates how green manufacturing can reduce lean wastes from the generation source, using four strategies, *viz.*, reducing waste generation, controlling a specific level of waste generation, eliminating what is produced from waste, and finally trying to prevent generating waste from the very beginning (Naderi, 1996).

[25] Source: Based on the scheme available at: http://www.frost.com/prod/servlet/market-insight-print.pag?docid=188029142

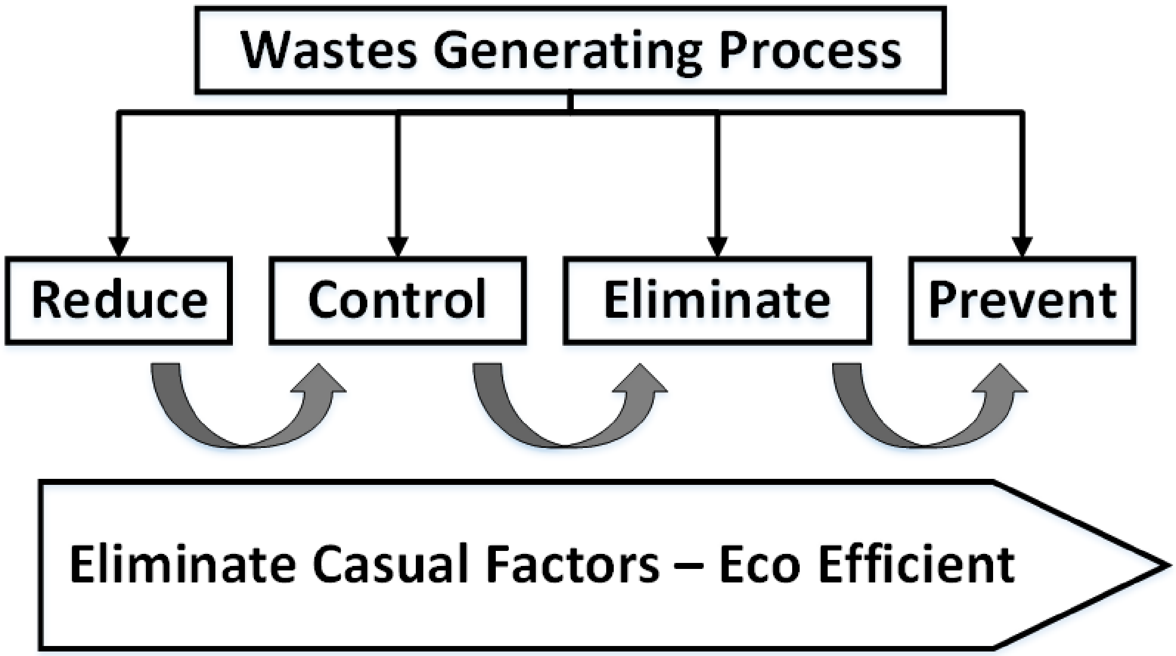

Figure 3.5: Green manufacturing and wastes[26].

3.3 Green Manufacturing: Tools and Techniques

Green manufacturing faces challenges regarding both product and process perspectives. Regarding the product perspective, green manufacturing should be able to meet customer demands for environmentally-friendly products, minimise resources use, and select materials that do not harm the environmental. Regarding the process perspective, green manufacturing aims at minimising the use of materials and the energy consumption, eliminating the use of hazardous substances, and reducing the waste generation. Within the green framework, both perspectives (product and process) should be addressed in an integrated way in an attempt to ensure the reduction of the product environmental footprint throughout its entire life cycle.

Generally speaking, green manufacturing tools can be classified into two groups of methods, namely, assessment oriented or improvement oriented methods. Methods belonging to the first group, such as the mass balance (also known as eco-balance) and the Life Cycle Assessment (LCA), conduct a conscious evaluation regarding the company's environmental impact in order to give an insight of the company's environmental efficiency. Based on this analysis, methods belonging to the second group, such as EOL strategies and DfE can be applied in order to achieve improvements in the environmental efficiency of the whole company.

[26] Source: Based on the scheme presented in (Deif, 2011).

3.3.1 Assessment Methods

3.3.1.1 Mass or Eco-Balance

The mass balance is one of the most useful tools that companies have to analyse their actual environmental impact. It consists in determining a process effectiveness and wastage in terms of its inputs and outputs, so that a clear picture of the flow of materials and energy within that particular process. A mass balance, often called within the green management framework, an eco-balance, can be applied to an individual product, process or even to the whole company. Figure 3.6 illustrates an eco-balance for products, processes and the entire company.

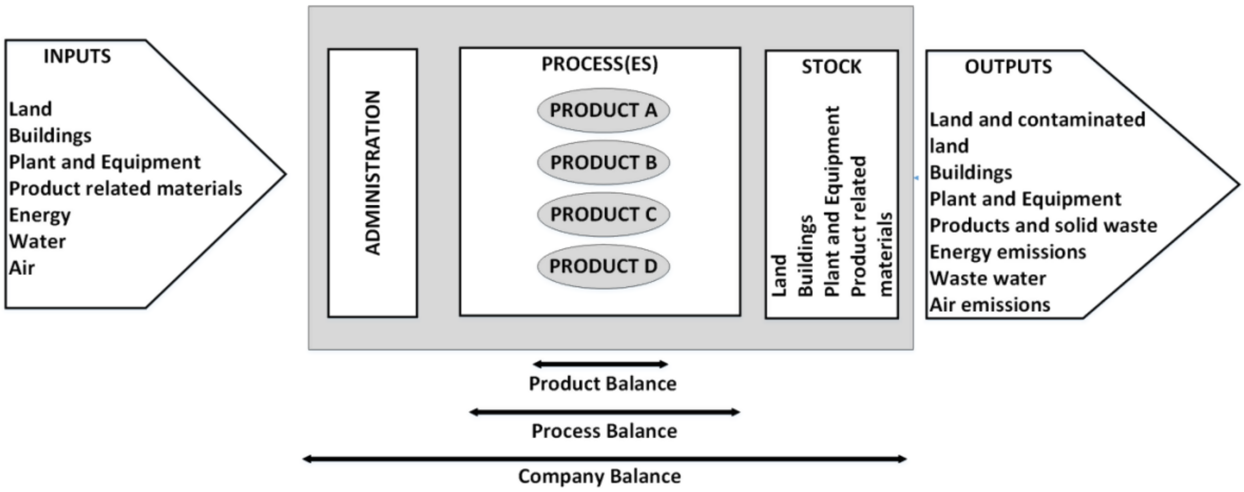

Figure 3.6: Eco balances[27].

3.3.1.2 Life Cycle Assessment

In the same line of the eco-balance introduced in Section 3.3.1.1, to evaluate the product (or service) life cycle is also a crucial task. The LCA is an internationally standardised method under ISO 14040 and ISO 14004 that can be used to identify and quantify the environmental and resource-related impact associated with a particular product throughout its entire life cycle, that is, from its design to its EOL (Deif, 2011). Figure 3.7 illustrates a typical LCA and its stages, which can be described as follows:

- Procurement Stage: In this stage, LCA evaluates whether companies have selected proper suppliers so that they can offer suitable materials, such as easily recyclable ones, avoiding the unusual or hazardous materials, in order to ensure the chosen materials are in agreement with international environmental standards (Zhang et al., 1997).

[27] Source: Based on the diagram presented in (Anderson, 1998).

- Manufacturing Stage: In this stage, LCA studies the use of resources in terms of material, water and energy in order to evaluate to what extent they have been minimised, as well as the power efficiency has been ensured throughout the whole manufacturing process (including packaging issues).
- Distribution Stage: In this stage, LCA evaluates the green characteristic of the distribution process, making special focus on the CO2 emissions which can be reduced by minimising the logistics.
- Usage Stage: In this stage, LCA evaluates whether the sold product does indeed help the costumer to save energy by optimising its power consumption.
- EOL Stage: In this stage, LCA evaluates the EOL strategies applied by the company regarding their environmental efficiency.

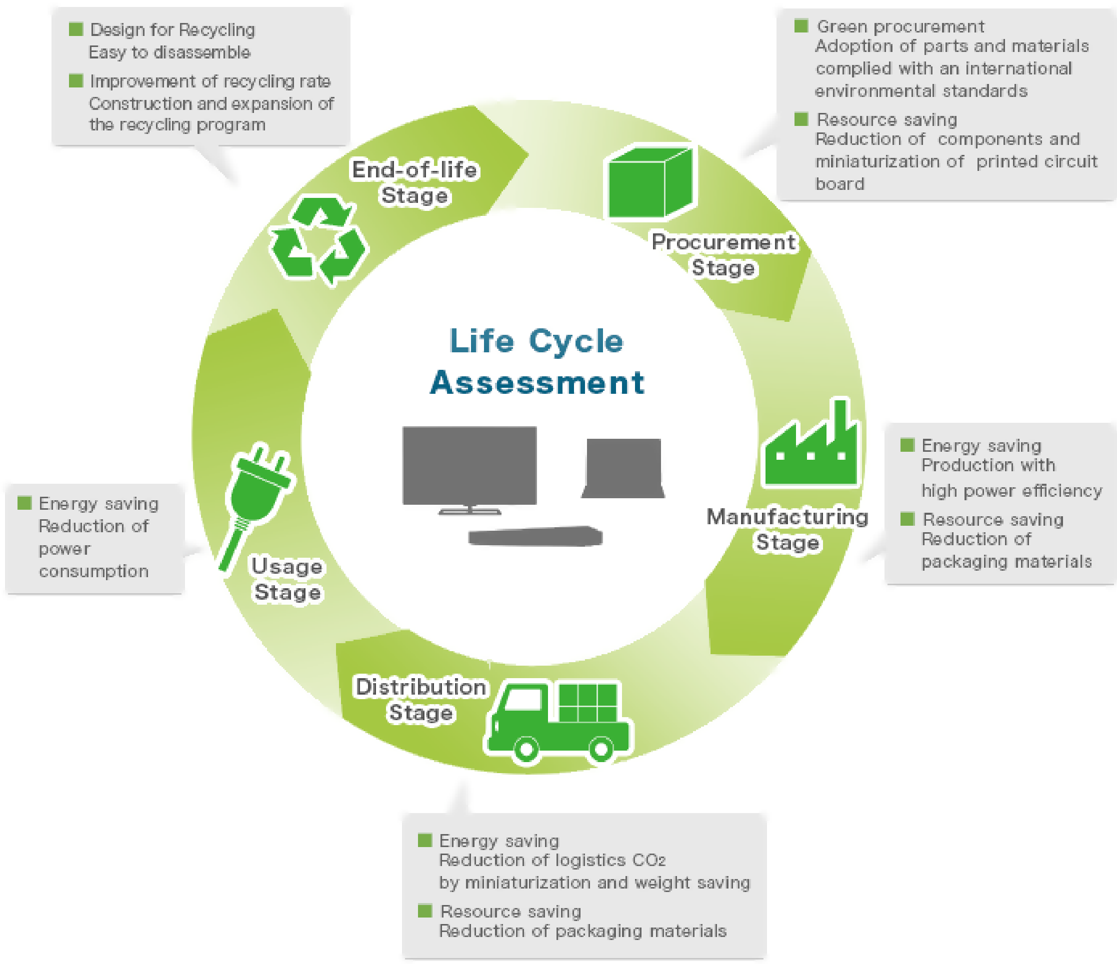

Figure 3.7: Life-cycle Assessment [28].

[28] Source: Based on the scheme available at: http://ecodyger.com/lca/

3.3.2 Improvement Methods

3.3.2.1 EOL Strategies

One of the key aspects in green manufacturing is to be responsible for the product and its environmental impact throughout the entire product life cycle including the concept of product EOL into the product life cycle. Researchers have long focused their attention to develop different strategies to handle EOL product (Toffel, 2002), (Yang et al., 2015), being remanufacturing, reconditioning/refurbishing, reusing, repurposing, repairing and recycling among the most popular ones. It is important to highlight that, when none of these desirable strategies is viable, companies have to resort to other EOL strategies which, although being less environmentally friendly, are also regulated and controlled, like incinerating and landfilling. These EOL strategies are described below, while Figure 3.8 shows how each of them can be integrated into the product life cycle:

- Remanufacturing: Making an already used product to work as if it was new, guaranteeing that it works as well as the actually new ones.
- Reconditioning/refurbishing: Reconditioning is aimed at rebuilding or repairing the principal components of a used product (even when there is no reported fault of such components) to return it to a satisfactory working condition.
- Reuse: To use an already used product at its EOL stage for the same purpose for what it has been produced to be used at its usage stage.
- Repurposing: Giving a used product (or some part of it) a new purpose (different from the one it has been designed for).
- Repair: To make a broken product (or component) be usable again.
- Recycling: Processing waste materials so that they can be used either for their original purpose or for a new one.
- Incineration: The incineration is the combustion process of organic wastes. This procedure generates energy, which can be recovered in order to produce heat or electric power, or not.
- Landfill: Landfill is the process of waste disposing by burial.

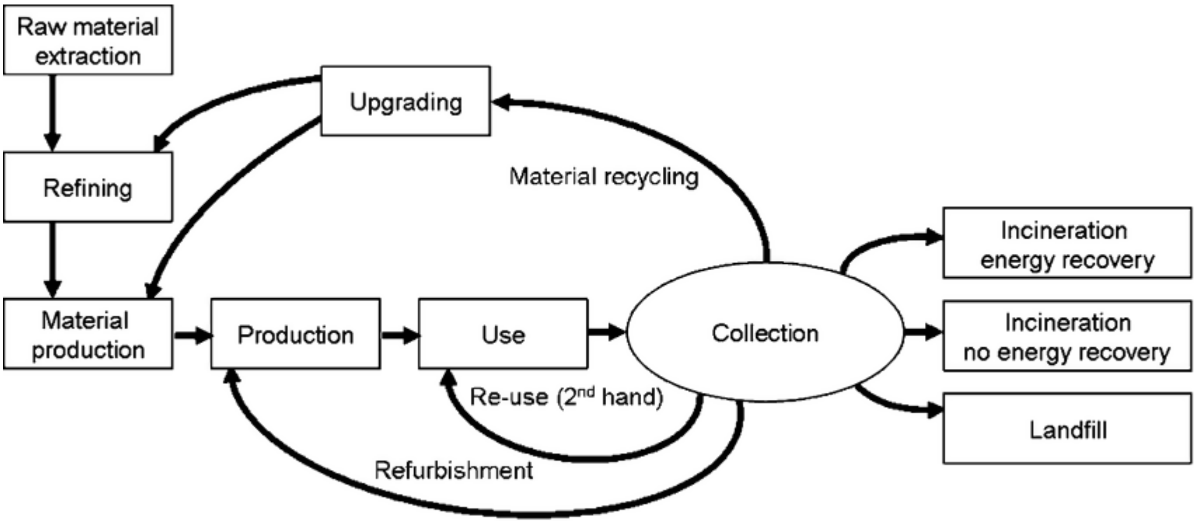

Figure 3.8: EOL strategies in the product life cycle (Rose et al., 1998)[29].

Finally, Table 3-1 shows the suitable scenario for applying each one of them as well as their pros and cons.

[29] Source: Based on the figure presented in (Huisman et al., 2004).

Table 3-1: When is each EOL strategy applicable? Their Pros and Cons[30].

EOL Strategy	When can it be implemented?	PROS	CONS
Remanufacturing	• Product should be easy to collect at EoL. • There exists a suitable market for as-new products. • The original product should have low technological obsolescence. • The cost of the production and raw materials has to be high enough to justify the need for remanufacturing. • The core of the product must be durable. • Product should be easy to disassembly down to component level.	• The production costs as well as the environmental impacts are reduced. • Possibility of making as-new products profitable. • The employees skills are widen, making them to work on a new manufacturing process to produce the as-new products.	• Remanufacturing can only be implemented to products which have specific characteristics • Product should allow disassembling so that the component can be recovered. • A new process has to be set up, so that remanufacturing implies investing time and money.
Reconditioning	• Product should be easy to collect at EoL. • The original product should have low technological obsolescence. • The production and raw materials cost has to be high enough to justify the need for reconditioning. • There exists a suitable market for second-life products. • Product that can be disassembly down to sub-assembly level.	• Only some parts of the original product are processed, saving money and reducing the environmental impact. • Increased skilled employment. • The employees skills are widen, making them to work on a new manufacturing process to produce the second-life products.	• Second-life products' quality is not easy to be guaranteed. • There is not a well-stablished market for second-life products. • Although reasonable functionality can be achieve, second-life products' aesthetics is usually far from being as-new ones.

[30] Source: Based on the data available at: http://www.remanufacturing.org.uk/pdf/story/1p295.pdf

Reusing	• Product should be easy to collect at EoL for resale purposes. • The original product should have low technological obsolescence. • The original product should have low aesthetic obsolescence. • There exists a suitable market for second-life products.	• There is little (or not at all) need for repairing. • The production costs are largely minimised, since the idea is to reuse the product as it is at its EOL. In this sense, the environmental impact is also largely reduced, since almost no industrial procedure is needed.	• Only products which have a very low technological and aesthetic obsolescence can be reused. • Reused products' quality and fitness for its new usage cannot always be guaranteed.
Repurposing	• Products should be able to work modularly. • Products should support standard and widely used interfaces, such as, USBs. • Products should be able to be monitored by computerised systems.	• A novel market can be built in order to introduce outdated technologies and aesthetics. • There is little (or not at all) need for repairing. • The environmental impact is also largely reduced, since almost no industrial procedure is needed.	• There is not a well-stablished market for second-life products. • Repurposed products' quality and fitness for its new usage cannot always be guaranteed.
Repairing	• The original product should be costly enough to justify the need for repairing, or should imply a sentimental cost so that people do not want to throw it away or to disassembly it. • Products which are not possible to replace or buy again. • The components of the product should be easy to replace without resorting to any destructive practice.	• In general, there is a well-stablished (although not big enough) market for product repairing. • Promotes the local skilled jobs. • The environmental impact is also largely reduced, since almost no industrial procedure is needed.	• Cost can be high due to the lack of large scale repairing systems. • Repaired products' quality and fitness for its new usage cannot always be guaranteed. • Repaired products are not always profitable.

Recycling	• Product should be easy to collect at EoL for recycling purposes. • Products that are made of recyclable materials. • The materials and components of the product should not allow further reusing. • Product should allow disassembling down to component level. • Products should be able to be built based on only one material or different, but distinguishable, ones. • Products which are made of few materials with a high cost in order to justify their extraction.	• Recycling constitutes a suitable option for companies to meet recovery regulations. • Promising branding opportunities. • Avoids material landfilling and reduces the production of further materials.	• The increasing manufacturer's responsibility will probably not be met by recycling. • There are usually more recycled products in the market than costumers willing to buy them.
Incinerating	• Products which are not able to be treated by any other more eco-friendly EoL strategy. • Products for which landfill would be environmentally harmful. • Products made of primarily organic materials, with low percentage of heavy metals.	• The recovered energy, either heat or electric power can provide the funding to treat the waste. • There is no need of using land. • Helps to reduce the waste volume.	• The ashes produced by incinerations are toxic and harmful for human and other species' health. • Negative impact on the environment.
Landfilling	• Products which are not able to be treated by any other more eco-friendly EoL strategy. • Products made of inert and non-toxic materials. • Products should be free of electronics (Waste Electrical and Electronic Equipment (WEEE) components.	• Already available infrastructure. • Easy and convenient.	• There is no recovery of valuable resources that may be part of the products that are landfilled. • Negative impact on the environment. • High taxes.

3.3.2.2 Design for Environment

DfE is a set of rules introduced in the 1990s in order to take into account the design performance in terms of the environmental, health and safety objectives over the entire process and product life cycle (Huisman et al., 2004). Basically, the idea of DfE is to take into account the environmental impact of the product and its corresponding production process throughout the entire life cycle from its very beginning in order to plan strategies that allow reducing the product footprint and handle its EOL. In this way, DfE is intended to optimise the relationship between environmental and economic systems, so that the produced products can fulfil customer's needs while their environmental and social impacts can be reduced. In addition, the driving forces behind DfE (shown in Figure 3.9) include not only costumers, but also international and governmental agencies, who are indeed the stakeholders in the environmental wellbeing matter.

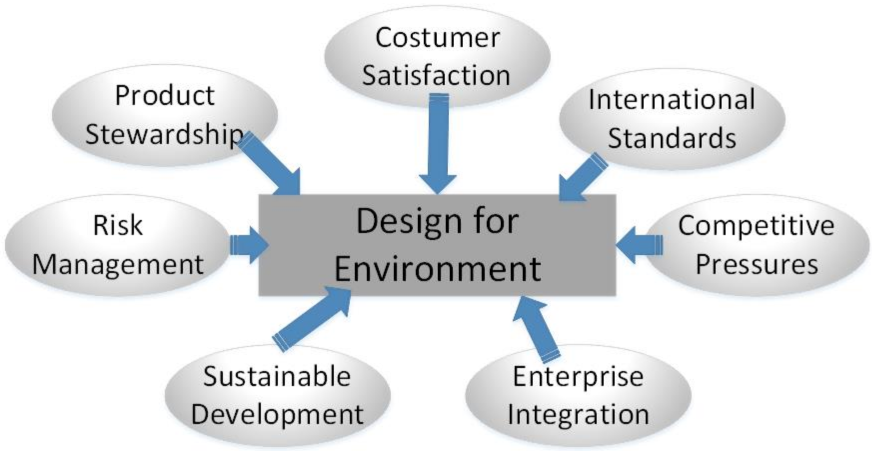

Figure 3.9: DfE driving forces[31].

DfE provides the basis for, taking into account the knowledge obtained from the LCA, design a product minimising its environmental footprint throughout its whole life cycle (while keeping it affordable to the costumer) by combining several topics related with design, such as, disassembly, recycling and disposal, among many others. According to (Fiksel, 1996), DfE relies on the following axioms:

- Design manufacturing processes that do not generate hazardous waste
- Use clean technologies.
- Design the product in order to ensure the chemical emissions are reduced and the energy consumption is optimised.
- Design products containing non-hazardous and eco-friendly recyclable materials and components.

[31] Source: Based on the diagram included in https://www.slideshare.net/aman1312/design-for-the-environment

- Design products containing reusable components.
- Design products to be easily disassembled.
- Design products to be capable of being reusable or recyclable at its EOL.

Finally, DfE is a widely accepted and used method for green designing since it has the advantage of being easily included in the traditional product development process as shown in Figure 3.10.

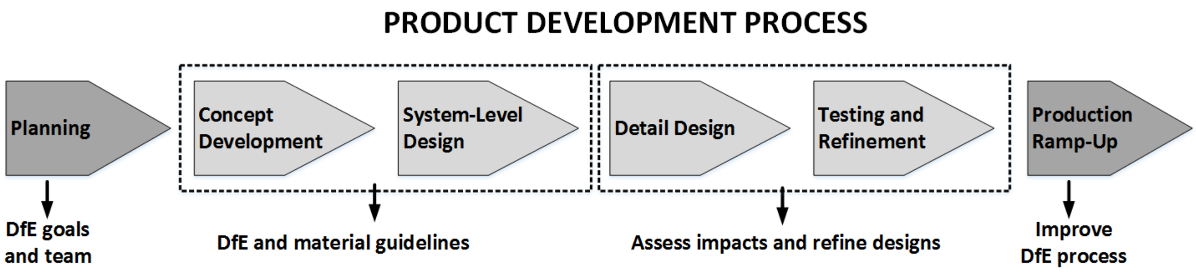

Figure 3.10: DfE product development process[32].

3.3.3 Towards Green Manufacturing: Integration of Assessment and Improvement Methods

Researchers have recently recognised the benefits of integrating LCA, which provides a useful tool for analysing a product's environmental impacts, and DfE tools, within the green product design phase in order to have a continuous feedback about the functional and ecological aspects of the design (Fleck et al., 1994). In this way, the collected data from the LCA should be used as the basis for the product design stage and, together with DfE strategies, would provide a solid basis for the green production process (Jeswiet and Hauschild, 2008) as shown in Figure 3.11.

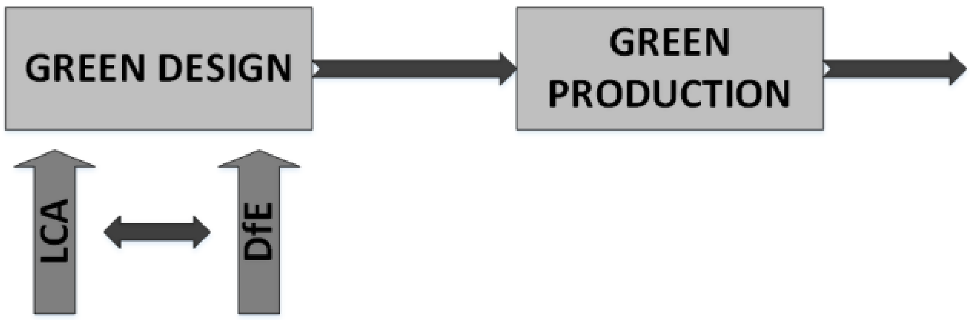

Figure 3.11: Green design based on LCA and DFE as the basis of green process (Gungor and Gupta, 1999) [33].

[32] Source: Based on the scheme available at https://www.slideshare.net/CircularEconomyAsia/design-for-environment

[33] Source: Based on the scheme presented in (Gungor and Gupta, 1999).

Once the product design has been carried out according to the DfE guidelines based on the corresponding LCA, the green production takes place. Unfortunately, there is a lack of systematic procedures, methods and tools available in the literature to address green production. This is probably due to the fact that the environmental practices strongly depend on diverse factors, such as, local or regional regulations, as well as technical, economic, societal and biological aspects. Then, although all of the green practices are aimed at the same environmental purposes, such as reducing the products toxicity and the resource and energy consumption, among others, each particular green manufacturing practice should be implemented resorting to specific available and suitable technologies based on strategic plans built on the basis of specific environmental goals identified by evaluation tools, such as LCA. Moreover, in (Gungor and Gupta, 1999) it is suggested that not only different companies, such as Ford, Benz, Toyota, GM and Phillips, among others, but also different regions and countries, such as US, Japan, Europe, India, China and Honk Kong, focus their attention in different aspects of the environmental issues. For instance, the US makes special focus in the regulation of the manufacturing process, while European countries are more concerned regarding product EOL, supply chain and reverse logistics.

Despite green practices implementation usually depends on specific regulations of companies and countries, it involves common elements as shown in Figure 3.12 (Rehman, 2013). The different green elements in Figure 3.12, *viz.*, Green Design (integrating LCA, DfE and Process Planning), Green Supply Chain, which closes the loop together with EOL Strategies/Green Disposal and Reverse Logistic, and Green Purchasing and Marketing, are described as follows:

- **Green Design**: This is the key step towards the green manufacturing since the environmental efficiency of the product entire life cycle mainly depends on this decision-making stage. The proposed scheme in (Rehman, 2013) agrees with the idea of combining LCA and DfE to design the green product. In addition, it is suggested to further integrate these tools with the green process planning. In this sense, the green process planning can complement the product design with the process design by selecting the process elements, optimising the process flow, and evaluating the process project. Different software, such as the one called Process Planning Support System for Green Manufacturing (GMPPSS) presented in (Rehman, 2013), has been proposed in the literature to support the process planning stage by providing useful benchmark data regarding resources and energy consumption as well as manufacturing processes' impact on environmental performance.

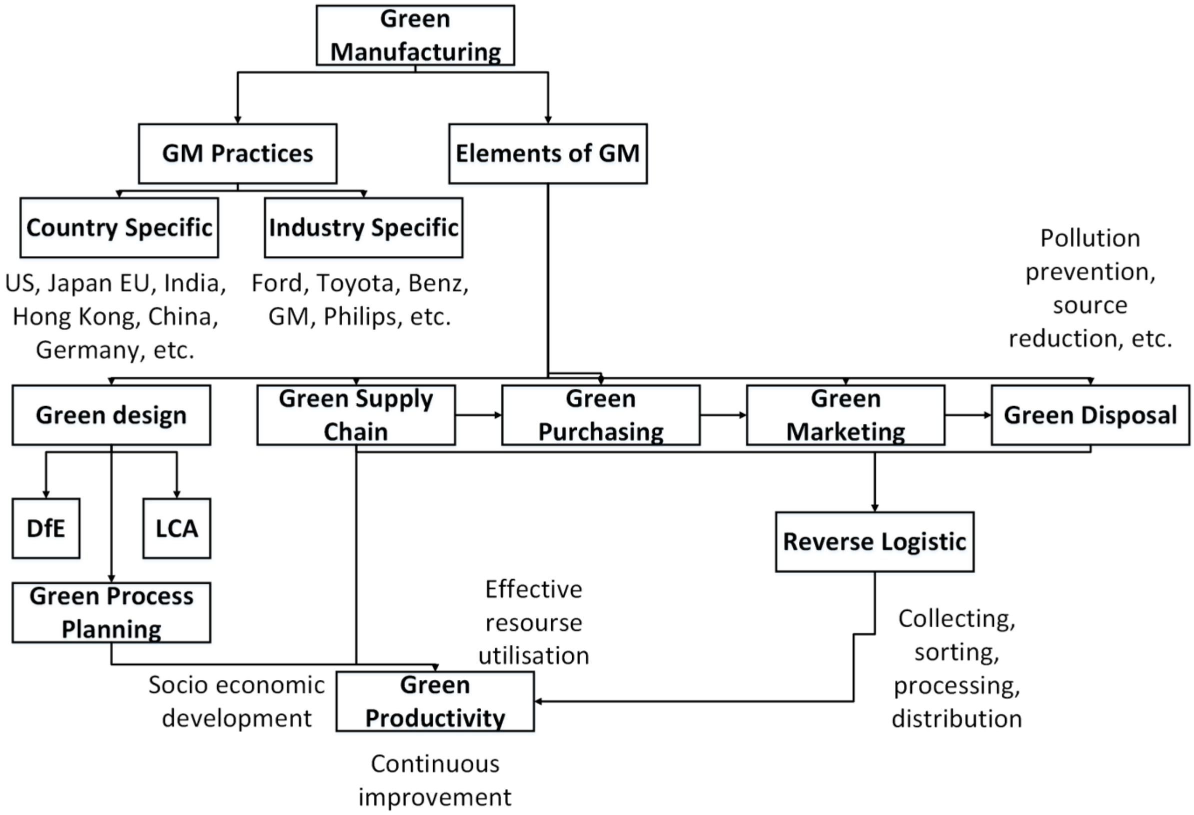

Figure 3.12: Green manufacturing and its elements[34].

- **Green Supply Chain**: The Green Supply Chain Management (GSCM) is a key approach in order to become sustainable. In (Yan et al., 2007), it is stated that, to be able to manage the supply chain from an environmental perspective, it is necessary to take into account the influence of implementing different green practices within different stages of the product life cycle, such as, product design, material selection and purchasing, manufacturing processes, delivery, and EOL strategies, on the GSCM. Figure 3.13 shows the benefits of implementing a green supply chain.
- **Green Disposal**: Green Disposal refers to the management of wastes that are harmful for the environment. The idea is to reduce the release of toxic substances in the whole product life cycle, planning a proper product EOL treatment.

[34] Source: Based on the scheme presented in (Rehman, 2013).

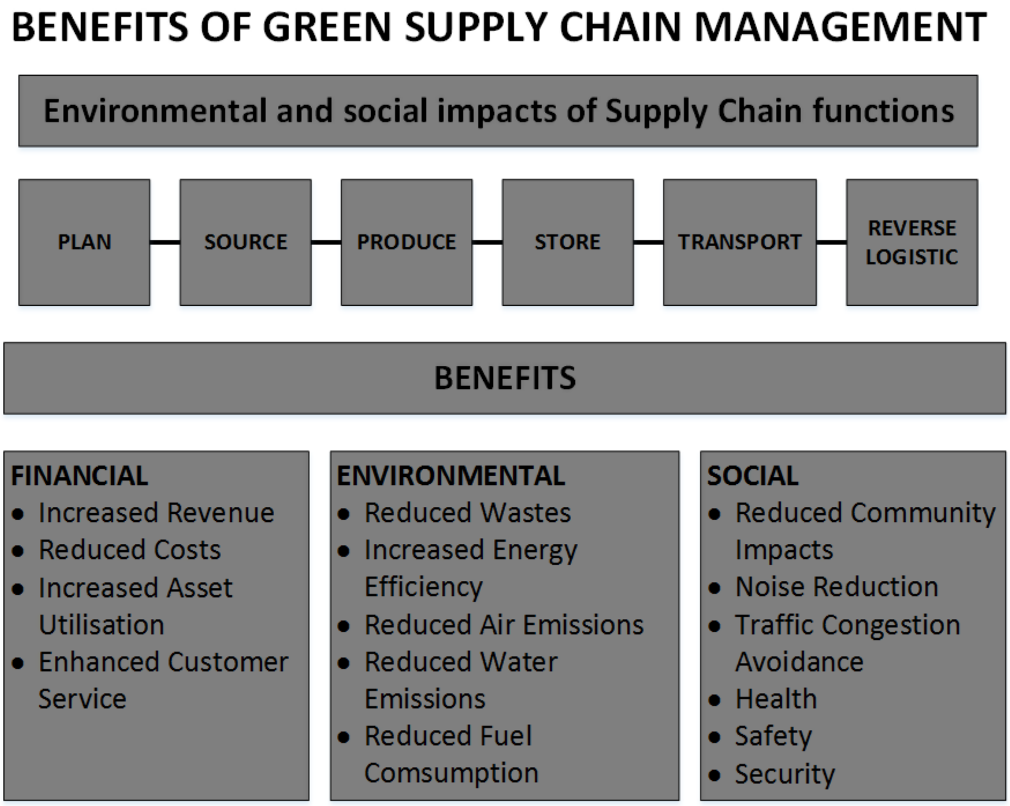

Figure 3.13: Benefits of the green supply chain[35].

- **Reverse Logistic**: Reverse logistics is a process that allows "closing the loop" of the product life cycle by applying EOL strategies, such as, reusing, remanufacturing or recycling the waste materials. The term "reverse" refers to the direction of such a process, which flows in the opposite direction as the traditional supply chain does. Figure 3.14 shows a green supply chain and its correspondent reverse logistic.

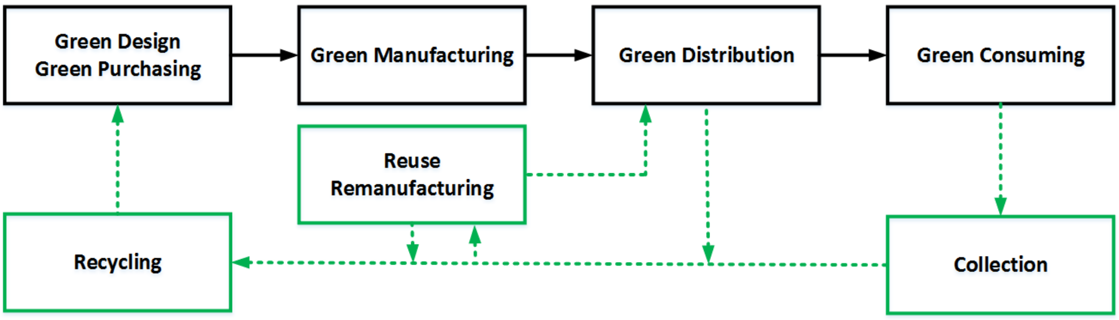

Figure 3.14: Green supply chain and reverse logistics (Shrivastava, 2007)[36].

[35] Source: Based on the scheme available at http://www.aims.education/supply-chain-blog/green-supply-chains-management/
[36] Source: Based on the scheme presented in (Liu and Chang, 2017).

- **Green Purchasing**: Green purchasing is focused on choosing and buying eco-friendly products, in an attempt to reduce the consumption of products that have a negative impact on the environment (Liu and Chang, 2017). Green purchasing can be interpreted from different points of view. On one hand, from a companies' point of view, green purchasing involves all the activities focused in promoting purchasing policies that encourage green manufacturing, such as, reducing water consumption, buying greener energy, office supplies, consumables, etc. On the other hand, from the costumers' point of view, green purchasing is often measured by the consumers' preferences for purchasing green products. This involves a complex decision-making behaviour, being considered by researchers in the field as a kind of socially responsible behaviour.
- **Green Marketing**: In last years, it has been demonstrated by public polls that consumers prefer to buy greener products (Chan, 2001). In this line, green marketing includes all the activities focused on selling green products by doing special emphasis on the credibility of the product as well as the consumer value and knowledge. Figure 3.15 shows the green market cycle from green purchasing to green marketing.

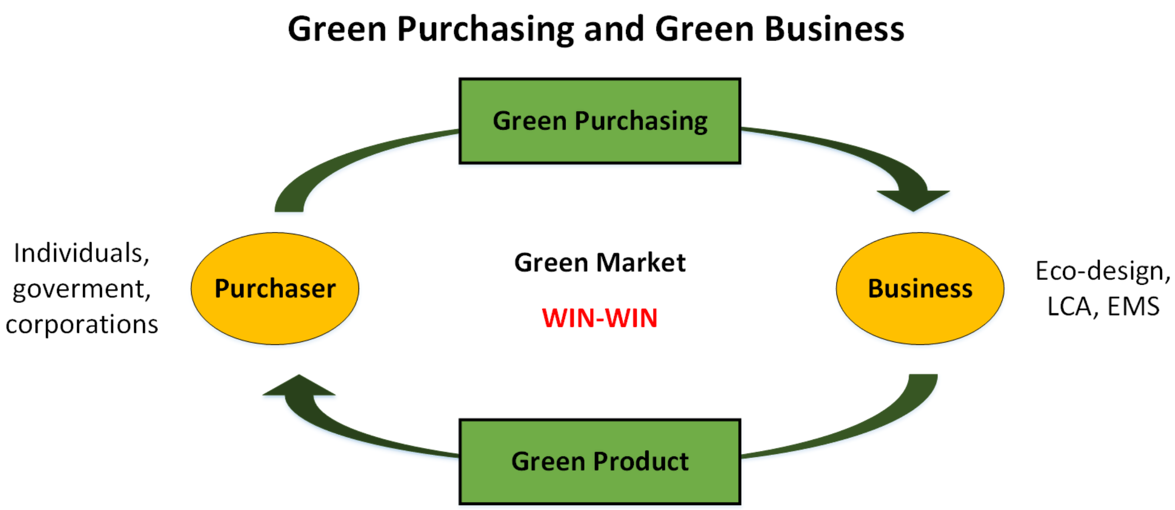

Figure 3.15: Green market cycle[37].

3.4 Current Trends in Green Manufacturing

In today's current worldwide environmental situation, where the climate state is getting worse every day and everyone is aware about the finite nature of the resources, companies are urged to adopt green initiatives (Syrek and Gul, 2017b) for the sake of surviving (Digalwar et al., 2013). On one hand, government regulations and international

[37] Source: Based on the green buying scheme available at https://slideplayer.com/slide/6896537/

standards are compelling companies to move towards greener solutions; on the other hand, the number of responsible costumers preferring to choose green products rather than non-environmentally friendly ones is growing. In this context, understanding the current trends in the green manufacturing field becomes crucial to any company trying to improve its environmental efficiency in order to keep their social image and their competitiveness. In this section, an exhaustive literature review in order to identify and analyse the current trends in green manufacturing, the main methods and tools proposed in the literature to implement it and their impact on the companies' sustainability, is carried out on the basis of the SLR principles presented in Section 2.4.

3.4.1 Research Questions and Search Methodology

The present SLR is aimed at giving an insight into the current trends for green manufacturing practices making special focus on their influence on the whole company sustainability. In this line, the following questions should be answered:

1. Which are the best current green manufacturing practices and their applications?
2. What is the actual impact of applying these practices in the companies' sustainability performance?

The first research question will be addressed in Section 3.4.3, while the second one will be addressed in Section 3.5.

The search for the relevant contributions related to these research questions has been carried out resorting to the resources described in Section 2.4.1, focusing the attention on the contributions published in the last two decades, taking as initial research points the following topics:

- Green manufacturing practices and their main applications
- Green manufacturing practices and their contribution towards economy, environment and social performance
- Green manufacturing practices and their impact on the sustainability performance

3.4.2 Thematic Synthesis

Following the search criteria described in Section 3.4.1 a total of 67 contributions to the field have been selected. Among them, 49 (73%) are from International journals (being 12 (18%) of them from the J. of Cleaner Production), while 3 (4%) are from books, and 15 (22%) are from Proceedings of International Conferences, belonging 5 (7.5%) of them to different issues of the Procedia series, such as, CIRP (1), Engineering (1), Manufacturing (1), Materials (1) and Social (1). This literature selection allows the same observations that have been done in Section 2.4.2 for the case of the SLR for the current trends in lean practices. On one hand, the chosen articles are relevant to the field since they have been published in journals with high IF and SJR indices. On the other hand, researchers tend to publish their contributions in specialised journals. In addition, the SLR conducted here shows that several researchers in the field of green manufacturing prefer publishing their contributions in the J. of Cleaner Production which is currently one of the most popular journals in the field.

In order to better analyse the selected articles in the SLR, a thematic synthesis is performed to identify and study the most relevant contributions regarding each one of the main topics in the green manufacturing field. Table 3-2 shows the resulting SLM based on this thematic synthesis. In particular, in order to analyse the most popular approaches in the green manufacturing field, their actual impact on the whole organisation's performance and, especially, on sustainability aspects, the 67 selected articles are thematically synthesised taking into account the following categories:

- Conceptual Analysis: Articles in this category address green concepts from a theoretical point of view. In general, these kinds of analyses are found in books.
- Literature Review: Literature reviews focus on collecting and discussing the main and most recent contributions to the field.
- Research Application: This category includes articles where authors propose different models and approaches to become greener. In particular, these proposed models are validated either using data from benchmark (ideally publicly available) databases or by simulation.
- Case Study/Empirical Study: These types of studies are held within the companies' context. Some of them resort to surveys to collect information regarding the different green practices implemented and their results, while some others perform experimental tests.
- Green Strategies: Articles classified in this category study or proposes green strategies to address different issues regarding the green aspects of the companies.
- Green Design: These articles study or propose different approaches and methodologies to conduct the product and process green designs.
- Green Production: These articles study or propose different approaches to actually reach a green production. As mentioned in Section 3.3.3, a lack in the literature has been reported regarding systematic methods or tools to address the

production issue from a green perspective. To include this category would allow analysing whether the lack in the literature remains or has been fixed.

- Green Supply Chain: To study these articles would allow evaluating how researchers in the field interpret the different issues related to GSCM.
- Green Purchasing/Marketing: Articles in this category would give an insight on the green business cycle, from the raw materials purchasing to the green product-oriented marketing strategies.
- Human Resources/Social Behaviour: Green practices are strongly related to human behaviour, cultural organisation and social context. Nevertheless, these aspects are not always taken into account in the literature. This category is included in order to analyse to what extent the human resource and social behaviour aspects are currently being taken into account in the literature.
- Performance Measurement: In order to evaluate the environmental, economic and social improvements achieved by applying green practices, it is necessary to have a systematic, standard and widely accepted framework to measure them. As in the case of lean practices, researchers in the field of green manufacturing also agree that there is a lack in the literature for such formal frameworks. To include this category helps to analyse the different efforts that researchers are making towards proposing new metrics to fill this gap in the literature.
- Impact on Performance: This category shows which are researchers' main concerns when implementing green manufacturing practices.
- Sustainability: To include this category allows analysing whether the sustainability aspect of applying green manufacturing practices has properly been addressed in the literature and which are the main findings regarding their relationship.

Table 3-2: SLM for current trends in green manufacturing.

Nº	Paper	Concept Anal.	Lit. Review	Research App.	Case Study/ Emp. Appl.	Green Strategies	Green Design	Green Prod.	Green Supply Chain	Green Purchase/ Marketing	EOL	Human Resources /Social Behaviour	Perform. Measure	Impact Perform	Sustain ability
1	A, R. C. (2007). Green Manufacturing: An Evaluation Of Environmentally Sustainable Manufacturing Practices and Their Impact on Competitive Outcomes. IEEE Trans. Engineer Manag, 3(54), 445–454.				x	x								x	
2	Rehman, M. (2013). Green manufacturing (GM): past, present and future (a state of the art). World Rev Sci, Technol and Sust. Develop, 10(1/2/3), 2013		x												
3	Chan, R. (2001). Determinants of Chinese consumers' green purchase behavior. Psychol & Marketing, 389-413.				x					x		x			
4	Deif, A. (2011). A system model for green manufacturing. J Cleaner Prod			x		x									
5	Digalwar, A., Tagalpallewar, A., & Sunnapwar, V. (2013). Green manufacturing				x								x	x	

	performance measures: an empirical investigation from Indian manufacturing industries. Measuring Business Excellence, 17(4), 59-75.														
6	Dilip Maruthi, G., & Rashmi, R. (2015). Green Manufacturing: It's Tools and Techniques that can be implemented in Manufacturing Sectors. Proc of Mat Today , 2, 3350-3355.			**x**		**x**									
7	Román, F. and Bras, B. (2005) 'Towards an effective approach to reduce manufacturing environmental burdens via process planning', Proc Int Mechanical Engineer Congress and Exposition.		**x**				**x**								
8	Liu, S., & Chang, Y. (2017). Manufacturers' Closed-Loop Orientation for Green Supply Chain Management. Sustainability.			**x**					**x**						
9	Melnyk, S., Sroufez, R., Montabon, F., & Hinds, T. (2001). Green MRP: identifying the material and environmental impacts of			**x**		**x**		**x**						**x**	

	production schedules. IntJ Prod Res 39 (8).														
10	Zhu, Q., Sarkis, J. and Lai, K. (2007) ‘GSCM – pressure, practices and performance within the Chinese automobile industries’, JO Cleaner Prod,15, 1041–1052.				**x**				**x**						
11	Paul, I., Bhole, G., & Chaudhari, J. (2014). A Review on Green Manufacturing: It's Important, Methodology and its Application. Proc Mat Sci 6, 1644-1649.		**x**												
12	Rao, P. (2004). Greening production: a South-East Asian experience. Int J Operat and Prod Manag 24(3), 289-320.				**x**										
13	Xu, S.X., Walker, H., Nairn, A. and Johnsen, T. et al. (2008) ‘A network approach to understanding ‘green buying’: a literature review’		**x**							**x**		**x**			
14	Zhonghua, Y. and Zhaowei, U. (2006) ‘Study on the integration of green manufacture and total quality management’, Proc			**x**		**x**									

	IntTechnol and Innovation Conf 754–748														
15	Syrek, I., & Gul, m. (2017). Factors Affecting Green Purchasing Behavior: A Study of Turkish Consumers . nternational J Acad Res in Business and Soc Sci.				**x**					**x**		**x**			
16	Yan, H., Fei, L., Huajun, C., & Hua, Z. (2007). Process Planning Support System for Green Manufacturing and its application. Frontiers of Mechanical Engineer in China, 104-109.			**x**		**x**	**x**								
17	L. Alonso, E.M. Rubio B.de Agustina R.Domingo, Latest clean manufacturing trends applied to a world class manufacturing management for improving logistics and environmental performance, Proc Manufac 2017, 1151-1158			**x**					**x**					**x**	
18	Sezen, B.; Cankaya, S.Y., Effects of Green Manufacturing and Eco-innovation on Sustainability Performance, Proc Soc and Behav Sci 99 2013,154-163				**x**									**x**	**x**

19	Manley, J.; Anastas, P.; Cue, B. Jr., Frontiers in Green Chemistry: meeting the grand challenges for sustainability in R&D and manufacturing, J Cleaner Prod (2008)			**x**			**x**								**x**
20	Thoo Ai Chin, T.A.; Tat, H.H.; Sulaimana, Z., Green Supply Chain Management, Environmental Collaboration and Sustainability Performance, 12th Global Conf on Sustainable Manufac (2015)			**x**					**x**						**x**
21	Niggeschmidt, S. ; Helu, M.; Diaz, N.; Behmann, B.; Lanza, G.; Dornfeld, D., Integrating Green and Sustainability Aspects into Life Cycle Performance Evaluation (2010)			**x**		**x**								**x**	
22	A. C. Thoo et al., "The Moderating Effect of Enviropreneurship on Green Supply Chain Management Practices and Sustainability Performance", Advanced Mat Res, 773-776, 2014		**x**						**x**						**x**

23	Siniawski, M.; Bowman, C., Metal working fluids: finding green in the manufacturing process, METAL WORKING FLUIDS: FINDING GREEN IN THE MANUFACTURING PROCESS (2009)			x											
24	Durham, D.R. JOM (2002), Environmentally benign manufacturing: Current practice and future trends, J Minerals, Metals and Mat Soc, 54, 5, 34–37			x		x									
25	Diaz, N.; Choi, S.; Helu, M.; Chen, Y.; Jayanathan, S.; Yasui, Y.; Kong, D.; Pavanaskar, S.; Dornfeld, D., Machine Tool Design and Operation Strategies for Green Manufacturing 2010			x				x							
26	Clifford C. S. Chan ; K.M. Yu ; K.L. Yung, Green manufacturing using integrated decision tools, 2010 IEEE Int Conf Ind Engineer and Engineer Manag, 2010			x		x	x								
27	Dornfeld, D., Green Manufacturing: Fundamentals and Applications 2013, Springer	x													

28	Tseng, M.L.; Chiu, S.F.; Tan, R.R.; Siriban-Manalang, A.B. , Sustainable consumption and production for Asia: sustainability through green design and practice		x			x			x	x					x
29	Sun, J.; Han, B.; Ekwaro Osire, S.; Zhang, H.C., Design For Environment: Methodologies, Tools, And Implementation, J Integrated Design and Process Sci 7(1) 2003:59-75			x		x	x								
30	TRIVEDI, P.; SHARMA, M., Impact of Green Production and Green Technology on Sustainability, Cases on Companies in India (2017), Int J Mechanical and Prod Engineer Res and Develop 7(6), 2017: 591-606				x									x	x
31	Kumar, N.; Agrahari, R.P.; Roy, D., Review of Green Supply Chain Processes, IFAC-PapersOnLine, 48, 3, 2015, 374-381		x						x						
32	S. H. YeoA. K. New, A Method for Green Process Planning in Electric Discharge Machining, Int J Advanced Manufac Technol,1999, 15, 4, 287–291			x		x	x								

33	Lee, S.G., Lye, S.W. and Khoo, M.K. (2001) 'A multi-objective methodology for evaluating product end-of-life options and disassembly', Int. J. Advance Manufac Technol, 18, 2, pp.148–156.			**x**							**x**			**x**	
34	Hicks, C. and Dietmar, R. (2007) 'Improving cleaner production through the application of environmental tools in China', JO Cleaner Prod, 15, 5, 395–408.				**x**										
35	Swathi Sri Darapu; Srikanth Satish Kumar Darapu, GREEN MANUFACTURING TECHNOLOGIES – A REVIEW, Conf: 29th Indian Engineer Congress, Hyderabad, APSC, IE(I) & Ministry of Urban Development, Govt. of India 2014		**x**			**x**									
36	Sanjeev Shrivastava, Shrivas tava R.L., (2017) "A systematic literature review on green manufacturing concepts in cement industries", Internati onal J Quality & Reliability Manag 34, 1, 68-90	**x**	**x**												

37	Shailee G. Acharya , Dr. Jeetendra A. Vadher , Dr. G. D. Acharya, A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries, Int J Emerging Technol and Advanced Engineer 4, 1, 2014		**x**												**x**
38	Jeswiet, J. and Hauschild, M.Z. (2008) 'Market forces and the need to design for the environment', Int. J. Sustainability Manufac 1, 41–57.			**x**			**x**								
39	S M Fatah UddinS; Mohammed Naved Khan, Young Consumer's Green Purchasing Behavior: Opportunities for Green Marketing 2018 J Global Marketing 31(4):1-12				**x**					**x**		**x**			
40	Bodo B. Schlegelmilch; Greg M. Bohlen; Adamantios Diamantopoulos, The link between green purchasing decisions and measures of environmental consciousness, European J of Marketing 30(5):35-55				**x**					**x**		**x**			

41	Ahemad, N., Montagno, R. and Firenze, R. (1998) 'Organization performance and environment consciousness: an empirical study', JO Manag Decision, 36, 2, 57–62.				**x**									**x**	
42	Andrews, S., Stearne, J. and Orbell, J. (2002) 'Awareness and adaptation of cleaner production in small to medium sized business in Geelong region Australia', IJO Cleaner Prod 10, 4, 373–380				**x**										
43	Dangelico , R.M.; Pujari, D.; Pontrandolfo, P., Green Product Innovation in Manufacturing Firms: A Sustainability-Oriented Dynamic Capability Perspective 2016, Business Strategy and the Environment			**x**											**x**
44	Johnstone, N., Pascale, S., Bjarne, Y. and Rolf, W. (2004) 'The firm, environmental management and environmental measures: lessons from a survey of European manufact. firms', J Environm Planning and Manag, 47, 5, 685–707.				**x**									**x**	

45	Baumann, H., Boons, F. and Bragd, A. (2002) ‘Mapping the green product development field: engineering, policy and business perspectives’, J Cleaner Prod, 10, 5			**x**			**x**								
46	Böhringer, C., Moslener, U., Oberndorfer, U. and Ziegler, A (2008) ‘Clean and productive? Evidence from the German Manufacturing Industry’, ZEW-Centre for European Economic Res Discussion Paper No. 08-091.				**x**									**x**	
47	Cagno, E., Trucco, P. and Tardini, L. (2005) ‘Cleaner production and profitability: analysis of 134 industrial pollution prevention project report’, IJO Cleaner Prod, 13, 6, 593–605.		**x**			**x**								**x**	
48	Chanintrakul, P., Coronado Mondragon, A.E., Lalwani, C. and Wong, C.Y. (2009) ‘Reverse logistics network design: a state of-the-art literature review’, Int. J. Business Performance and Supply Chain Modelling, 1, 1, 61–81		**x**						**x**						

49	Chen, Y-S. (2008) 'The driver of Green innovation and Green image – Green core competence', J Business Ethics, 81, 3, 531–543.			**x**									**X**	**X**	
50	Curkovic, S. (2003) 'Environmentally responsible manufacturing: the development and validation of a measurement model', European J of Operat Res, 146, 1, 130–155.				**x**								**X**	**X**	
51	Hui, I.K., Chan, A.H.S. and Pun, K.F. (2001) 'A study of the environmental management system implementation practices', J Cleaner Prod 9, 4, 269–276.				**x**	**x**									
52	Florida, R., Atlas, M. and Cline, M. (2000) 'What makes companies Green? Organizational and geographic factors in the adoption of environmental innovations', Econom Geography, 77, 3, 209–224.			**x**		**x**									
53	Gehin, A., Zwolinski, P. and Brissaud, D. (2008) 'A tool to implement sustainable end-of-life strategies in the product development phase', J Cleaner Prod, 16, 5, 566–576.			**x**			**x**				**x**				

54	Govindrajulu, N. and Daily, F. (2004) ‘Motivating employees for environmental improvement’, JO Ind Manag and Data Sys, 104, 4, 364–372.			**x**								**x**		**x**	
55	Gutowski, T. (2002) ‘Environmentally benign manufacturing and ecomaterials; product induced mater flows’, Mat Trans, 43, 3, 282–284.			**x**		**x**	**x**								
56	Gutowski, T., Murphy, C., Allen, D., Bauer, D., Bras, B., Piwonka, T., Sheng, P., Sutherland, J., Thurston, D. and Wolff, E. (2005) ‘Environmentally benign manufacturing: observations from Japan, Europe and the United States’, J Cleaner Prod, 13, 1,		**x**			**x**									
57	Hamdouch, A. and Depret, M-H. (2010) ‘Policy integration strategy and the development of the ‘green economy’: foundations and implementation patterns’, J of Environm Planning and Manag, 53, 4, 473 490.	**x**													

58	Harris, L.C. and Crane, A. (2002) 'The greening of organizational culture: management views on the depth, degree and diffusion of change', J Organizational Change Manag 15, 3, 214–234.		x									x			
59	He, Y., Liu, F., Shi, J. (2008) 'A framework of scheduling models in machining workshop for Green manufacturing', J Advanced Manufac Sys 7, 2, 319–322.			x		x		X							
60	Hervani, A.A., Helms, M.M. and Sarkis, J. (2005) 'Performance measurement for green supply chain management', Benchmarking: An Int Journal, 12, 4, 330–353.		x						x				x	x	
61	Hosseini, A. (2007) 'Identification of Green management system factors: a conceptualized model', IJO Manufacturing Sci. and Engg. Manag, 2, 3,221–228.	x													
62	Ilomaki, M. and Melanen, M. (2001) 'Waste minimization in small and medium sized enterprises, do EMS help', JO Cleaner Prod 9, 3, 209–217.				x										

63	Bashkite, V; Karaulova, T.; Starodubtseva, O., Framework for Innovation-oriented Product End-of-life Strategies Development, Proc Engineer, 69, 2014: 526-535			**x**		**x**					**x**				
64	Yang, S., Ong, S., & Nee, Y. (2015). EOL strategy planning for components of returned products. The Int J of Advanced Manufac Technol			**x**		**x**					**x**				
65	Yatish Joshia; Zillur Rahmanb, Factors Affecting Green Purchase Behaviour and Future Research Directions, Int Strategic Manag 3,2015: 128-143		**x**							**x**		**x**			
66	FITZGERALD, D.; HERRMANN, W.; SANDBORN, P.; SCHMIDT, L., Beyond Tools: A Design for Environment Process, Int J Performability Eng., 1, 2, 2005: 105-120			**x**		**x**	**x**	**x**							
67	Madanhire, I.; Mbohwa, C., Achieving Environmental Performance through Design for Environment (DFE) Process in Foundry Operations, Proc CIRP, 2016, 121-126			**x**		**x**	**x**								

3.4.3 Findings for the Current Trends in the Green Manufacturing

The conducted SLR confirms the increasing concern of scholars and manufacturers regarding the green movement, being 16 (23.9%) out of the 67 selected articles listed in the SLM in Table 3-2 literature reviews (Deif, 2011), (Rehman, 2013), (Thoo et al., 2014), (Tseng et al., 2013), (Shrivastava and Shrivastava, 2017), (Acharya et al., 2014), (Chanintrakul et al., 2009), (Gutowski et al., 2005), (Hervani et al., 2005), (Yatish and Rahman, 2015), (Roman and Bras, 2005), (Paul et al., 2014), (Xu et al., 2008), (Kumar et al., 2015), (Darapu and Kumar Darapu, 2014), (Cagno et al., 2005). Moreover, 9 of these 16 literature reviews have been published during the 2010s, showing that the academic and manufacture worlds' tendency towards studying greener practices have increased in the last decade. Among the selected literature reviews, 6 are devoted to general concepts of green manufacturing (Harris and Crane, 2002), (Rehman, 2013), (Paul et al., 2014), (Acharya et al., 2014), (Gutowski et al., 2005), (Shrivastava and Shrivastava, 2017), while the other address different aspects involved in green manufacturing, such as, GSCM (Darapu and Kumar Darapu, 2014), (Hervani et al., 2005), (Chanintrakul et al., 2009), (Thoo et al., 2014), green design (Kumar et al., 2015), (Roman and Bras, 2005), green purchasing (Tseng et al., 2013), (Xu et al., 2008), organisational culture changes (Yatish and Rahman, 2015), and pollution prevention (Harris and Crane, 2002). Here, it is important to highlight that, the fact that more than a 20% of the selected articles in the SLR are devoted to review the contributions to the field, suggests that researchers have focused their attention in collecting, understanding, studying and evaluating the recent efforts done towards becoming greener, in an attempt to fill the gap in the literature regarding benchmark knowledge about green manufacturing practices. The rest of the contributions in the SLM of Table 3-2 are mainly focused in proposing different approaches to address different green aspects on different stages of the entire product life cycle (29 (43.3%)) and, in a lesser number, case studies or empirical research 18 (26.8%). Only 4 (5.9%) articles among the 67 selected ones address green manufacturing from a conceptual perspective. This shows that researchers in the field tend to study, analyse and propose different practical green approaches, paying less attention to the development of theoretical frameworks that could lead to unified concepts and criteria. In this way, the widespread idea in the field that, due to the customised nature of green solutions, there is a lack in the literature of studies providing unified definitions, as well as standard and well-stablished methodologies to actually implement the green principles, is reinforced. In fact, several researchers recognise this issue as the key challenge in the field (Cagno et al., 2005), (Rehman, 2013), (Yan et al., 2007).

Although there exist a literature gap regarding widely accepted and applied green methods and tools, in recent years researchers in the field have indeed focused their efforts towards filling this gap. For instance, in the recent literature review presented in (Dangelico et al., 2016), the lack of a unified green manufacturing framework is discussed and a universal framework is proposed. The SLR conducted here, confirms this tendency, being 23 (34.3%) of the selected articles devoted to the study of green strategies. In particular, these articles address these strategies either by conducting a literature review, in order to identify widely used methods or report successful implementations in an attempt to widespread their use (3), carrying out experimental tests (2) or by proposing new (usually customised) approaches (18), which is the most commonly way in which researchers address the green strategies study. In addition, the literature gap seems to be bigger regarding some stages in the product life cycle, such as green production activities which, according to(Rehman, 2013), have been overlooked by researchers in the field. Moreover, authors in (He et al., 2008) state that researchers have mainly focused their attention on design and process planning activities, rather than in green production issues, developing techniques like LCA and DfE that have largely stablished themselves as the most popular green design techniques (He et al., 2008). The SLR conducted here, agrees with the observations made in(Rehman, 2013), being only 4 (5.9%) articles devoted to the study of green production issues (most of them focused on the production schedule (2)), while 12 (17.9%) articles address green design practices, either doing focus on the process planning stage (3) or in DfE tools (9). In addition, 9 (13.4%) articles are devoted to GSCM practices, 6 (8.9%) to green purchasing/marketing activities, and 4 (5.9%) to EOL strategies. Finally, although green practices are strongly dependent on social behaviour, it seems that not enough attention has been paid in the literature regarding the human resources (2 (3%)) and social behavioural aspects (6 (8.9%)) involved in green practices. Table 3-3 summarises the most relevant and novel proposed green strategies for each of the different stages in the product life cycle, such as, design, production, supply chain and EOL, as well as studies for green purchasing and marketing.

In addition, since the green thinking considers the product life cycle and the production processes from a holistic point of view, researchers have not only proposed approaches to address green practices in each of the stages in the product life cycle, but they have also focused their attention in developing green models capable to address the green manufacturing issues considering all the companies' activities as a unified working system (He et al., 2008), (Rehman, 2013), (Deif, 2011). In (Roman and Bras, 2005), after conducting an exhaustive literature review, a novel universal green manufacturing framework is proposed in an attempt to integrate the different factors identified during the literature review procedure required for a successful implementation of green manufacturing. Figure 3.16 shows the proposed approach in (Rehman, 2013). In (Rehman, 2013), a novel system model for green manufacturing implementation is presented. The proposed model suggests different planning activities to be carried out in order to greener a company while providing the required control metrics to do so in an open mixed architecture. Finally, in (Deif, 2011), a system structured approach for green manufacturing based on different system scale levels, including a unit-process and supply chain levels, is proposed.

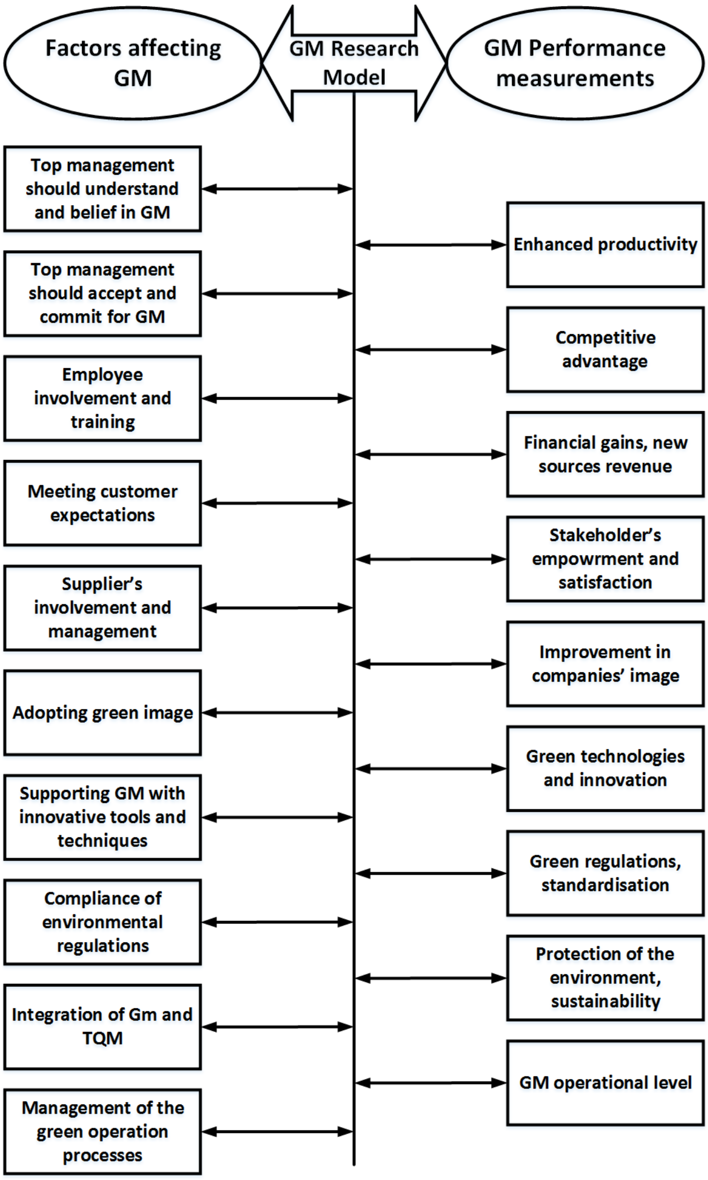

Figure 3.16: Universal green manufacturing framework proposed in (Roman and Bras, 2005)[38].

[38] Source: Based on the scheme presented in (Rehman, 2013).

Table 3-3: Main green strategies proposed for each product life stage.

Product Life Cycle Stage		Nº	Article	Proposal
Green Design	**Process Planning**	**16**	(Rehman, 2013)	A process planning system is proposed for green manufacturing based on three function modules focused on selecting elements, evaluating projects and optimising the process flow, respectively.
		32	(Yan et al., 2007)	A multi-objective analysis is proposed based on a utility function capable of integrating different crucial factors, such as, time, energy and quality in the context of an Electric Discharge Machining (EDM) process.
	DfE	**53**	(Yeo and New, 1999)	Different EOL strategies are studied and to what extent they can be included in the design phase is evaluated.
		66	(Gehin et al., 2008)	An innovative DfE approach is developed for being implemented in Black and Decker aimed at improving its environmental performance.
Green Production		**9**	(Fitzgerald et al., 2005)	A novel tool based on MRP is proposed to integrate environmental objectives into planning activities and waste stream identification.
		25	(Melnyk et al., 2001)	Different green strategies are proposed in order to perform the selection of suitable process parameters, to estimate the optimal energy consumption, and to recover energy.
		59	(Diaz et al., 2010)	A framework for production scheduling activities is proposed taking into account resource as well as environmental issues.
Green Supply Chain		**8**	(He et al., 2008)	A new closed-loop orientation approach is proposed to address the GSCM implementation.
EOL		**33**	(Liu and Chang, 2017)	A novel multi-objective approach is proposed in order to select the best EOL strategy for a particular product.
		63	(Lee et al., 2001)	A Theory of Inventive Problem-Solving tools (TRIZ) based approach is proposed to select the best EOL solution (either standard or innovative) to extend product life cycle.
		64	(Bashkite et al., 2011)	A new approach focused on the component EOL strategy planning is proposed to assist manufacturers when deciding regarding the remanufacturability of a product.

Green Purchasing/ Marketing	**3**	(Yang et al., 2015)	A survey is conducted in order to evaluate the green purchasing behaviour of Chinese consumers. In particular, different social, cultural and psychological factors influencing such behaviour are studied.
	15	(Chan, 2005)	The correlation between green purchasing and different factors, such as, environmentalism and economically behaviour is analysed different well-known statistical test, such as, t-tests, ANOVA and multiple regression analysis, for Turkish citizens.
	39	(Syrek and Gul, 2017b)	A theoretical model is proposed to evaluate to what extent different behaviours, such as, altruism and environmental conscious influence consumers' willingness to buy greener.

Nowadays, the widespread concept of environmental responsibility has made companies to move towards greener practices in order to improve not only their environmental performance but also their public image (Fatah and Khan, 2018) and competitiveness (Chen, 2008). In fact, the SLR conducted here show that companies adopting green practices are concerned regarding their impact on the overall performance (4), as well as in particular aspects, such as environmental (9), economic (4), sustainability (4), social (3), production (3), business (1) and material efficiency (1). Nevertheless, although there are 21 (31.3%) articles in the SLR devoted to explicitly address the green practices' impacts on the companies' performances, most of them address such an issue from a qualitative perspective (18 (26.8%)), while only 3 (4.5%) address it from a quantitative perspective (Rusinko, 2007), (Digalwar et al., 2013), (Hervani et al., 2005). Moreover, according to (Curkovic, 2013), the currently available research on the impact of green practices on organisational outcomes is not only qualitative but also mainly inconclusive. In (Rusinko, 2007), this lack of theory based measures is discussed, and measures previously used within the TQM area are used to develop ERM-related measures, which are validated on data from US automotive industries. In (Curkovic, 2013), a performance measure that allows manufacturers estimating the green manufacturing perception in their organisations is developed based on the study of different relevant green variables identified in the context of Indian manufacturing industries. In (Digalwar et al., 2013), a novel framework for analyse, design and evaluate GSCM performance tools is provided. Finally, from the analysis of these articles, it can be noticed that these works are mainly focused in local studies proposing performance measures based on US (Hervani et al., 2005) or Indian (Curkovic, 2013) manufacturers' experiences. This suggests that there is not only a lack of formal measures but there is also a lack of studies evaluating to what extend the (few) proposed methods can be applied within the context of different manufacturing industries from different countries under different regulations.

Reasons such as the ones mentioned above, like public image and competitiveness, are not the only reasons why companies adopt green manufacturing principles. In fact, it is a well-known fact that one of the main reasons why companies adopt green practices is because of the high pressure of governmental regulations and stakeholders. Unfortunately, to move towards green practices is not always straightforward, since complying with international standards and governmental regulations often requires a huge investment (Digalwar et al., 2013). This is particularly noticeable in the case of SMEs companies (Ciocci and Pecht, 2006), (Chen, 2008), where the reduction of wastes seems to be driven by the costs of raw materials rather than by waste costs (Andrews et al., 2002). In this context, researchers and manufacturers agree that it is crucial to find procedures to support SMEs in increasing their environmental-oriented practices that are, in most of the cases, at a very early stage (Andrews et al., 2002), being SMEs' green image poorer than the one corresponding to large enterprises (Andrews et al., 2002). Nevertheless, there is still too little research conducted in this direction, being only 5 (7.5%) articles in the present SLR devoted to study green practices within the framework of SMEs companies (Chen, 2008), (Chen, 2008), (Ilomaki and Melanen, 2001), (Andrews et al., 2002),(Thoo et al., 2015). In addition, these works are also mainly locally focused, evaluating to what extent SMEs from Australian (Hicks and Dietmar, 2007), Finnish (Andrews et al., 2002), Taiwanese (Ilomaki and Melanen, 2001), Malaysian (Chen, 2008) and Chinese (Thoo et al., 2015) cities have been able to adopt green practices.

The local nature of many of the studies in the SLR is not surprising since green practices do have a strong regional component, being forced to comply different governmental regulations. In (Hicks and Dietmar, 2007), a detailed analysis regarding which are the main green concerns of pioneer countries in terms of green practices is presented. Table 3-4 summarises the findings in (Rehman, 2013), showing that countries in the EU as well as US and Japan are focused in refining their green practices, while emerging countries, such as India, China and Hong Kong are still taking their first steps towards greening their companies. In the present SLR, 22 (32.8%) articles report case studies conducted in companies from different countries, such as US (Rehman, 2013), (Gutowski et al., 2005), (Melnyk et al., 2001), China (Rusinko, 2007), (Liu and Chang, 2017), (Zhu et al., 2007), (Chan, 2001), India (Hicks and Dietmar, 2007), (Digalwar et al., 2013), (Trivedi and Sharma, 2017), Turkey (Fatah and Khan, 2018), (Syrek and Gul, 2017a), Malaysia (Sezen and Cankaya, 2013), (Thoo et al., 2014), UK (Thoo et al., 2015), Australia (Schlegelmilch et al., 1996), Germany (Andrews et al., 2002), Taiwan (Bohringer et al., 2008), Hong Kong (Chen, 2008), Japan (Hui et al., 2001), Iran (Gutowski et al., 2005) and Finland (Hosseini, 2007). The observations found in these articles are in agreement with the ones in (Ilomaki and Melanen, 2001). Finally, from the articles in the SLR addressing case studies, it can be seen that manufacturing industries, in particular, automotive and electronic ones, are currently the most urged to implement green practices, while other manufacturing industries, like chemistry, machine tool, cement and foundry are also moving towards greener solutions.

Table 3-4: Current green concerns of main green practitioners (Rehman, 2013)[39].

Country	Main Green Practices
US	Green practices are mainly focused on the manufacturing process stage. In particular, the main concern is the compliance of green regulations regarding material and processes.
European Union	• Product EOL • GSCM • Reverse Logistics
Germany	Most of the green practices are aimed at dealing with products at their EOL point. In particular, the regulation of different green product disposal strategies is being discussed. In addition, researchers are not only interest in green disposal, but they are also interested in the development of different closed loop recycling strategies.
Japan	Japanese manufacturers are mainly concerned about green products. In this line, the development of innovative green products in order to gain market seems to be their priority.
China	The Chinese environmental situation makes companies, especially automotive ones, to be mainly concerned in the compliance of well-known international environmental standards and regulations, such as, RoHS (Restriction of Hazardous Substances) and WEEE.
Hong Kong	Industries in Hong Kong are mainly focused in the compliance of RoHS directives, but they are also addressing more specific issues like green design and green production management.
India	To date, only a few of the Indian manufacturing companies has been able to ensure the compliance of environmental regulations like the RoHS directive. Most of them are still at the early stages of green manufacturing trying to reduce energy and water consumption, as well as hazardous substances, waste and emissions.

Finally, Figure 3.17 summarises the information gathered from the SLR and discussed above, showing the main concerns of researchers and manufacturers in the field of green manufacturing, the different approaches that have been proposed in the literature to address green practices, and the main performance implications that have been evaluated.

[39] Source: Based on results presented in (Rehman, 2013).

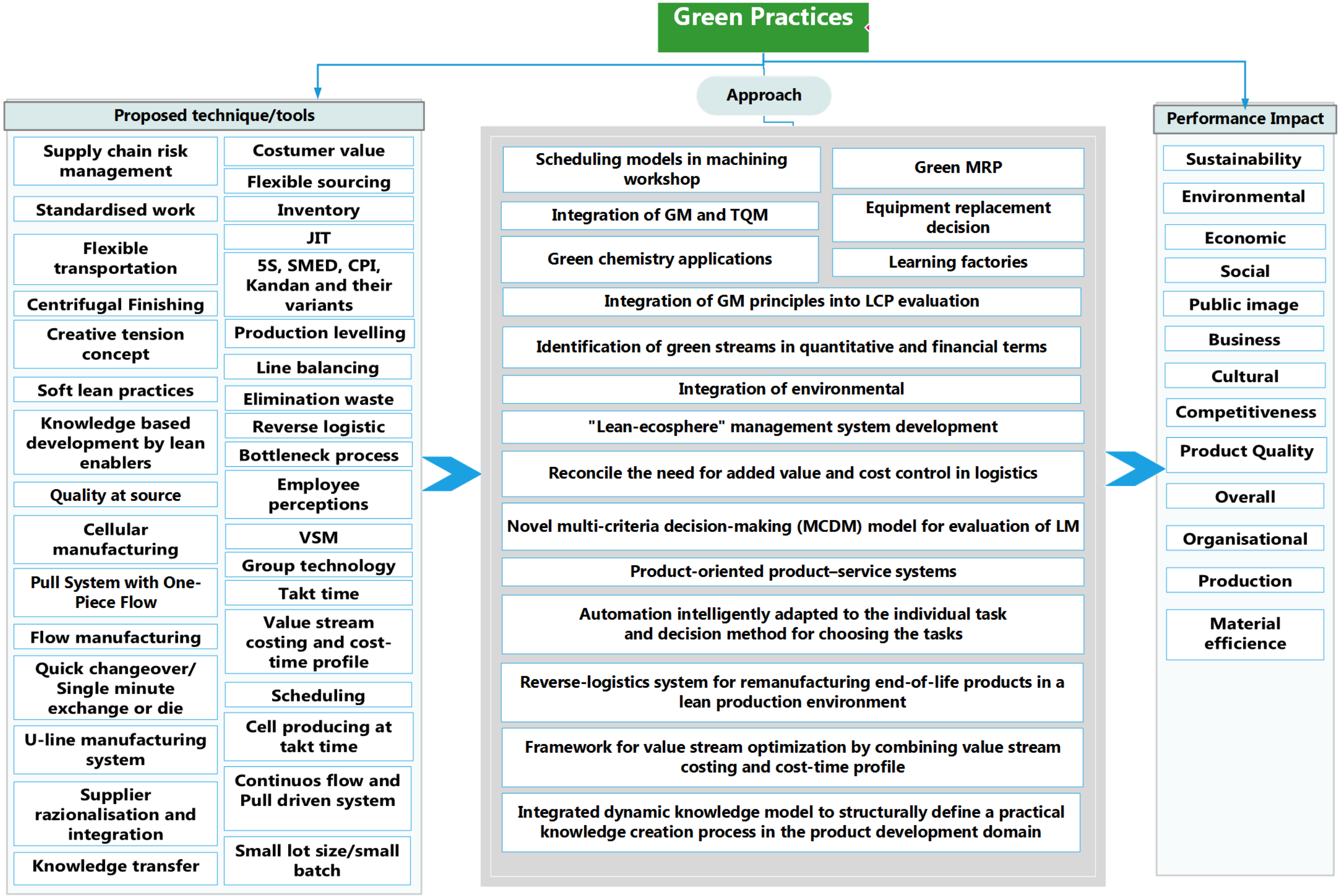

Figure 3.17: Summary of green practices in the SLR: Main concerns, proposed approaches, and their performance impact.

3.5 Green Manufacturing and its Link with Sustainability

Green manufacturing is mainly aimed at reducing the companies' environmental footprint by minimising the use of materials and the energy consumption, eliminating the use of toxic substances, and reducing the waste generation. According to (Rehman, 2013), taking into account the widely accepted definition of sustainability introduced in (Deif, 2011), where sustainability is defined as fulfilling the needs of the current generation without having compromise future generations and being able to fulfil their needs as well, any eco-friendly approach aimed at taking care of the environmental resources can be interpreted as sustainable. In addition, although green manufacturing is mainly focused on solving environmental issues, social and economic aspects are also usually taken into account within the framework of green practices. Then, green manufacturing could be interpreted as a strategy to keep balance economically, environmentally and socially within a manufacturing framework. In this line, in (WCED, 1987), the relationship between green manufacturing and sustainability is summarised by defining green manufacturing as a "sustainable" approach aimed at designing and planning the product development and the process flow in such a way that the environmental footprint of the whole system is minimised. Finally, it is also important to say that this tight relationship between the sustainability concept and the green manufacturing methodology has led some researchers to use both terms interchangeably (Deif, 2011), as in the cases of (Rehman, 2013), (Lee et al., 2001).

In the SLR conducted in Section 3.4, there are 11 (16.4%) articles devoted to address the actual impact of green manufacturing in the sustainability of the company as a whole. In particular, the impact of different green practices within the different stages of the green manufacturing cycle, such as green supply chain (Alonso et al., 2017), (Thoo et al., 2015), (Thoo et al., 2014), green chemistry practices (Tseng et al., 2013), green innovation (Manley et al., 2008), green life cycle evaluation (Sezen and Cankaya, 2013), green design (Niggeschmidt et al., 2010), (Tseng et al., 2013), green production (Sun et al., 2003), green technology (Acharya et al., 2014), green product (Trivedi and Sharma, 2017), and green organisational culture (Dangelico et al., 2016), are addressed. In addition, according to (Harris and Crane, 2002), different interpretations can be associated with the sustainability concept depending on the particular implementation under consideration. For instance, in the business field, sustainability is defined as the employment of suitable strategies in order to be able to ensure that the current companies' and stakeholders' needs can be satisfied while protecting the available human and natural resources in order they keep being available for future needs (Deif, 2011). In this line, among the articles selected in the SLR, there are 5 (7.5%) articles that studies how can green manufacturing help to reach sustainability regarding specific aspects of the company, such as, sustainable development (Deloitte and Touche, 1992), (Hosseini, 2007), sustainable products (Gehin et al., 2008), and how can green purchasing and marketing lead to business sustainability (Paul et al., 2014), (Syrek and Gul, 2017a).

Among the 16 articles selected in the SLR explicitly addressing the sustainability concept either from a holistic perspective or from a more specific one, 9 have been published after 2010. This shows that, although in last years, sustainability has become a trending topic in the manufacturing field, the relationship between green manufacturing practices and sustainability has long been studied in the field. This is probably due to the fact that since they were first introduced in the early 1990s green practices have had a tight relationship with the sustainable concept. In addition, these articles have been published in different specialised journals, such as, J. of Cleaner Production (3), Integrated Design and Process Science (1), Mechanical and Production Engineering Research and Development (1), Manufacturing Sciences and Engineering (1), Management Emerging Technology and Advanced Engineering (1), Business Strategy and the Environment (1), Academic Research in Business and Social Sciences (1), Advanced Materials Research (1), and Organizational Change Management (1); and other types of publications, such as conferences like Procedia - Social and Behavioral Sciences (1) and Materials Science (1) and Global Conference on Sustainable Manufacturing (1), and University repositories (UC Berkeley: Laboratory for Manufacturing and Sustainability (1)). In this sense, it can be seen that researchers addressing sustainability issues tend to publish their articles in specialised journals and conferences. Nevertheless, although the J. of Cleaner Production is one of the most frequently chosen, as it is in the case of most of the research about green manufacturing, in the particular case of articles addressing sustainability issues there is not a unique publication bringing together all the contributions.

In general, researchers agree that green manufacturing can lead to sustainability, having a positive impact not only on environmental but also on economic and social aspects. Among the selected articles in the SLR conducted in Section 3.4, several examples can be found confirming this (Xu et al., 2008), (Sezen and Cankaya, 2013), (Acharya et al., 2014), (Trivedi and Sharma, 2017), (Dangelico et al., 2016), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008). Some researchers have conducted different experimental case studies in order to evaluate the link between green manufacturing and sustainability, in an attempt to fill the gap in the literature regarding practical and real life evidence (Xu et al., 2008), (Sezen and Cankaya, 2013), (Acharya et al., 2014). In (Dangelico et al., 2016), data from Turkish automotive, chemistry and electronic companies show that green manufacturing is positively correlated with environmental and social performances. In addition, in (Sezen and Cankaya, 2013) it is also suggested that innovations in green processes lead to improvements in the whole company's sustainability. In (Sezen and Cankaya, 2013), a green manufacturing approach towards achieving sustainability within the context of foundries is proposed. In (Acharya et al., 2014), a novel sustainability-oriented model is proposed and the impact of applying the proposed approach on the performance of green products within the context of an Italian market is analysed.

Some other researchers give an insight into the link between green manufacturing and sustainability by analysing different aspects of the green practices and proposing new approaches to implement them (Dangelico et al., 2016), (Trivedi and Sharma, 2017), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008), (Xu et al., 2008). In (Syrek and Gul, 2017a), authors state that DfE practices optimise the interaction of the economic and the environmental systems, producing a sustainable development and enterprise integration. On the other hand, in (Sun et al., 2003), it is stated that DfE practices are not enough to ensure sustainability, suggesting that EOL strategies should be integrated from the beginning in order to reach sustainability. Researchers in (Gehin et al., 2008) and (Thoo et al., 2015) focus their attention in the link between GSCM practices and sustainability performance proposing an environmental collaboration referred to as "environpreneurship" to facilitate this link in a Malaysian manufacturing industry. The proposed model in (Thoo et al., 2014) is shown in Figure 3.18. Authors in (Thoo et al., 2015) agree with the observations in (Xu et al., 2008) and (Thoo et al., 2015) regarding the influence of GSCM with respect to sustainability aspects. Moreover, they suggest that the green supply chain should be extended to include green purchasing and marketing for the sake of sustainability. In this line, they propose the network approach shown in Figure 3.19, which considers the different stakeholders as interdependent actors within this network, suggesting that a novel and joint view of green manufacturing would lead to sustainable organisations and, even more important, sustainable societies.

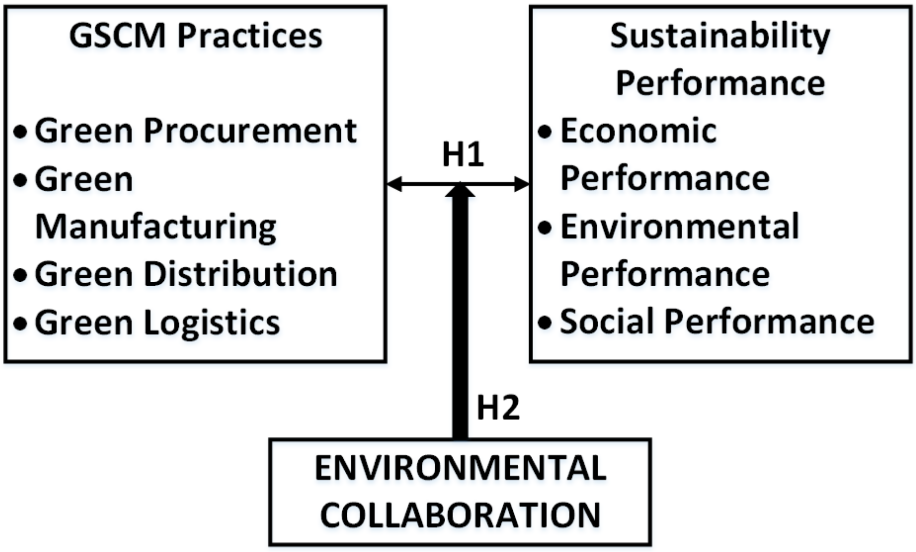

Figure 3.18: Green collaboration to enhance the relationship between GSCM practices and sustainability performance[40].

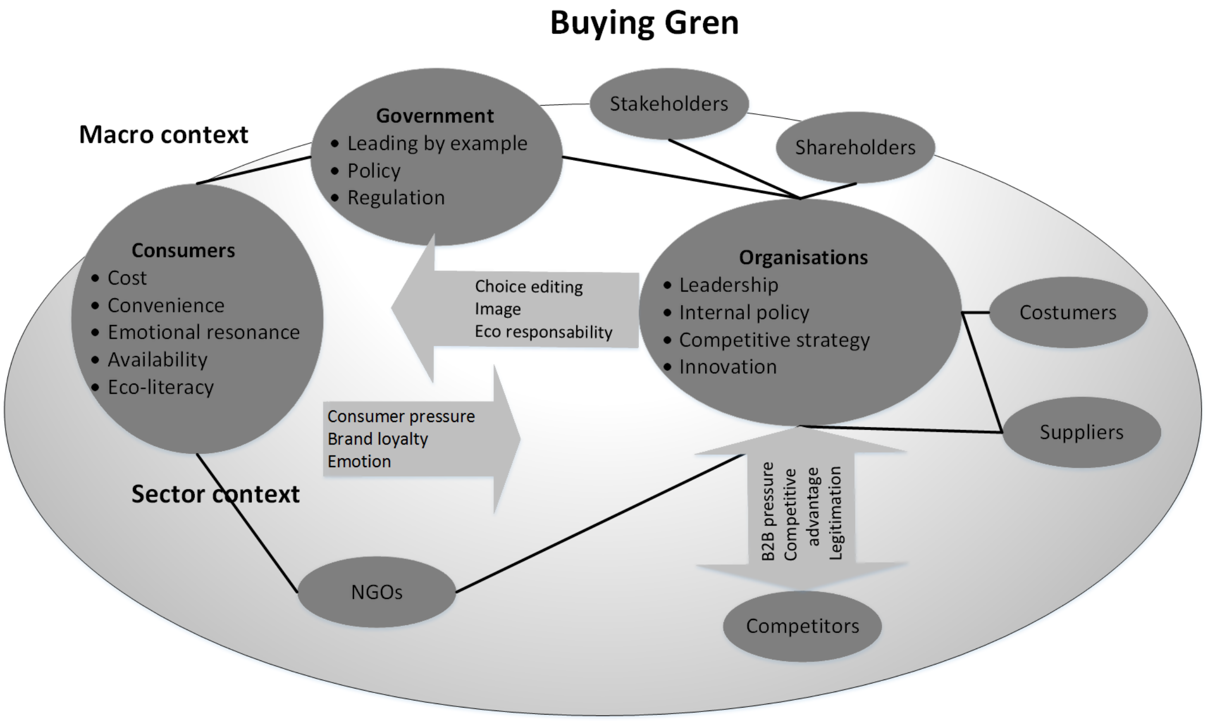

Figure 3.19: Network approach proposed in (Thoo et al., 2014) for the sake of sustainability[41].

[40] Source: Based on the scheme preseted in (Thoo et al., 2015).
[41] Source: Based on the scheme presented in (Xu et al., 2008).

Finally, in recent years, there has been a strong tendency for researchers to believe that green technology and innovation are the key aspects to allow green manufacturing to reach sustainability (Xu et al., 2008), (Tseng et al., 2013), (Dangelico et al., 2016), (Trivedi and Sharma, 2017), (Sezen and Cankaya, 2013). Moreover, authors in (Manley et al., 2008) go even further, suggesting that green chemistry and the possibility of developing DfE strategies at a molecular level are seen as the future practices to reach sustainability. On the other hand, authors in (Manley et al., 2008) argue that, in order to become sustainable, organisational actions should go beyond the technical, methodological and technological fixes discussed here, making the focus on new environmentally responsible values, beliefs and behaviours.

Finally, according to the analysed articles in the SLR conducted in Section 3.4, there are different green aspects, such as GSCM, DfE, green marketing, green purchasing, green production, green product, green technology and innovation that can influence the company's sustainability performance. Figure 3.20 shows the proportion of articles in the SLR addressing the impact of each of these green aspects in the sustainability performance. From Figure 3.20, it can be seen that, according to the articles analysed in the conducted SLR, green technology and innovations are the most influencing green aspects.

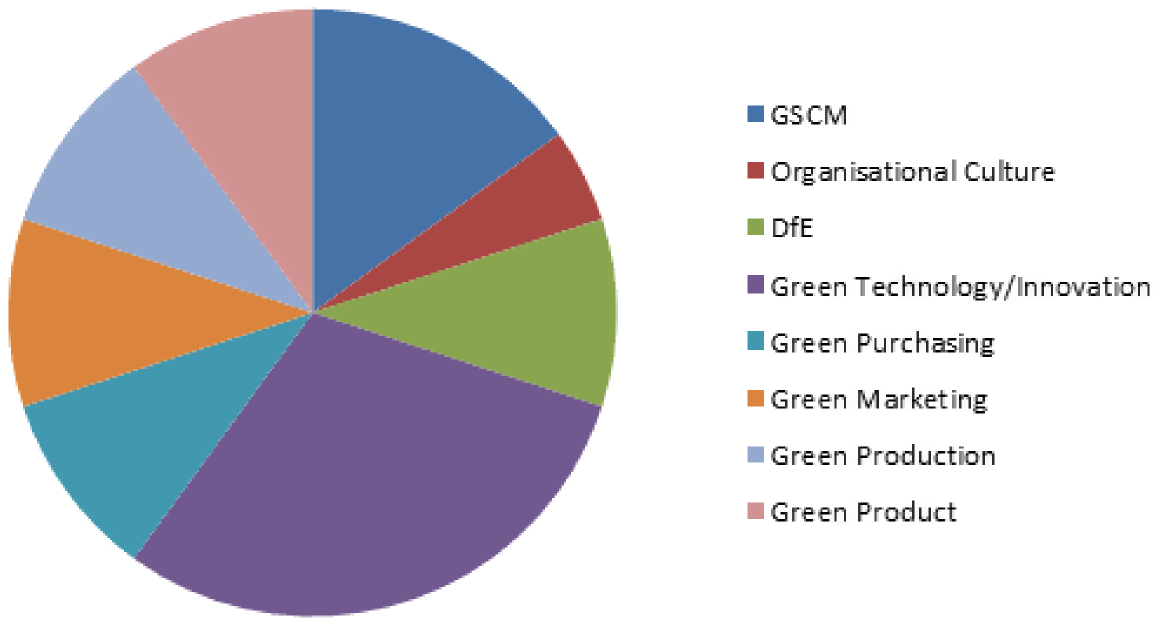

Figure 3.20: Main green aspects influencing sustainability.

3.6 Main Findings and Research Gaps from the Green Manufacturing SLR

The main findings and research gaps identified in the SLR conducted in this chapter are summarised in Table 3-5 and, respectively Table 3-6.

Table 3-5: Summary of the main finding identified in the Green Manufacturing SLR.

Findings	Sources
Green solutions are usually customised.	(Cagno et al., 2005), (Rehman, 2013), (Yan et al., 2007)
Most of the currently implemented green solutions are focused on supply chain management issues.	(Rehman, 2013), (Gehin et al., 2008), (Thoo et al., 2015)
The main reasons why companies adopt green manufacturing are: • **public image** • **competitiveness** • **high pressure of governmental regulations** • **stakeholders' pressure**	(Rehman, 2013)
SMEs found it extremely hard to implement green practices due to financial and technical issues.	(Ciocci and Pecht, 2006), (Chen, 2008)
Green practices have a strong regional component, being forced to comply different governmental regulations.	(Hicks and Dietmar, 2007), (Rehman, 2013)
EOL strategies should be integrated from the beginning in order to reach sustainability.	(Sun et al., 2003)
Green technology and innovation are the key aspects to allow green manufacturing to reach sustainability.	(Xu et al., 2008), (Tseng et al., 2013), (Dangelico et al., 2016), (Trivedi and Sharma, 2017), (Sezen and Cankaya, 2013)
The main green aspects that influence the	

sustainability performance of the companies are:

- **GSCM**
- **DfE**
- **green marketing**
- **green purchasing**
- **green production**
- **green product**
- **green technology**
- **green innovation**

Table 3-6: Summary of the main research gaps identified in the Green Manufacturing SLR.

Gaps	Sources
There is a lack of unified definitions, as well as standard and well-stablished methodologies to implement the green principles.	(Cagno et al., 2005), (Rehman, 2013), (Yan et al., 2007)
There is a lack for standard and widely accepted performance measurements associated with the different green tools and practices.	(Rusinko, 2007), (Digalwar et al., 2013), (Hervani et al., 2005). (Curkovic, 2013)
There is a lack of real life case studies evaluating the green influence in the companies' sustainability performance.	(Rusinko, 2007), (Digalwar et al., 2013), (Hervani et al., 2005). (Curkovic, 2013)
Some stages in the product life cycle, such as green production activities have been overlooked by researchers in the field.	(Rehman, 2013), (He et al., 2008)
There is a lack of studies evaluating to what extend green methods available in the literature can be implemented within the context of different manufacturing industries from different countries under different regulations.	(Curkovic, 2013)

There is a need for a higher costumer and supplier involvement.	
Implementing green practices requires a huge investment.	(Digalwar et al., 2013)
It is crucial to develop new procedures to support SMEs in increasing their environmental-oriented practices.	(Ciocci and Pecht, 2006), (Chen, 2008), (Andrews et al., 2002).
There is a need for government support.	
Organisational actions should go beyond the technical, methodological and technological fixes, making more focus on new environmentally responsible values, beliefs and behaviours.	(Manley et al., 2008)

3.7 Chapter Summary

In this chapter, the most popular green practices have been described in order to give some insight into the field of green manufacturing which is in constant development. In particular, a SLR has been carried out in order to study the diverse green solutions currently being implemented within the real manufacturing scenario, as well as their link with sustainability aspects. Based on the SLR conducted in this chapter, it can be concluded that, although some standard green practices, such as LCA and EOL strategies, can be mentioned, most of the currently implemented green practices are customised according to the companies' needs. In this context, it becomes crucial to develop green solutions that can be widely adaptable to different manufacturing scenarios in order to achieve further and comparable sustainability improvements. In addition, although green practices are, by nature, highly focused on environmental aspects (Harris and Crane, 2002), (Alonso et al., 2017), (Thoo et al., 2015), (Cagno et al., 2005), as well as capable of reaching improvements in the social performance (Govindrajulu and Daily, 2004), (Alonso et al., 2017), being their impact on economic aspects traditionally called into question, in recent years some researchers have begun to consider that green practices can actually lead to economic improvements (Hicks and Dietmar, 2007), (Zhu and Sarkis, 2004), (Bohringer et al., 2008), (Miroshnychenko et al., 2017).

Despite the promising economic green perspective, the relationship between green practices and the economic performance remains unclear. In this line, being green practices highly environment-oriented and lean practices highly economic-oriented, researchers have suggested combining them towards achieving the required balance among the different aspects of sustainability. Such integration have demonstrated to be a complex and challenging task. In Chapter 4, the actual possibility of combining lean and green practice into a single approach is evaluated and the available theoretical as well as practical methods towards implementing it are studied by conducting an exhaustive SLR.

4 LEAN-GREEN MANUFACTURING APPROACH: LITERATURE REVIEW

4.1 Introduction

The current rapidly changing and highly competitive market has put companies under a great pressure not only to be successful, but also to sustain their success into the future. In addition, in recent years, companies have become more aware of the fact that it is no longer enough to take care of economic aspects, being crucial to also take care of environmental and social aspects in order to actually succeed and lead in the current and future markets. In this context, companies are urged to move towards novel and innovative manufacturing practices that can maintain a healthy balance among economic, environmental and social performances, which are the three pillars of the sustainability performance.

As it has been discussed in Chapter 2, lean practices have widely been adopted by companies all over the world, even by those that do not belong to the manufacturing sector (Rao and Holt, 2005), (Herron and Hicks, 2008), (Soni et al., 2013), (Borges Lopes et al., 2015), (Hobbs, 2004), for the sake of developing an efficient manufacturing approach by increasing value to customers while reducing the resource and time consumptions via waste elimination. By nature, lean practices are mainly focused on economic issues, nevertheless, they can also positively contribute (to a certain extent) to environmental (Dickson et al., 2009b), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), and social (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018) issues. Moreover, in recent years, several efforts have been done towards evaluating to what extent lean practices can fulfil the current environmental requirements (Bortolotti et al., 2015), (Ahuja, 2012), (Venkat and Wakeland, 2006), as well as towards extending, modifying and updating lean practices so that they can address social and environmental aspects more efficiently (Dhingraa et al., 2014), reporting promising results (Garza Reyes, 2015a), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013), (Chiappetta Jabbour et al., 2013). Based on these results, there are several researchers that argue that sustainability is an evolution of lean practices (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013), (Chiappetta Jabbour et al., 2013). Nevertheless, there are the ones that argue that lean practices have not reached yet the maturity level required to ensure sustainability (Dieste and Panizzolo, 2018), suggesting that a more holistic approach, including health and safety is required (Peto, 2012). In this line, many companies' leaders have realised that, since lean practices are not always capable of fulfilling neither the environmental requirements imposed by international standards and government regulations, nor the required social responsibility level, the implementation of green practices should be considered instead. As it has been discussed in Chapter 3, green practices are focused on reducing hazardous emissions, getting rid of the consumption of wasteful resources, recycling, and minimising health risks throughout the entire manufacturing process, by minimising the environmental footprint during the whole product life cycle (Marhani et al., 2013). In this way, the implementation of green practices is expected to lead to improvements in the companies' environmental performance as well as their public image. In addition, in recent years, several studies in the literature have shown that green practices can also lead to improvements in the whole companies' sustainability performance (Deif, 2011), (Sezen and Cankaya, 2013), (Acharya et al., 2014), (Trivedi and Sharma, 2017), (Dangelico et al., 2016), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008). Nevertheless, despite these promising results, the relationship between green practices and the economic performance remains unclear, being not straightforward and often called into question by practitioners and researchers arguing that they can be a burden for reaching improvements regarding design and production processes. In this sense, the actual capability of green practices towards reaching sustainable improvements is still highly questioned.

In this context, researchers have recognised that, on one hand, although lean practices, which are mainly focused on economic aspects (Xu et al., 2008), (Chunguang et al., 2018), (Khanchanapong et al., 2014), (Belekoukias, 2014), (Hofer et al., 2012), do have a positive impact on environmental (Camuffo and Gerli, 2014), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017) and social (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018) aspects, these positive impacts are not always enough to reach the sustainability level required by the highly competitive market. On the other hand, green practices are mainly focused on environmental aspects (Bortolotti et al., 2015), (Alonso et al., 2017), (Thoo et al., 2015), (Cagno et al., 2005) and do have a great positive impact on social (Govindrajulu and Daily, 2004), (Alonso et al., 2017) aspects, but their positive impact on the economic performance has largely been called into question (Hicks and Dietmar, 2007), (Zhu and Sarkis, 2004), (Bohringer et al., 2008), (Miroshnychenko et al., 2017). In this conflicting situation, researchers and practitioners have realised that neither lean nor green practices seem to be completely suitable to keep the expected balance among economic, environmental and social aspects towards reaching the required level of sustainability. In this line, the idea of integrating both manufacturing approaches into a single combined approach so that simultaneous advantage can be taken of the operational, financial and (to a lesser extent) social benefits obtained by lean practices, as well as of the environmental and social benefits obtained by green practices, arises (Rao and Holt, 2005), (Garza Reyes et al., 2014), (Dües et al., 2012), (Galeazzo et al., 2014). In particular, researchers expect that to implement both practices together could generate a complementary atmosphere leading to concurrent enhancement of operational, financial, environmental and social performances, by complementing lean benefits, such as, cost and lead time reduction and increased product quality, with green practices aimed at reducing the environmental impact of the whole manufacturing process, while working in a socially enhanced environment where employees are not only well-trained and engaged but also enjoy a cleaner, safer and healthier environment.

Although research regarding the individual implementation of lean and green manufacturing approaches abounds, as it has been shown in Chapters 2 and 3, respectively, there is still much research to be conducted regarding the feasibility of integrating them into a single approach (Garza Reyes, 2015b), (Garza Reyes, 2015a), (Garza Reyes et al., 2014), (Hayani et al., 2016). In this line, the link between lean and green manufacturing should be revisited. Researchers agree that the leading similarity between both manufacturing practices is their waste reduction nature (Prasad & Sharma, 2014), (Hayani et al., 2016), (Garza Reyes et al., 2014), (Mollenkopf et al., 2010), (Dües et al., 2012), (Duarte and Cruz-Machado, 2013). They highlight that, although lean waste definition is focused on reducing any non-value added activity and green waste definition is focused on reducing environmental impacts, they are both designed to increase the efficiency and effectiveness of the value stream or system (Prasad & Sharma, 2014). In this context, several researchers suggest that the alignment between lean and green paradigms is natural, making their link in terms of methods and tools become natural too. Nevertheless, practically implementing lean and green manufacturing together is not straightforward. In a recent literature review by (Kurdve et al., 2014), conflicting results have been reported regarding whether green and lean practices are actually suitable to work together. On one hand, there are the ones who favour their integration (Garza Reyes, 2015b), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), arguing that they can support each other, whenever implemented together, generating a synergetic effect, in the sense that their strengths can be enhanced while their weaknesses can be disguised. On the other hand, there are the ones who do not favour their integration (Galeazzo et al., 2014), (Mollenkopf et al., 2010), arguing that both approaches differ in their main objectives, so they are likely to have different impacts on the overall company's performance, making it not always a good choice to combine them. In this conflicting context, further research needs to be conducted towards evaluating the actual possibility of integrating the lean and green approaches, the potential of the combined approach and its influence on operational, financial, environmental and social performances towards reaching the next level of sustainability. In this line, an in-depth analysis based on a SLR is performed in this chapter in order to give some insight into these current challenges in the manufacturing field.

The remaining of the chapter is organised as follows. In Section 4.2, the need for resorting to a combined lean-green approach and what are the actual possibilities of doing so is discussed. In particular, a SLR is conducted in order to study the similarities as well as differences between lean and green practices, their actual capability of working together and the currently strategies adopted towards practically implementing within the real manufacturing scenario. In Section 4.3, the link between the combined lean-green approach with the different considered sustainability aspects and its capability of improving them simultaneously are addressed. In Section 4.4, the main findings and gaps identified in the SLR are summarised. Finally, in Section 4.5 the chapter summary is provided.

4.2 Lean-Green Manufacturing Approach

In recent years, companies have recognised that, in order to lead in the current and future markets, it is mandatory to move towards the next level of sustainability. In Chapters 2 and 3, the current trends in lean and green manufacturing practices, respectively, as well as their link with the different sustainability aspects have been discussed, showing that several efforts have been undertaken in order to reach further improvements in the sustainability performance, either from the lean (Kleindorfer et al., 2005), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). perspective or from the green (Chiappetta Jabbour et al., 2013), (Sezen and Cankaya, 2013), (Acharya et al., 2014), (Trivedi and Sharma, 2017), (Dangelico et al., 2016), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008) one. Nevertheless, despite these great efforts as well as the promising results reported in the literature regarding lean practices leading to environmental improvements (Xu et al., 2008), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017) and green practices leading to economic improvements (Dieste and Panizzolo, 2018), many researchers have concluded that, due to the fact that neither lean nor green practices have particularly been aimed at addressing the three pillars of sustainability simultaneously, their contributions towards these three sustainability aspects would not be enough when implemented individually, being necessary to implement them in a combined framework.

In general, researchers agree that the integration of lean and green practices into a combined approach is a quite complex and challenging task (Paul et al., 2014), (Garza Reyes, 2015b), (Garza Reyes et al., 2014), (Hayani et al., 2016). In order to give some insight in this direction, in this section an exhaustive literature review, based on the SLR principles presented in Section 2.4, is conducted in order to identify and analyse the main similarities and differences between both practices, evaluate to what extent they can actually be implemented together, and study the different combination strategies proposed in the literature, their potential and their capability of keeping the balance among economic, environmental and social performances towards achieving a superior level of sustainability.

4.2.1 Research Questions and Search Methodology

The present SLR is aimed at giving an insight into the current research in the field regarding the integration of lean and green approaches, making special focus on the potential such combination can have towards improving the whole company's sustainability performance. In this line, the following questions should be answered:

1. Which are the actual possibilities of integrating lean and green practices into a combined approach?
2. Which are the currently proposed strategies to implement the combined lean-green approach?
3. What is the actual (and expected) impact of implementing the combined lean-green approach in the sustainability performance?

Each of these research questions will be addressed in Sections 4.2.3, 4.2.4 and 4.3, respectively. The search for the relevant contributions related to these research questions has been carried out resorting to the resources described in Section 2.4.1, focusing the attention on the contributions published in the last two decades, taking as initial research points the following topics:

- Compatibility between lean and green manufacturing practices: similarities, differences and synergy
- Main strategies towards implementing the combined lean-green approach
- The lean-green approach and its actual potential towards achieving further improvements in the sustainability performance

4.2.2 Thematic Synthesis

Following the search criteria described in Section 4.2.1, a total of 45 contributions to the field have been selected. Among them, 35 (77.7%) are from International journals (being 11 (24.4%) of them from the J. of Cleaner Production and 4 (8.8%) from the J. of Production Economics), while only one (2.2%) is from a book, and 10 (22.2%) are from Proceedings of International Conferences. This literature selection allows the same observations that have been done in the cases of the SLRs regarding lean and green practices carried out in Sections 2.4.2 and 3.4.2, respectively, regarding the relevancy of the selected journals. In addition, as in the particular case of the SLR conducted for green practices, researchers addressing the combined approach also tend to publish their contributions in the J. of Cleaner Production which is currently one of the most popular journals in the field.

In order to better analyse the selected articles in the SLR, a thematic synthesis is performed to identify and study the most relevant contributions addressing the main concerns regarding the integration of lean and green practices into a combined approach. Table 4-1 shows the resulting SLM based on this thematic synthesis. In particular, the 45 selected articles are thematically synthesised taking into account the following categories:

- Conceptual Analysis: Articles in this category address the lean and green practices integration from a theoretical point of view. In general, these kinds of analyses are found in books.
- Literature Review: Literature reviews focus on collecting and discussing the main and most recent contributions regarding integrating lean and green practices. In particular, they can address the integration issues either by performing a lean vs. green analysis, or by proposing strategies to implement it.
- Research Application: This category includes articles where authors propose different models and approaches to actually implement the lean-green approach.
- Case Study/Empirical Study: These types of studies are held within the companies' manufacturing context. Some of them resort to surveys, while some others perform experimental tests.
- Lean vs. Green Analysis: Articles classified in this category study the actual possibility of combining lean and green practices based on their main similarities and differences.
- Lean and Green Synergy: These articles evaluate to what extent lean and green practices can actually be implemented together within a synergetic environment,

in the sense that their strengths can be enhanced while their weaknesses can be disguised.

- Lean-green Implementation: This category aims to gather the proposed approaches to practically implement the lean-green combination.
- Impact on Performance: This category shows which are the main pursued objectives behind implementing the combined lean-green approach.
- Sustainability: In this category, it is intended to include articles that evaluate the actual impacts of the combined approach to the sustainability performance and to what extent (and how) further improvements can be achieved when the combination approach is implemented.

Table 4-1: SLM for the lean-green approach.

Nº	Paper	Conceptual analysis	Lit. Review	Research App.	Case Study/ Empirical Appl.	Lean vs. Green Analysis	Lean and Green Synergy	Lean-Green Implementation	Impact on Performanc e	Sustainability
1	Dües, C.M., Kim Hua Tan, Ming Lim. "Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain." J. of Cleaner Prod. 40 (2013): 93-100.		x			x	x			
2	Bashkite, V., Karaulova, T. "Integration of Green thinking into Lean fundamentals by Theory of Inventive Problems-Solving tools." DAAAM International, Vienna, Austria, EU (2012): 345-350.			x				x		X
3	Geof, M., Pawloski, J.,Standridge, C.R.. "A case study of lean, sustainable manufacturing." J. of Industrial Engineer. and Manag. 3.1 (2010): 11-32.				x				x	X
4	Tiwara, R. "Green lean manufacturing: Way to sustainable productivity improvement".Intern		x		x				x	x

	ational Journal Of Engineering Research and General Science 4(6) (2016):243-262									
5	Bergmiller, Gary G., and Paul R. McCright. "Parallel models for lean and green operations." Proceedings of the 2009 Industrial Engineering Research Conference, Miami, FL. 2009.			**x**				**x**	**x**	
6	Rosenbaum, Sergio, Mauricio Toledo, and Vicente Gonzalez. "Green-lean approach for assessing environmental and production waste in construction. "Proceedings for the 20th Annual Conference of the IGLC, San Diego, USA. 2012.				**x**			**x**	**x**	**X**
7	Pampanelli A.B., Found P., Bernardes A.M. (2015) Sustainable Manufacturing: The Lean and Green Business Model. In: Chiarini A. (eds) Sustainable Operations Management. Measuring Operations			**x**				**x**		**x**

	Performance. Springer, Cham									
8	Dhingra, Rajive, Reid Kress, and Girish Upreti. "Does lean mean green?." Journal of Cleaner Production 85 (2014): 1-7.		**x**			**x**	**x**			**X**
9	Chiarini, A. "Sustainable manufacturing-greening processes using specific Lean Production tools: an empirical observation from European motorcycle component manufacturers" Journal Cleaner Production 85 (2014) 226-233	**X**			**x**			**x**		**X**
10	Ng, Ruisheng, Jonathan Sze Choong Low, and Bin Song. "Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric." Journal of Cleaner Production(2015).		**x**	**x**	**x**			**x**		**X**

11	Verrier, Brunilde, et al. "Combining organizational performance with sustainable development issues: the Lean and Green project benchmarking repository." Journal of Cleaner Production 85 (2014): 83-93.				**x**			**x**		**X**
12	Galeazzo, Ambra, Andrea Furlan, and Andrea Vinelli. "Lean and green in action: interdependencies and performance of pollution prevention projects." Journal of Cleaner Production 85 (2014): 191-200.				**x**	**x**	**x**		**x**	
13	Kurdve, Martin, et al. "Lean and Green integration into production system models– Experiences from Swedish industry." Journal of Cleaner Production 85 (2014): 180-190.				**x**			**x**	**x**	**X**
14	Folinas, Dimitris, et al. "Exploring the greening of the food supply chain with lean thinking techniques." Procedia Technology 8 (2013): 416-424.			**x**	**x**			**x**		

15	Fahimnia, Behnam, Joseph Sarkis, and Ali Eshragh. "A tradeoff model for green supply chain planning: A leanness-versus-greenness analysis." Omega 54 (2015): 173-190.	**x**				**x**				
16	Kainuma, Yasutaka, and Nobuhiko Tawara. "A multiple attribute utility theory approach to lean and green supply chain management." International Journal of Production Economics 101.1 (2006): 99-108.			**x**				**x**		**X**
17	Yang, Ma Ga Mark, Paul Hong, and Sachin B. Modi. "Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms." International Journal of Production Economics 129.2 (2011): 251-				**x**					

18	Garza Reyes, J.A. "Lean and green – a systematic review of the state of the art literature." Journal Cleaner Production 102 (2015): 18-29		**x**			**x**	**x**	**x**		**X**
19	Diaz Elsayeda, N. , Jondralb, A. , Greinacherb, S., Dornfelda, D., Lanza, G. "Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments". CIRP Annals 62(1) (2013): 475-478			**x**	**x**			**x**		
20	Cobra, R.L.R.B., Guardia, M., Queiroz, G. A., Oliveira, J. A., Ometto, A. R., Esposto, K. F. ""Waste" as the Common "Gene" Connecting Cleaner Production and Lean Manufacturing: A Proposition of a Hybrid Definition" Environ. Qual. Manag (2015)	**x**				**x**				
21	Lin Wu, Nachiappan Subramanian, M. D. Abdulrahman, Chang Liu, Kee Hung Lai, Kulwant				**x**			**x**	**x**	**x**

	S. Pawar "The Impact of Integrated Practices of Lean , Green , and Social Management Systems on Firm Sustainability Performance — Evidence from Chinese Fashion AutoParts Suppliers" (2015)									
22	Garza Reyes, et al. 2015, Green lean and the need for Six Sigma, International Journal of Lean Six Sigma		**x**			**x**	**x**			**x**
23	Ahuja, R. (2012). Sustainable Construction: Is Lean Green? *International Conference on Sustainable Design, Engineering, and Construction.*	**x**				**x**				**x**
24	Bortolini, M., E. Ferrari, E., Galizia, F., & Mora, C. (2016). A Reference Framework Integrating Lean and Green Principles within Supply Chain Management. *International Journal of Economics and Management Engineering,* 10(3).			**x**				**x**		**x**

25	Campos, L., & Vazquez-Brust, D. (2016). Lean and green synergies in supply chain management. *Supply Chain Management: An International Journal,* 21(5), 627-641.		**x**				**x**			**x**
26	Carvalho, H., & Cruz-Machado, V. (2009). Integrating Lean, Agile, Resilience and Green Paradigms in Supply Chain Management (LARG_SCM). In *Third International Conference on Management Science and Engineering Management (pp. 3-14).*			**x**				**x**		**x**
27	Dawood, L., & Abdullah, Z. (2017). Effect of Manufacturing Activities on Lean - Green Management Integration . *International Conference on Industrial Engineering and Operations Management .*			**x**				**x**	**x**	**x**

28	Duarte, S., & Cruz-Machado, V. (2013). Modelling Lean and Green: A Review from Business Models. *International Journal of Lean Six Sigma.*		**x**			**x**	**x**			
29	Fercoq, A., Lamouri, S., Carbone, V., Lelièvre, A., & Lemieux, A. (2013). Combining lean and green in manufacturing: a model of waste management. *IFAC Proceedings Volumes, 46(9), 117-122.*			**x**				**x**		
30	Franchetti, M., Bedal, K., Ulloa, J., & Grodek, S. (2009). Lean and Green: Industrial engineering methods are natural stepping stones to green engineering . *Industrial Engineer: IE, Vol. 41(No. 9), pp. 24-29.*	**x**				**x**	**x**			
31	Garza Reyes, J., Winck Jacques, G., Lim, M., Kumar, V., & Rocha Lona, L. (2014). Lean and green – synergies, differences, limitations, and the need for Six Sigma.		**x**			**x**	**x**			**x**

	. Innovative and Knowledge-Based Production Management in a Global-Local World, (pp. 71-81).									
32	Hallam, C., & Contreras, C. (2016). The Interrelation of Lean and Green Manufacturing Practices: A Case of Push or Pull in Implementation. *Proceedings of PICMET '16: Technology Management for Social Innovation.*		**x**							**x**
33	Hayani, S., Said, E., Govindan, K., & Mokhlis, A. (2016). A framework for the integration of Green and Lean Six Sigma for superior sustainability performance. *International Journal of Production Research.*			**x**	**x**			**x**	**x**	**x**
34	Johansson, G., & Winroth, M. (2009). Lean vs. Green manufacturing: Similarities and differences. *16th International Annual EurOMA Conference: Implementation -*	**x**				**x**				

	realizing Operations Management Knowledge.									
35	Kumar, M., & Sanchez Rodrigues, V. (2018). Synergetic effect of lean and green on innovation: A resource-based perspective. *International Journal of Production Economics.*	**x**			**x**		**x**			
36	Mollenkopf, D. S., Tate, W., & Ueltschy, M. (2010). Green, lean, and global supply chains. *International Journal of Physical Distribution & Logistics Management, 40(1/2), 14-41.*		**x**			**x**				
37	Rajive, D., Kress, R., & Upreti, G. (2014). Does lean mean green? Journal of Cleaner Production 85.	**x**				**x**				
38	Vipul, G., Gopalakrishnan, N., & Padmanav, A. (2018). Can lean lead to green? Assessment of radial tyre manufacturing processes using				**x**	**x**				

	system dynamics modelling. *Computers & Operations Research, 89, 284-306.*									
39	Aguado et al. (2013) Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation				**x**					**x**
40	Azevedo et al. (2012) Influence of green and lean upstream supply chain management practices on business sustainability			**x**	**x**				**x**	**x**
41	Wiengarten et al. (2013) Exploring synergetic effects between investments in environmental and quality/lean practices in supply chains	**x**			**x**		**x**			**X**
42	Wadhwa (2014) Synergizing lean and green for continuous improvements				**x**		**x**	**x**		**X**
43	Larson and Greenwood (2004) Perfect complements: synergies between	**x**					**x**			**X**

	lean production and eco-sustainability initiatives									
44	Salleh et al. (2012) Green lean total quality information management in Malaysian automotive companies				**x**			**x**		
45	Thanki, S.; Govindan, K.; JiteshThakkar, J. 2016 An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. Journal of Cleaner Production				**x**			**x**		

4.2.3 Towards a Lean-Green Approach

The conducted SLR confirms that, in recent years, researchers have focused their efforts towards understanding the actual possibility of integrating lean and green practices in order to reach a higher level of sustainability. In fact, the 45 (100%) articles in the SLM of Table 4-1 have been published after 2000, while 40 (88.8%) of them have been published after 2010. Here, it is important to highlight that, despite the great efforts reported in the literature towards investigating the combined approach, only 45 articles have been found in the literature explicitly addressing this issue which, in comparison with the 73 and 67 articles gathered in the SLRs for lean and green practices, respectively, demonstrates that too much research has still to be conducted in this direction (Kurdve et al., 2014), (Garza Reyes, 2015b), (Garza Reyes et al., 2014), (Kurdve et al., 2014).

Among the 45 selected articles, the majority (24 (53.3%)) study the integration of lean and green practices from a general and theoretical point of view (being 14 (31.1%) of them literature reviews and 10 (22.2%) conceptual analyses). On the other hand, 12 (26.6%) articles address the combination issue from a more practical point of view, proposing integration frameworks and approaches based on simulations and (when available) benchmark data, while 19 (42.2%) conduct empirical case studies. The lack of further practical analyses is probably due to the fact that, since the idea of implementing lean and green practices together is relatively new, there are not many companies that have already adopted such a combined approach, making researchers to resort to simulations, theoretical analyses and pilot experiments to test their research hypotheses and proposals.

The integration of lean and green practices into a combined approach is a quite complex and challenging task (Hayani et al., 2016), (Garza Reyes, 2015b), (Garza Reyes et al., 2014), (Kurdve et al., 2014). In order to be able to propose a combination strategy capable of integrating lean and green practices in such a way that they can work in a synergetic environment, in the sense that their strengths can be enhanced while their weaknesses can be disguised, it becomes crucial to understand the main similarities and differences between them. From the SLR conducted here, it can be seen that several researchers have focused their attention on studying lean and green practices concurrent and divergent points in order to provide a suitable starting point for developing their combination strategy. In particular, 16 (35.5%) from the 45 articles have been published with this purpose. These contributions are discussed in Section 4.2.3.1. In addition, to be aware of lean and green similarities and differences makes researchers to be able to better evaluate whether both practices can actually be implemented together as well as to study which are the potential benefits of such integration. In fact, several researchers have focused their attention in analysing to what extent lean and green practices, with their similarities and differences, are compatible and can yield improved results when being combined. Contributions in this direction have been found in 15 (33.3%) of the articles selected in the SLR, and are discussed in Section 4.2.3.2.

4.2.3.1 Lean vs. Green Manufacturing: Similarities and Differences

The SLM of Table 4-1 shows that several works (16 (35.5%)) have been presented in the literature studying the main similarities and differences between lean and green practices, concluding (most of them) that both practices are complementary and, to some extent, overlapping. In general, researchers agree that, although lean and green practices do differ in their main objectives, being the former mainly focused on adding value to customers while reducing the resource and time consumptions, and the latter focused on reducing the environmental footprint throughout the whole product life, their main similarity, which is waste reduction, appears to be obvious (Hayani et al., 2016), (Garza Reyes et al., 2014). In fact, according to (Mollenkopf et al., 2010), both practices are aimed at minimising (ideally eliminating) waste, no matter what type of waste they are focused on. Researchers in (Mollenkopf et al., 2010) and (Dües et al., 2012) agree with the observations reported in (Duarte and Cruz-Machado, 2013) and (Garza Reyes et al., 2014). Nevertheless, they further suggest that the different methods for reducing such wastes and, even more important, the different definitions of what wastes are, are indeed the main conflicting points between lean and green practices. In the same line, authors in (Mollenkopf et al., 2010) state that green practices go further than lean ones being concerned not only in waste reduction but also in process efficiency and optimization of raw material consumption. Researchers in (Mollenkopf et al., 2010) also highlight that the main difference between lean and green practices is the waste definition, arguing that while lean practices are focused on workforce and space reduction as well as increasing flexibility and capacity utilisation, green practices are aimed at reducing, reusing, recycling, reworking, returning, and remanufacturing. On the other hand, in (Duarte and Cruz-Machado, 2013) it is argued that, although lean and green wastes definition can differ, lean non-value added activities can be considered as energy and natural resources wastage, associating, in this way, the seven lean wastes with the ones defined within the green manufacturing context. In this same line, (Choudharya, et al., 2018) perform a comparison between lean and green wastes, providing a good summary of their relationship as shown in Table 4-2.

Table 4-2: Synergy between lean and green wastes (Choudharya, et al., 2018)[42].

Lean Waste	Outcome	Green Waste
Overproduction	Storage, excess production time, scrap	Energy
Transportation	Travel, packaging scrap	Transportation, material
Inventory	Storage, raw material scrap (shelf life)	Energy, material
Motion	Time and energy loss	Garbage
Waiting	Time and energy loss	Energy
Defects	Scrap, excess production time	Garbage, material, energy
Over processing	Excess production time	Energy

According to the articles selected in the SLR conducted here, most researchers in the field highlight waste reduction philosophy (Carvalho and Cruz-Machado, 2009), resource productivity, organisational change and source reduction (Mollenkopf et al., 2010), among the main similarities between both practices, while identify their main focus (Johansson and Winroth, 2009), the waste definition (Johansson and Winroth, 2009), the type of customer, the manufacturing strategies, some adopted methods and practices (Mollenkopf et al., 2010) and the EOL strategies (Dües et al., 2012), as their main differences. Finally, in order to further visualise and understand the main similarities and differences reported in the literature, they are summarised in Figure 4.1 and Table 4-2, respectively.

[42] Source: Table based on the one presented in (Choudharya, et al., 2018).

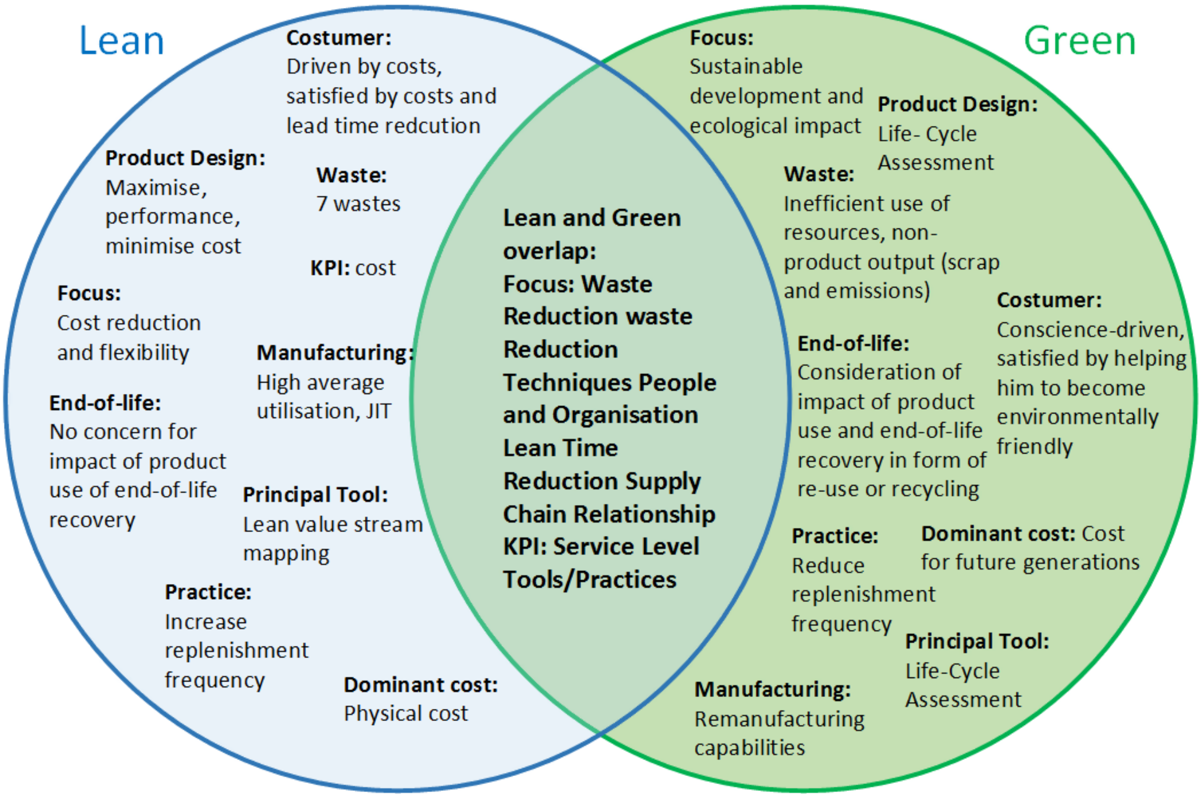

Figure 4.1: Lean and green common points[43].

[43] Source: Diagram based on the one presented in (Ng et al., 2015).

Table 4-3: Lean vs. Green manufacturing[44].

Manufacturing Philosophy	Lean	Green
Main Focus	Increase value to customers while reducing the resource and time consumptions via waste elimination (Ng et al., 2015).	Reduce environmental footprint and minimise health risks throughout the entire product life cycle (Dües et al., 2012).
Basic principles	Lean principles (Deif, 2011): • Long-term thinking • Elimination of wastes • People commitment • Continuous improvements	Green principles are mainly focused on (Womack et al., 1990): • Pollution prevention • Reduction of toxic substances • DfE
Waste	Lean 7 wastes (Mollenkopf et al., 2010): • Transport • Inventory • Motion • Waiting • Over-processing • Over-production • Defects	Green wastes (Choudharya, et al., 2018): • Energy • Water • Material • Transportation • Emissions • Biodiversity • : •
Methods/tools	Well-defined, documented and widely used standard methods and tools (Bashkite and Karaulova, 2012).	Although different tools, such as, LCA, DfE and EOL strategies are widely used, green practices are usually based on customised approaches (Bashkite and Karaulova, 2012).
Product Design	Design is focused in increasing the quality and performance, while reducing costs (Rehman, 2013).	Design, including tools such as DfE, focuses on decrease scrap in many areas of the product life cycle by planning waste reduction from the first stages of the production (Carvalho and Cruz-Machado, 2009).
Inventory	Replenishment frequencies are increased (Carvalho and Cruz-Machado, 2009).	High replenishment frequencies imply higher emissions, so replenishment frequencies need to be reduced (Venkat and Wakeland, 2006).

[44] Source: Compiled by the author.

Pollution	CO2 emission is not reduced (Venkat and Wakeland, 2006).	Reduces any pollution that happens during the production process (King and Lenox, 2001).
Supply chain	Close cooperation with suppliers (King and Lenox, 2001).	Suppliers' involvement is crucial since environmental footprint should be minimised throughout the entire product life cycle including its EOL.
Product EOL	No concern for product use impact or EOL recovery (Dües et al., 2012).	Includes EOL strategies into the product life cycle for which the company is responsible (Dües et al., 2012).
Costumers	Customers are focused on high quality and low priced services and products (Zhang et al., 1997), (Dües et al., 2012).	Customers are focused on services and products that are produced in an eco-friendly way (Bashkite et al., 2011), (Dües et al., 2012).

4.2.3.2 Lean vs. Green Manufacturing: Towards an Integrated Approach

The different opinions discussed in Section 4.2.3.1, show that the discussion about which are the common and conflicting points between lean and green practices is still open. As a consequence, so it is the discussion regarding whether they are actually compatible and suitable to work together. In addition, not only too little empirical evidence of successful cases adopting lean-green approaches can be found in the literature (Bashkite et al., 2011), (Garza Reyes et al., 2014), but also the results that can currently be found are conflicting (Hayani et al., 2016). On one hand, there are researchers that argue that lean and green practices can work together since they can be concurrent generating a synergy regarding waste reduction, energy, material and time consumption, supply chain management and product life cycle optimisation (Garza Reyes, 2015b), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), (Galeazzo et al., 2014). On the other hand, there are the ones that state that lean and green practices are not always compatible, existing some areas where combining them can be particularly hard (Bergmiller and McCright, 2009), (Mollenkopf et al., 2010), (Kleindorfer et al., 2005). For example, the inventory level is one of the most critical aspects when combining lean and green approaches. In this case, while lean practices focus on producing, transporting and packing small lot sizes to fulfil customers' requirements, the high replenishment frequency can imply higher emissions and more packaging wastes, contradicting green principles.

In the SLR conducted here, 15 (33.3%) articles evaluate whether lean and green practices can be implemented together. On one hand, researchers who are reluctant to combine both approaches are concerned about whether lean practices, which are focused on waste reduction from the customers' added value perspective, optimising cost, quality and lead times, will still be profitable after incorporating green practices towards environmental objectives which are not always in line with lean objectives. In this line, authors in(Johansson and Winroth, 2009), suggest that the main strategic challenge consists in deciding how to implement green practices in combination with lean ones, without diminishing the potential profitability achieved by the latter, while being able to keep the balance between economic, environmental and social performances. Moreover, in (Nunes and Bennett, 2010) it is stated that, within a combined framework, lean practices will not always be able to limit the negative impact on operational aspects that green practices could have, being also true the other way around. Finally, in (Garza Reyes, 2015a), authors also state that lean-green approaches will have to face the same challenges that lean and green practices have to face when implemented individually. For instance, in (Garza Reyes et al., 2014), it is highlighted that, as it is usually the case of green practices, in order to implement the lean-green approach, practitioners should have to resort to customised approaches, while in (Kumar and Sanchez Rodrigues, 2018), it is stated that one of the main barriers for the implementation of the lean-green approach is the fact that a huge investment in equipment is required.

On the other hand, there are many researchers that agree that, although lean and green manufacturing approaches are not completely compatible and do differ in their main focus, to be aware of their similarities and differences and, even more important, to be capable of handling them, can indeed give practitioners the opportunity to improve both methods so that they can efficiently match. Moreover, in (Joseph, 2019), a case study conducted on a Brazilian large multinational company, shows that synergetic effects can emerge even if lean and green practices are applied in different areas, with no joining strategy. In Figure 4.2, the synergetic model introduced in (Campos and Vazquez-Brust, 2016) is shown. Then, taking into account that, according to (Campos and Vazquez-Brust, 2016), lean and green practices can be synergetic even when being implemented without a combination strategy, researchers who favour the integration have further studied their compatibility (beyond their similarities and differences), evaluating to what extent lean and green practices can be synergetic, in such a way that they can obtain better performance when being implemented together than when summing their individual performances. In this way, researchers intend to be able to propose joining strategies capable of generating the synergetic effect, taking advantage of it, and further potentiating its results.

According to (Campos and Vazquez-Brust, 2016), the synergetic hypothesis is suitable since there exist a similar structure for the implementation of successful lean and green practices. In this line, in the SLR conducted here 14 (31.1%) articles address the compatibility from the synergetic point of view. In (Dawood and Abdullah, 2017), authors state that companies looking for being lean will have more success if they also seek green objectives. In the same line, several researchers in the field who have largely discussed about “how green can be lean”, such as the ones in (Bergmiller and McCright, 2009) and (Dhingraa et al., 2014), have concluded that, since lean practices are not aimed at green objectives, they cannot replace green practices towards achieving green results, but they can provide a continuous improvement, flexible and employees’ engagement culture creating a suitable and highly favouring environment for the implementation of green initiatives. Authors in (Venkat and Wakeland, 2006), agree with them, stating that the lean culture can be a catalyst for green practices, facilitating the adoption of environmental practices. Moreover, a particular example of such catalytic effect can be found in (Dües et al., 2012), where it has been proved that the impact of lean practices on operational supply chain performance can be improved by preventing pollution and recycling. According to (Wiengarten et al., 2013), lean and green practices can generate sequential or reciprocal interactions, supporting each other, working in a complementary and synergetic environment. In (Galeazzo et al., 2014), the synergetic effect generated by lean and green practices has proved to achieve several benefits, such as, fostering innovations and reducing the production costs of eco-friendly products. Finally, in (Kumar and Sanchez Rodrigues, 2018), empirical evidence shows that, in order to actually reach the beneficial synergetic effect between lean and green practices, it is necessary to customise some operational aspects of the company as well as to ensure fluent collaboration with suppliers.

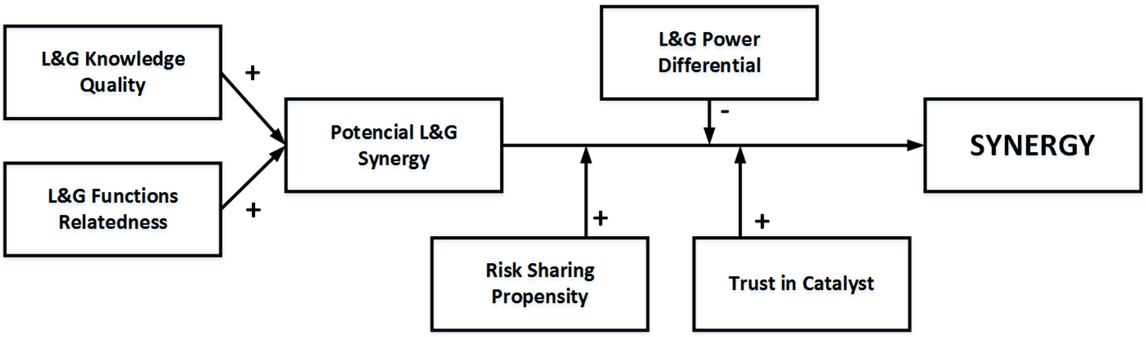

Figure 4.2: Synergetic model in (Campos & Vazquez-Brust, 2016).

Finally, Figure 4.3 graphically depicts how different lean and green techniques can complement each other towards achieving the expected synergetic effect capable of leading to a continuous improvement.

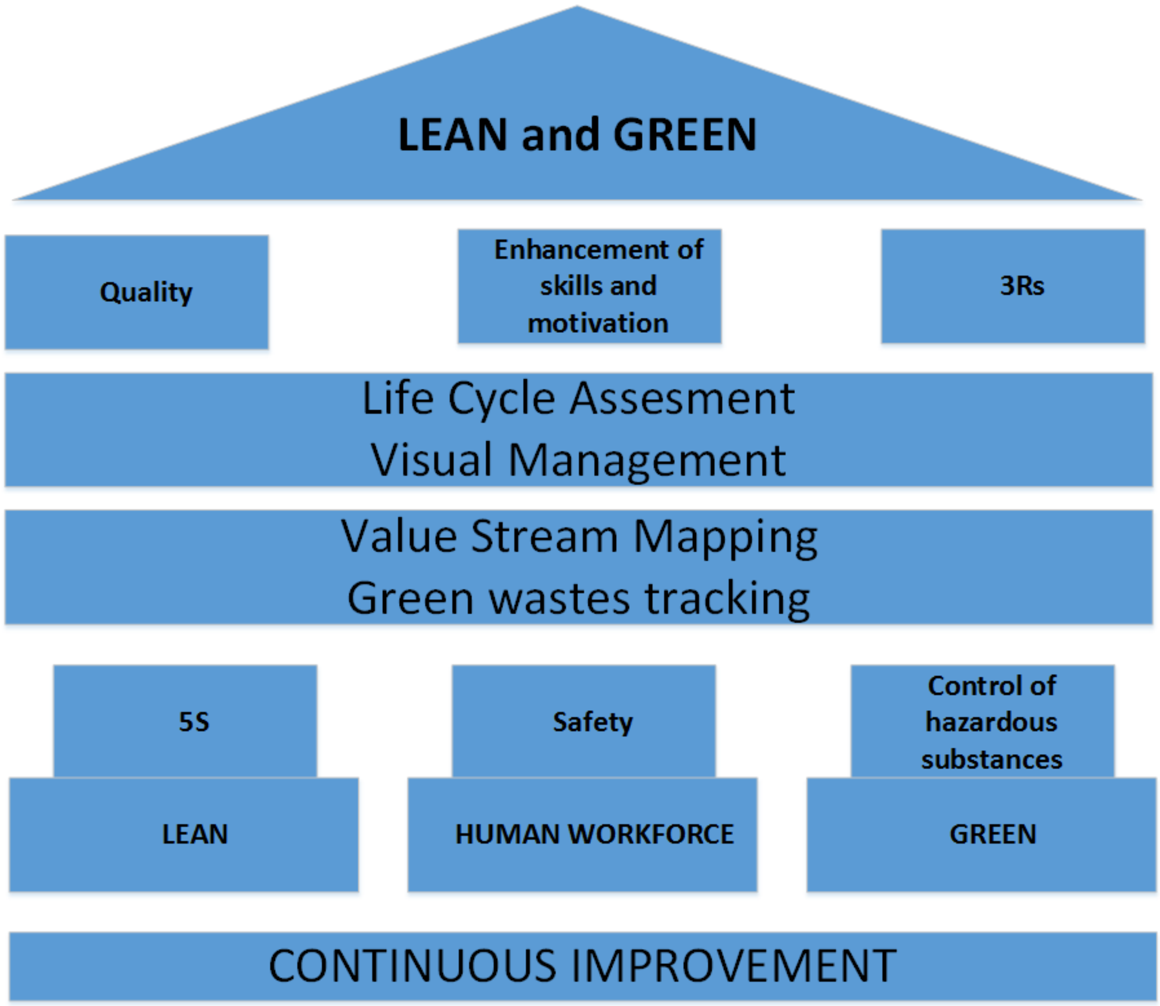

Figure 4.3: Lean and green techniques synergy (Verrier, et al., 2015)[45].

4.2.4 Lean-Green Approach: State-of-the-art Implementations

Although the synergetic effects of implementing lean and green practices in an integrated environment have been demonstrated by several researchers in the field (Kumar and Sanchez Rodrigues, 2018), (Wadhwa, 2014a), (Larson and Greenwood, 2004), (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), the practical implementation of such a combined approach is a quite complex and challenging task that has not been yet investigated deeply enough (Wu et al., 2015), (Garza Reyes, 2015b), (Kurdve et al., 2014), (Garza Reyes et al., 2014). In fact, although several researchers recommend the integration of lean and green practices towards reaching further sustainability improvements, they also agree that there is a lack in the literature of suitable integration and combination strategies (Hayani et al., 2016). In particular, according to authors in (Kurdve et al., 2014), the research gap is still deeper due to the lack of sustainability metrics. In addition, most of the current proposed approaches in the literature are

[45] Source: Based on the figure introduced in (Verrier, et al., 2015).

customised since, as in the case of green practices being implemented individually, lean-green approaches are also aimed at fulfilling particular needs of the companies, related with local culture, policies and regulations.

In order to fill the above mentioned research gaps and provide some insight towards the actual implementation of lean-green combined approaches, several efforts have been done in recent years to develop and implement these kinds of manufacturing approaches. The SLR conducted here, confirms this tendency including 21 (46.6%) articles where different approaches have been proposed to implement the combination of lean and green practices. In general, researchers agree that different combination schemes, such as, sequential and parallel, can be adopted to integrate lean and green practices(Kurdve et al., 2014). In this line, there are the ones that propose to combine them into a new, single and stand-alone lean-green approach (Galeazzo et al., 2014), (Bashkite and Karaulova, 2012), (Bergmiller and McCright, 2099), (Rosenbaum et al., 2012), (Yasutaka and Tawara, 2006), (Fercoq et al., 2013), (Hayani et al., 2016), (Salleh et al., 2012), (Thanki et al., 2016), while there are others that, based on the fact that lean practices are not only well-documented but also widely (and successfully) adopted all over the world, as well as that the lean culture do favour the implementation of green initiatives, propose to use an already stablished lean environment as a catalyst to the adoption and further incorporation of green practices (Cobra et al., 2015), (Pampanelli et al., 2014), (Chiarini, 2014), (Ng et al., 2015), (Dhingraa et al., 2014), (Venkat and Wakeland, 2006).

Within the first group, waste management methods, like Waste Reducing Techniques (WRT), are the most used strategies to perform the combination (Dües et al., 2012), (Bergmiller and McCright, 2099), (Bashkite and Karaulova, 2012), (Fercoq et al., 2013), (Kurdve et al., 2014). In (Cobra et al., 2015), a combined approach based on the Theory of Inventive Problems-Solving tools, is presented. Researchers in (Bashkite and Karaulova, 2012), assume that green and lean practices have mutually exclusive design requirements, and propose to combine them into the same system based on a waste contradiction matrix. In (Bashkite and Karaulova, 2012), a waste minimisation framework based on an advanced 3R (Reduction-Reuse-Recovery) method, is proposed. In addition, although there is a strong tendency of using waste management methods, some other approaches have been proposed to address the combination from the first group's perspective. In (Fercoq et al., 2013), the multiple attribute utility theory method is used for assessing a lean-green supply chain. In (Yasutaka and Tawara, 2006), a Green Lean Total Quality (GLTQ) Information Management System, which is an Information Management (IM) system within the context of an Environmental Management System

(EMS), integrated to TQM and lean principles, is proposed. In this way, authors in (Salleh et al., 2012) intend to achieve total communication efficiency based on a green-lean TQM system, demonstrating that the proposed approach allows generating more revenues and also providing Research & Develop facilities. In (Salleh et al., 2012), a combined lean-green approach based on the integration of management systems, such as ISO 9001 and 14001, is proposed. In (Kurdve et al., 2014), an Analytical Hierarchical Process (AHP) is used to integrate TPM and ISO 14001principles into a lean-green combined framework. In (Thanki et al., 2016), a case study is conducted on different Alsatian industrial companies in order to develop a lean-green management framework based on lean indicators as well as green performance and intentions indicators.

Within the second group, several researchers have proposed to incorporate green practices to manufacturing processes that have already adopted a lean philosophy. In this line, one of the most frequently proposed approaches consists in taking advantage of the flexible nature of lean practices by modifying and adapting them so that they can work in combination with green practices towards the same objectives. In particular, the most frequently reported adapted lean tools are VSM ((Verrier et al., 2014), (Rosenbaum et al., 2012), (Pampanelli et al., 2014)) and Continuous Improvements principles (Folinas et al., 2013). In (Wadhwa, 2014b), the implementation of lean and green practices combined within a continuous improvement culture in a SME foundry is studied. In (Wadhwa, 2014b), VSM is adapted to address environmental and production wastes. In (Rosenbaum et al., 2012), the VSM tool is proposed for determining waste, in terms of measuring the carbon dioxide emissions particularly across organisational boundaries within the context of a food industry. In (Folinas et al., 2013), a green-lean business model based on five principles, *viz.*, stable value stream, identification of environmental impacts, measurement and improvement of the environmental value streams, and CIs, is developed for a global engineering company. In (Pampanelli et al., 2014), a novel metric integrating metrics derived from lean and green implementations. Experimental results in (Ng et al., 2015) show that the proposed approach is capable of reducing the carbon footprint by improving not only the Carbon-Value Efficiency but also the production lead time.

In Figure 4.3, the most relevant contributions towards the integration of lean and green practices, in terms of the main proposed approaches, their objectives and their main impacts on the companies’ performance, are shown. Here, it is important to highlight that, although lean as well as green practices do include activities that can be implemented throughout different areas of the company, addressing different stages of the productive process, the articles selected in the SLR show a strong tendency of implementing and evaluating the lean-green approach within the context of supply chain management (Ng et al., 2015), (Dües et al., 2012), (Yasutaka and Tawara, 2006), (Bortolini et al., 2016), (Campos and Vazquez-Brust, 2016), (Mollenkopf et al., 2010), (Wiengarten et al., 2013). In fact, although there are the ones that reports the combination of both practices to address other manufacturing issues, such as, metrics (Folinas et al., 2013), (Ng et al., 2015), quality (Verrier et al., 2014), (Kurdve et al., 2014), safety (Yasutaka and Tawara, 2006), lead time (Kurdve et al., 2014), customer service (Yasutaka and Tawara, 2006), cost (Yasutaka and Tawara, 2006), inventory (Yasutaka and Tawara, 2006) and transportation (Dawood and Abdullah, 2017), there exists the necessity for more research regarding the different production stages (Dawood and Abdullah, 2017). Finally, in (Rosenbaum et al., 2012) and (Garza Reyes et al., 2014) it is stated that there is a lack in the literature regarding empirical evidence of practical implementation of the combined lean-green approach. In order to fill this gap, among the 21 (46.6%) articles proposing strategies for implementing the lean-green combination, 9 (20%) have report results obtained by the lean-green implementation within real manufacturing scenarios from different countries all over the world, such as, construction projects (Hayani et al., 2016), metal stamped parts production (Rosenbaum et al., 2012), Swedish industry (Ng et al., 2015), food industry (Kurdve et al., 2014), part production in the automotive sector (Folinas et al., 2013), Chinese Fashion AutoParts industry (Diaz Elsayed et al., 2013) and SME foundry (Wu et al., 2015). In (Wadhwa, 2014b), authors go even further, presenting the results obtained by implementing the proposed lean-green approach in different companies, with different sizes and operating in a different business areas, giving researchers in the field benchmark data allowing them to expand their approaches to other companies and manufacturing sectors.

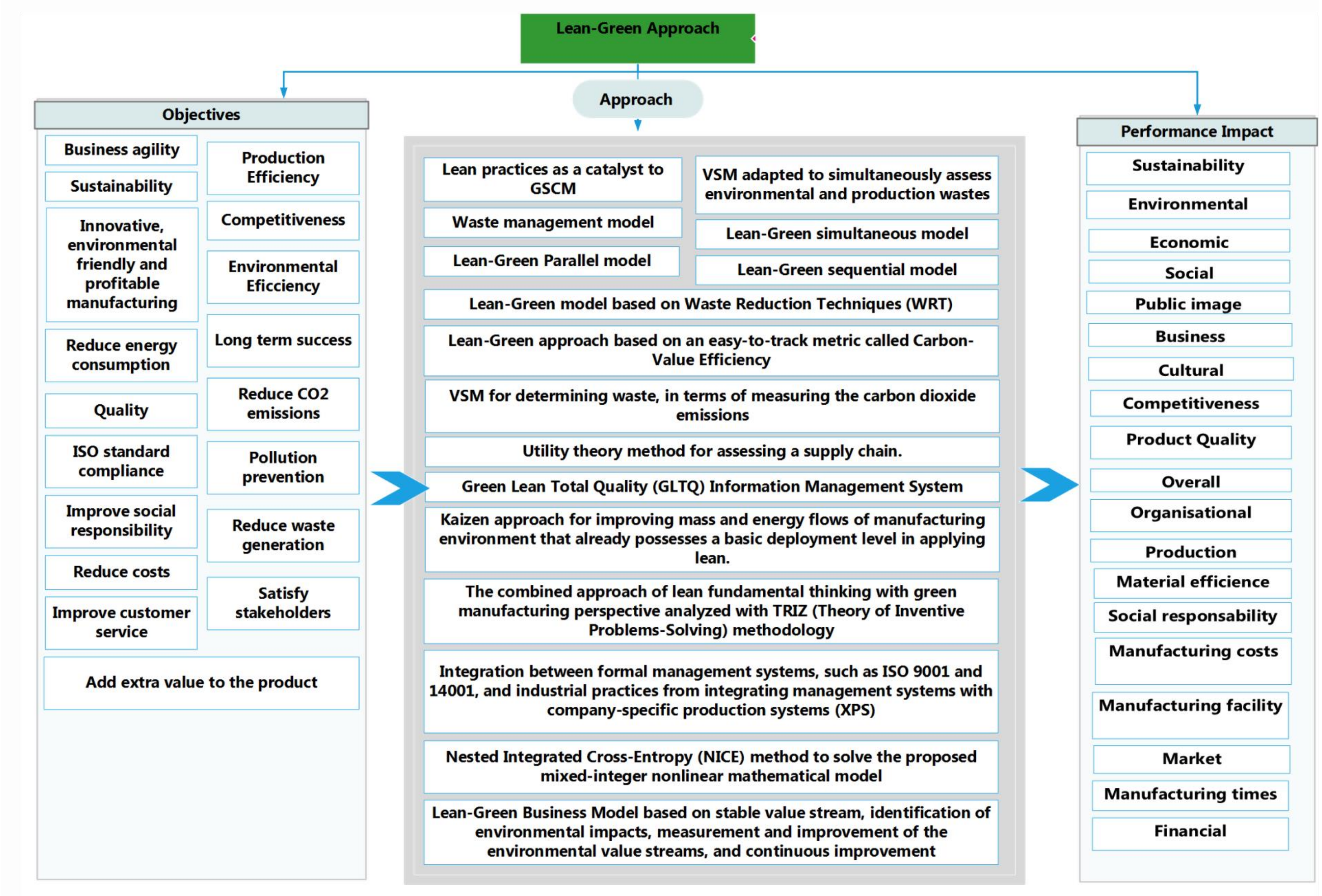

Figure 4.4: Summary of the proposed lean-green approaches in the SLR: Main concerns, proposed approaches, and their performance impact.

4.3 Lean-Green Approach and its Link with Sustainability

In recent years, companies have tried to move towards more sustainable manufacturing practices, in terms of economic, environmental and social aspects. In Chapters 2 and 3, in-depth analyses have been carried out for lean and green practices as well as for their link with sustainability, respectively. On one hand, these analyses have shown that lean practices are, by nature, mainly focused in operational (Hayani et al., 2016), (Chunguang et al., 2018), (Khanchanapong et al., 2014) and financial (Belekoukias, 2014), (Hofer et al., 2012) aspects, while being capable (to some extent) of contributing towards environmental (Camuffo and Gerli, 2014), (Fliedner, 2008) , (Alves Pinto Junior and Veiga Mendes, 2017) and social (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018) performances. On the other hand, green practices are, also by nature, highly focused on environmental aspects (Bortolotti et al., 2015), (Alonso et al., 2017), (Thoo et al., 2015), (Cagno et al., 2005), as well as capable of reaching improvements in the social performance (Govindrajulu and Daily, 2004), (Alonso et al., 2017), being their impact on economic aspects highly called into question, existing the ones that consider green practices can actually lead to economic improvements (Hicks and Dietmar, 2007), (Zhu and Sarkis, 2004), (Bohringer et al., 2008), (Miroshnychenko et al., 2017), and the ones that consider them as a burden for operational and financial aspects. In this context, although several efforts have been done towards improving sustainable aspects from the lean (Rao and Holt, 2005), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013) as well as from the green (Chiappetta Jabbour et al., 2013), (Sezen and Cankaya, 2013), (Acharya et al., 2014), (Trivedi and Sharma, 2017), (Dangelico et al., 2016), (Thoo et al., 2015), (Thoo et al., 2014), (Tseng et al., 2013), (Sun et al., 2003), (Manley et al., 2008) perspective, several researchers agree that neither lean nor green practices are enough to ensure sustainable results when being implemented individually (Xu et al., 2008), (Rajive et al., 2014), (Peto, 2012), (Hayani et al., 2016). Then, the need for new strategies towards reaching a superior level of sustainability arises. In this line, several researchers have proposed the idea of integrating lean and green practices, taking simultaneous advantage of their positive impacts on each of the three pillars of sustainability, while smoothing their negative impacts (if any), as the natural next step towards a higher level of sustainability.

Based on the above discussion, it can be noticed that, unlike lean practices, that are mainly aimed at operational and financial aspects, and green practices, that are mainly aimed at environmental aspects, the idea of a lean-green approach has indeed been born to address the three pillars of sustainability simultaneously. In this way, it can be said that the lean-green concept is tightly linked with sustainability, being sustainability its main focus and objective. In this line, it seems natural that most of the works in the literature addressing the lean-green approach measure their performances in terms of sustainability improvements. In particular, in the SLR conducted here, most of the selected articles (30 (66.6%) out of the 45) explicitly report results in terms of the companies' sustainability performances. In general, the authors of these articles agree that, provided the synergetic effect is achieved, the green-lean approach can lead to improvements on economic, environmental and social performances simultaneously (Marhani et al., 2013), (Pampanelli et al., 2014), (Chiarini, 2014), (Ng et al., 2015), (Verrier et al., 2014), (Kurdve et al., 2014), (Wadhwa, 2014a), (Garza Reyes, 2015b), (Wu et al., 2015). Moreover, in (Aguado et al., 2013) it is stated that the integration of lean and green practices into a combined approach is the key aspect towards achieving a superior sustainability performance.

In (Hayani et al., 2016), it is stated that, to fully address sustainability aspects, it is crucial to develop standard and benchmark sustainability metrics. In fact, only 3 (6.6%) of the 30 selected articles explicitly reporting results in terms of sustainability performance, address the performance analysis from a quantitative perspective by defining new metrics related with sustainability aspects (Kurdve et al., 2014), (Ng et al., 2015), (Yasutaka and Tawara, 2006). In (Verrier et al., 2014), a carbon-value efficiency metric is defined to measure the performance of a metal stamped parts production process, showing improvements in terms of the carbon-value efficiency, production lead time and carbon footprint. In (Ng et al., 2015), the multiple attribute utility theory method is proposed to measure the performance of supply chains in terms of managerial and environmental performances. In (Yasutaka and Tawara, 2006), a lean-green management framework is developed on the basis of lean and green indicators, allowing companies to benchmark their lean and green practices. Finally, in (Verrier et al., 2014) it is further highlighted that, for the sake of succeeding in the implementation of lean-green approaches, companies not only need to have access to benchmark sustainability metrics, but they also to fully consider operational, cultural and business opportunities.

The SLR conducted here shows that, in recent years, promising sustainability results have been reported in the literature when implementing the combined approach. Moreover, many of these results have been obtained within the context of real manufacturing scenarios, suggesting that several efforts have been done towards filling the research gap highlighted in (Kurdve et al., 2014) and (Garza Reyes et al., 2014) regarding the lack of empirical evidence of successful lean and green integration cases in the real manufacturing scenario. In this line, in the SLR conducted here, 19 (42.2%) articles evaluate the potential and actual sustainability performance improvements that the lean-green approach implementation can achieve within real manufacturing scenarios, such as, the construction of a hospital, within the particular application of a structural concrete work stage (Hayani et al., 2016), an European motorcycle component manufacturer (Rosenbaum et al., 2012), a Swedish industry (Chiarini, 2014), a food industry supply chain (Kurdve et al., 2014), an Indian automotive sector (Folinas et al., 2013), a Chinese Fashion AutoParts suppliers (Diaz Elsayed et al., 2013), a metal stamped parts processes (Wu et al., 2015), Alsatian industrial companies(Ng et al., 2015), a Portuguese automaker (Verrier et al., 2014) and a SME foundry industry (Azevedo et al., 2012), among others, reporting many successful cases. In particular, articles in the SLR report results either from literature reviews based on case studies, surveys and empirical research evaluating the synergetic effect between lean and green practices, or from empirical evidence obtained from the actual implementation of novel proposed lean-green approaches. Among the literature reviews, studies conducted within the Indian automotive SME industry have reported improvements regarding productivity, by constantly enhancing the business efficiency and effectiveness, when combining lean and green practices (Wadhwa, 2014b); while studies conducted within the context of foundry SMEs, suggest that lean and green management strategies should be implemented in a continuous improvement context in order to achieve sustainable continuous improvements (Tiwari and Tiwari, 2016). Regarding the survey case studies, in (Wadhwa, 2014b), empirical results evaluating the lean and green synergetic effects within the supply chain are reported based on survey data collected by the *Global Manufacturing Research Group*[46] in European countries. In (Wiengarten et al., 2013), the analysis of three pollution-prevention projects implemented by two large multinational companies have been conducted, concluding that lean and green practices can generate a synergetic effect. In (Galeazzo et al., 2014), semi-structured interviews with interdisciplinary teams responsible of integrating lean and green practices in two manufacturing companies in the UK, are conducted, showing that, to achieve synergetic effects, it is usually required to customise the companies' operational profile as well as to ensure collaboration with suppliers. In addition, authors in (Kumar and Sanchez Rodrigues, 2018), highlight that environmentally-friendly products are easier and cheaper to produce when applying the lean-green approach. In Table 4-3, the main success factors pointed out by researchers reporting the promising results discussed here

[46] https://gmrg.org/

regarding sustainability performance based on the implementation of the lean-green approach are summarised.

Table 4-4: Critical success factors for implementing the green-lean approach.

Success factor	Source
The lean-green approach implementation should be gradual, allowing companies to set priorities, and identify key goals.	(Kumar and Sanchez Rodrigues, 2018)
Operational roles and responsibilities need to be broadened to include sustainability issues.	(Hayani et al., 2016)
Sustainability metrics should be developed.	(Kurdve et al., 2014)
There is a need for openness of employees, stakeholders, customers, leaders and suppliers towards innovation.	(Kurdve et al., 2014)
Effective information management is crucial towards reaching sustainability improvements.	(Salleh et al., 2012)
Management commitment is crucial for achieving sustainability standards.	(Salleh et al., 2012)
A lean working environment, consisting in trained, engaged and committed employees, as well as continuous improvements culture, favours the implementation of green initiatives in combination with lean practices towards sustainability.	(Dües et al., 2012), (Dües et al., 2012)
Customer focus and integration is crucial to achieve sustainable results.	(Salleh et al., 2012), (Bashkite and Karaulova, 2012)
A key aspect towards implementing innovative lean-green approaches is to ensure system and process change management.	(Dües et al., 2012)
Effective planning is needed towards combining lean and green practices in a synergetic way.	(Kumar and Sanchez Rodrigues, 2018)
Team and end-to-end supply chain integration is crucial to achieve sustainable results.	(Kumar and Sanchez Rodrigues, 2018), (Dües et al., 2012), (Yasutaka and Tawara, 2006), (Bortolini et al., 2016), (Campos and Vazquez-Brust, 2016), (Mollenkopf et al., 2010), (Wiengarten et al., 2013)
It is usually needed to customise the lean-green approach in order to fulfil the particular needs of the companies.	(Folinas et al., 2013), (Kumar and Sanchez Rodrigues, 2018)

The adoption of a continuous improvement culture is crucial towards implementing a lean-green approach and obtaining sustainable results.	(Ng et al., 2015)
Benchmarking of suppliers against each other can help to implement lean-green strategies more efficiently.	(Wadhwa, 2014b)
Strong communication and coordination between different sectors is crucial for being able to implement the lean-green approach.	(Verrier et al., 2014)
Evaluation and review of performance and progress towards targets can lead to improvements in the sustainable results.	(Salleh et al., 2012), (Kurdve et al., 2014)
Wide understanding, acceptance and adoption of lean and green concepts are needed towards being able to actually implement them together in a synergetic way.	(Ng et al., 2015), (Garza Reyes, 2015b), (Mollenkopf et al., 2010), (Dües et al., 2012), (Duarte and Cruz-Machado, 2013)
Understanding of lean contributions towards implementation of green initiatives helps to take advantage of lean culture as a catalyst for green practices.	(Venkat and Wakeland, 2006), (Dües et al., 2012), (Rajive et al., 2014)

4.4 Main Findings and Research Gaps from the Lean-Green Manufacturing SLR

The analysis of the information gathered from the SLR conducted in theis chapter has provided an in-depth insight into the actual possibilities of effectively implementing them lean and green manufacturing together, the main strategies currently proposed to do so, and the reported results in terms of sustainability performance. Based on them, the findings and research gaps summarised in Table 4-5 and Table 4-6 and, respectively, have been identified.

Table 4-5: Main research findings.

Findings	Sources
Although lean and green manufacturing systems can be similar, there exist several disagreeing	(Mackenzie and Knipe, 2006), (Franchetti et al., 2009), (Dües et al., 2012), (Garza Reyes et al.,

points between them. In particular, their main focus, the waste definition and the customer target, can be mentioned. In this context, although lean organisational culture can help to enhance the green results obtained by implementing green practices, there are some lean objectives that are in conflict with green ones, making their combination into a single approach to be a quite complex and challenging task.	2014), (Mollenkopf et al., 2010)
Green practices are mainly focused on the environment, while lean sometimes perceives environmental issues as a problem for products, services, designs and production processes.	(Ng et al., 2015)
Designing products based on lean principles increases the product quality while reduces the production costs. Green manufacturing focus on decreasing scrap during the whole product life cycle, by planning and designing for the environment from the first stages of production.	(Garza Reyes et al., 2014)
Although green and lean approaches have different methods for eliminating waste, they can focus at the same wastes, by extending the 7 lean wastes to address wastes from the green perspective, such as, air emissions and solid, hazardous and water wastes.	(Carvalho and Cruz-Machado, 2009)
The replenishment frequency (associated with the inventory level) is a critical aspect towards combining the lean and green approaches. From a lean perspective, the replenishment frequency should be high in order to fulfil customers' requirements, while for a green perspective, a high replenishment frequency imply higher emissions, so this frequency have to be reduced.	(Bashkite and Karaulova, 2012)
Lean and green manufacturing have different target customers. On one hand, lean manufacturing focuses on minimising non-value added activities from the customers' perspective; while, on the other hand, green manufacturing is targeted at the ethics of customers, being aimed at customers that are willing to consume services	(Venkat and Wakeland, 2006), (Bashkite and Karaulova, 2012)

and products that are produced in an eco-friendly way.	
CO_2 emissions are not necessarily reduced by lean practices, while green practices reduce any pollution that may occur during the production process.	(Dües et al., 2012), (King and Lenox, 2001)
Lean methods and tools are well-defined, documented, standard and widely used. On the other hand, green practices are usually based on customised approaches.	(Galeazzo et al., 2014)
Although literature about lean and green practices implemented individually abounds, there is a lack of further research regarding combination strategies.	(Bashkite and Karaulova, 2012), (Garza Reyes, 2015b)
Further research needs to be conducted to provide empirical evidence supporting the combination of lean and green approaches within the real manufacturing scenario.	(Ng et al., 2015), (Garza Reyes et al., 2014)
Most of the proposed lean-green approaches are based on waste management techniques.	(Hayani et al., 2016), (Bergmiller and McCright, 2099), (Bashkite and Karaulova, 2012), (Fercoq et al., 2013), (Kurdve et al., 2014)
In general, practitioners will have to resort to customised methods to be able to combine lean and green practices.	(Cobra et al., 2015)
Most of the proposed lean-green approaches are focused on the supply chain area.	(Kumar and Sanchez Rodrigues, 2018), (Dües et al., 2012), (Yasutaka and Tawara, 2006), (Bortolini et al., 2016), (Campos and Vazquez-Brust, 2016), (Mollenkopf et al., 2010), (Wiengarten et al., 2013)
SVM is the most adapted lean tool to address green objectives.	(Folinas et al., 2013), (Rosenbaum et al., 2012), (Pampanelli et al., 2014)
There exists the necessity for more research regarding the lean-green approaches focused on the production stage.	(Folinas et al., 2013)
The continuous improvement-based waste elimination lean culture creates a favourable platform to address environmental issues.	(Rosenbaum et al., 2012), (Dües et al., 2012), (Dhingraa et al., 2014)

Employee, suppliers, local community, and customer environmental conscious highly influence the firms' environmental and social performances.	(Venkat and Wakeland, 2006), (Dües et al., 2012), (Dhingraa et al., 2014)
Lean and green practices can efficiently be implemented together since they have the same structure and they are synergetic.	(Venkat and Wakeland, 2006), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), (Galeazzo et al., 2014)

Table 4-6: Research gaps.

Research gaps	Sources
Although plenty of research regarding the lean and green practices being implemented together can be found in the literature, since their integration into a single approach is quite a complex task, there is still too much research to be conducted in this direction.	(Bergmiller and McCright, 2009), (Garza Reyes, 2015a), (Kurdve et al., 2014)
It is still not clear in the literature to what extent and how lean tools are able to help towards reducing manufacturing environmental impacts when it seems to be a conflict of interests between environmental performance and cost, quality, and time performances.	(Hayani et al., 2016), (Garza Reyes et al., 2014), (Peto, 2012), (Nunes and Bennett, 2010), (Kumar et al., 2015)
Lean looks to the wastes definitions from a time and cost perspective and not from an environmental point of view. This means that new definitions should be covered for the waste types according to the status of the manufacturing firm, in order to show more hidden sources of waste.	(Joseph, 2019)
A framework or a model is required to measure the depth of the existing gap between companies' capabilities for achieving lean and green objectives before designing a green-lean manufacturing approach. In this way, the proposed combined approach would be able to address the problem and fill this gap in a smooth way.	(Nicholas, 2010)

It is unclear in the literature how an optimum lean-green approach can be developed in a conflicting environment between lean and green practices.	(Hayani et al., 2016), (Garza Reyes et al., 2014), (Nunes and Bennett, 2010), (Kumar et al., 2015)
Hybrid balanced solutions are needed to be considered in order to achieve the required outcomes from the lean-green approach.	(Joseph, 2019), (Bashkite and Karaulova, 2012), (Bergmiller and McCright, 2099), (Rosenbaum et al., 2012), (Yasutaka and Tawara, 2006), (Fercoq et al., 2013), (Hayani et al., 2016), (Salleh et al., 2012), (Thanki et al., 2016)
There is a need for developing standard and widely used performance metrics, in particular, regarding environmental as well as social aspects. This results in a further lack of sustainability metrics.	(Cobra et al., 2015), (Kurdve et al., 2014)

4.5 Chapter Summary

Despite the promising results highlighted in Chapters 2 and 3 regarding the important contributions of lean and green practices towards sustainability, respectively, researchers have concluded that lean and green implementations as stand-alone systems are usually not enough to ensure the required balance between the three pillars of sustainability, suggesting further combining them into a single approach. In this way, researchers expect to achieve further improvements in the sustainability performance moving towards the next level of sustainability. In this chapter, the actual possibility of implementing the lean-green approach has been evaluated. On one hand, the analysis of the concurrent and divergent points between both practices as well as the synergetic effects they can achieve when being implemented together have been analysed. On the other hand, the main challenges reported in the literature regarding their combination have also been discussed. Then, the main currently proposed strategies to actually implement the lean-green approach within a combination framework have been introduced and, finally, the link of the combined lean-green approach with sustainability has been explored by analysing the different sustainability performance results reported in the literature, in terms of economic, environmental and social performances. In general, despite the great challenges faced by practitioners when practically implementing the lean-green combined approach, the theoretical and empirical promising results reported in the literature demonstrate that lean and green practices can generate a synergetic atmosphere when being implemented together, in the sense that their strengths can be enhanced and their weaknesses can be disguised, suggesting that the lean-green combined approach is the natural step towards achieving more sustainable manufacturing systems capable of keeping the balance among the three sustainability pillars, *viz.*, economic, environmental and social, simultaneously.

In Chapter 5, the research methodology framework employed to conduct the research within the context of this thesis is described. In particular, each of the research steps and decisions involved in the chosen research process is explained in detail.

5 RESEARCH METHODOLOGY

5.1 Introduction

In (Venkat and Wakeland, 2006), research is defined as an investigation based on logical relationships where data is collected, analysed and interpreted towards giving an in-depth insight into a particular phenomenon. In general, research is conducted to investigate facts by describing, explaining, understanding, criticising and analysing them, to reconfirm (or refute) previous results, to solve already existing and new issues, to support theories, and to suggest further research directions, among many other purposes (Burns, 1997), (Oberiri, 2017). All of these actions involve creative thinking which should be carried out in a systematically and replicable way (Ghauri and Grønhaug, 2002). In order to do so, the research design as well as the methodological framework supporting the implementation of such designed research should be defined. The research design provides the researcher a well-defined plan for implementing the research strategy, in terms of research sites, and data collection procedures (MacMillan & Schumacher, 2001). The research methodology, on its part, provides the researcher the systematic approach to conduct the designed research plan within a particular paradigm or theoretical framework, setting the fundamental basis for investigating the addressed problem using the proposed research design, as well as the set of rules that should be employed to actually implement the selected research methods and procedures (Saunders, et al., 2000), (Creswell, 2014).

In this thesis, the research is designed based on an exploratory approach. In particular, the exploratory approach is well-suited for conducting research within the context of problems that, although having been studied before, are still open, having no definitive and clear definitions or conclusions (Easterby-Smith, et al., 2015). This is, in fact, the case of lean-green manufacturing, confirming the suitability and applicability of this design approach to the conducted research. In addition, the exploratory approach allows the researcher to define the addressed problem more precisely, establishing research priorities and a clear research plan towards better understanding the problem, providing useful insights, identifying relevant issues and gaps, and developing new ideas.

In order to decide which methodological approach is the best suited for the conducted research, different factors, such as its relevance to the research project and its replicability should be considered (Jankowicz, 2013), (Walter, 2006). According to (Mackenzie and Knipe, 2006), there is a plethora of literature proposing different methods for addressing the research design, being sometimes even confusing to select the best suited one. In such a context, it is crucial to deeply understand the research problem as well as the main aims of the conducted research in order to be able to select the most suitable research methodology to address it. In this line, the significance, motivation, focus and main objectives of the conducted research discussed in Chapter 1 are revisited, and the main research questions are formulated in Section 5.2. Once these key aspects of the conducted research have already been established, the researcher is in the position to select the research methodology employed to conduct his research.. In this thesis, the highly popular onion model proposed by (Somekh and Lewin, 2005) is used to explain the followed research methodology. The onion model, which is one of the most popular approaches in the business area (Saunders et al., 2000), provides the researcher a useful framework to plan the way in which he is going to conduct his research, having the advantage of being flexible, easy to adapt to almost any type of research and any kind of context. In the practice, the research is conducted following a series of steps which, within the context of the onion model, can be associated with the "onion layers" allowing the researcher to take a progressive and smooth path towards achieving the research objective based on peeling the onion off from the outer layers (associated with general issues, such as framing the conducted research within a research philosophy) to the inner ones (associated with more specific issues, such as data collection, processing and analysis). Specifically, the conducted research will be explained in terms of the research philosophy, approach, strategy, methods, time horizons, and techniques, as shown in Figure 5.1. In this way, using at the onion model as a research guideline, the researcher is allowed to clearly explain each of the steps he takes during his research, detailing and justifying the main decisions and actions taken in each of them, so that other researchers can replicate it.

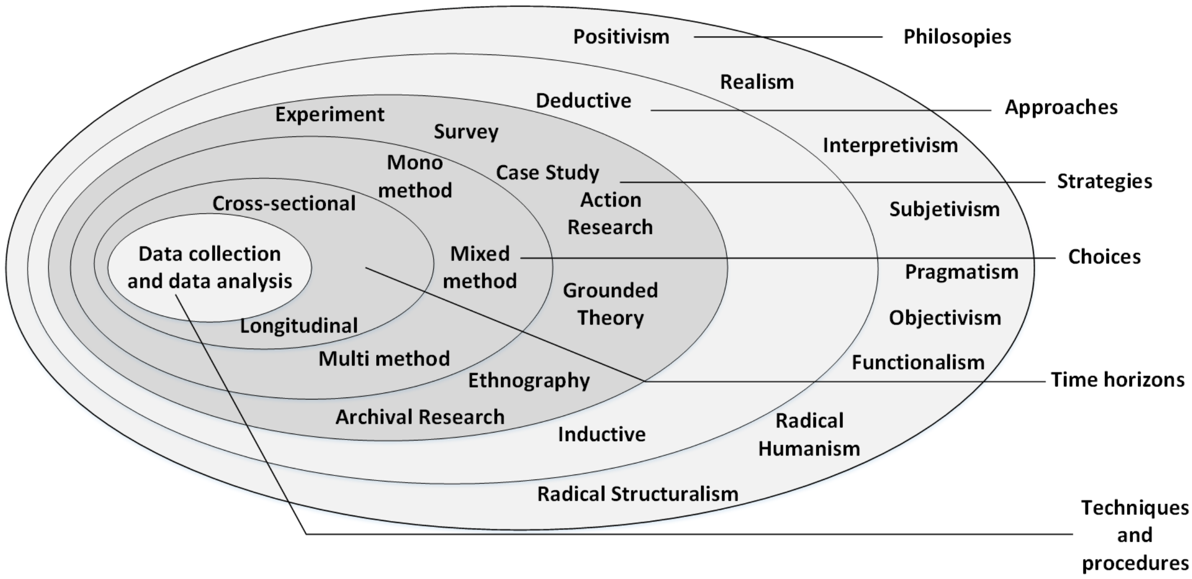

Figure 5.1: Research onion model(Saunders et al., 2000)[47].

The remaining of the chapter is organised as follows. Revisiting the motivations, aims and objectives of the conducted research presented in Sections 1.2 and 1.3, respectively, the research questions are summarised in Section 5.2. In Section 5.3, the used research plan and methodology is described in terms of the different layers in the onion model. In particular, the employed research philosophy, approach, strategy, methods, time horizon and techniques are described, and the main decisions and choices made for each one of them are discussed. Finally, the chapter summary is provided in Section 5.4.

5.2 Research Questions

To actually combine lean and green approaches is a complex and challenging task (Saunders et al., 2000), (Garza Reyes, 2015b), (Kurdve et al., 2014), (Garza Reyes et al., 2014). The conducted research is aimed at developing a new framework capable of combining lean, green and lean-green approaches in a synergetic and efficient way in order to achieve a superior sustainable performance keeping the balance among economic, environmental and social performances simultaneously. Then, the main research question that the conducted research aims to answer is:

“Which is the most efficient strategy to combine lean, green and lean-green approaches towards achieving simultaneous improvements in economic, environmental and social performances?”

In order to be capable of answering this question, the conducted research should allow the researcher to answer previous questions associated with the main question, such as:

[47] Source: Based on the scheme presented in (Saunders et al., 2000).

- *Which are the current trends in lean and green manufacturing and their link with the different aspects of sustainability?*
- *To what extent are these practices (lean and green) actually implemented in the real manufacturing scenario? Which benefits have been reported? Which barriers have practitioners encountered?*
- *Which are the currently available and implemented lean-green strategies and their link with sustainability?*
- *Which are the best strategies or theories to combine different manufacturing approaches?*

The conducted research and, thereby, the selected methodology to conduct it, is intended to answer each one of the above listed questions towards finally answering the main research question and being able to achieve the research objectives.

5.3 Methodological Approach

As discussed in Section 5.1, the conducted research is designed based on an exploratory approach. Given its fundamental nature, exploratory research often relies on techniques including the analysis of secondary data, such as available literature, especially literature reviews, and public or corporate statistical data, as well as primary data, consisting in qualitative and quantitative approaches, such as surveys, in-depth interviews and case studies (Hox & Boeiji, 2005). This is actually the case of the conducted research in this thesis since, in order to deeply explore and understand the lean-green manufacturing situation, the researcher needs to gather data from different sources. In particular, in this thesis, the research is conducted as follows. In a first stage, secondary data regarding the current trends in lean, green and lean-green manufacturing practices is collected by a literature review. Using secondary data allows the researcher not only to identify what has already been done in the field, but also to explore new relationships and patterns within the existing data towards pointing out research gaps and future research directions (Vartanian, 2011). Based on the analysis of the secondary data, a set of hypotheses is developed regarding how lean, green and lean-green approaches can contribute towards improving sustainability in terms of economic, environmental and social performances. Based on these hypotheses, a new manufacturing framework (model) is designed integrating lean, green and lean-green approaches. Finally, primary data is collected via a survey carried out in different Saudi manufacturing companies towards testing the proposed hypotheses in order to validate the proposed combined manufacturing framework. The use of primary data is expected to lead to further and new insights and, being collected directly by the researcher, provide greater confidence in the obtained outcomes (Creswell, 2014).

5.3.1 Research Philosophy

The research philosophy reflects the researchers' perception and thinking, constituting the conceptual framework setting the basis for the beliefs and assumptions that support the researchers' work towards achieving their research objectives (Saunders et al., 2000), (Holden and Lynch, 2004). In this line, researchers should choose the research philosophy which provides them the best tools to deal with the sources and development of his research (Guba and Lincoln, 1994). In addition, the selection of the research philosophy should not be only based on theoretical and conceptual issues but, since it has many practical implications, it should be also based on practical issues. There exists plenty of research in the literature to help researchers to understand and decide which is the best suited research paradigm and philosophy for their particular research (Bajpai, 2011), (Gibson and Gareth, 1979), (Eastman and Bailey, 1996), (Holden and Lynch, 2004), (Hirschman, 1986), (Tuli, 2010). The main research philosophies within the business and management fields are positivism, interpretivism, realism and pragmatism (Taylor, 2008). In this thesis, a pragmatic framework, which is highly focused on actions, situations, and consequences, being mainly concerned with applications and solutions, is adopted. The suitability of pragmatism to the conducted research relies in the fact that this research philosophy allows the researcher emphasizing the research problem giving him the freedom of using all the available approaches, methods, techniques, procedures and data collections based on the particular research needs and purposes, towards understanding it and deriving new knowledge about it (Saunders, et al., 2000), (Creswell, 2014).

5.3.2 Research Approach

The reseacrh approach determines the way in which researchers intend to deal with the testing facts and the research findings in order to reach their conclusions. The research approach can be classified into deductive and inductive as shown in Figure 5.2. The deductive approach is a top-down approach consisting in developing a theory, followed by formulating hypotheses, collecting and analysing the data, to finally accepting (or refuting) the formulated hypotheses. In this way, the deductive approach allows the researcher to obtain empirical evidence of the studied phenomenon (Tashakkori and Teddlie, 1998). The inductive approach, on the other hand, is a bottom-up approach, moving in the inverse direction, starting with the observation of the phenomenon, followed by the analysis of the different found patterns and themes towards establishing their relationship (if any), to finally arrive at the development of a theory (model).

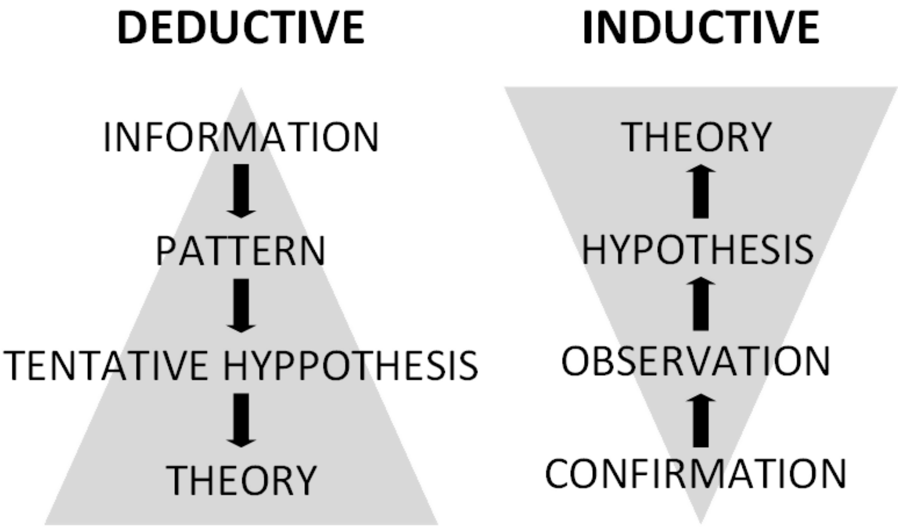

Figure 5.2: Deductive and inductive research approaches[48] .

The particular purpose of the research and how it is carried out are the main aspects to be considered when deciding whether to use an inductive or deductive approach. In general, the inductive approach is mainly used to address the qualitative aspect of the research, in the sense that the researcher begins with observations, proceeds with generalizations, and finally arrives at the revealing of the paradigm. According to the research flow described in Section 5.1, the conducted research which begins with the observation of the phenomenon by collecting secondary data (literature review), follows with the analysis of the found patterns to establish their relationship and develop a model (manufacturing framework), and ends with the manufacturing framework validation based on the primary data collected via a survey, is framed within the inductive approach. The inductive approach has the advantage of being based on a more flexible structure than the deductive one, providing the researcher the freedom to change the research emphasis whenever he deems it necessary according to the research progress. This flexibility is fundamental when analyzing data from different sources, and constitutes an important advantage for the conducted research, allowing the researcher to handle the

[48] Based on the scheme available at: https://www.google.com/imgres?imgurl=https%3A%2F%2Fs-media-cache-ak0.pinimg.com%2F736x%2F41%2F66%2F67%2F4166671a879b8bcebb472b7c291853fd.jpg&imgrefurl=http%3A%2F%2Fdanahollowayfilmandtv.blogspot.com%2F2015%2F12%2Fdeductive-and-inductive-research.html&docid=dR0rlO7a7y1efM&tbnid=riKCvCdHfLx2ZM%3A&vet=10ahUKEwj00LCk-dThAhWlJrkGHdp8DFkQMwg8KAQwBA..i&w=436&h=235&bih=675&biw=1517&q=deductive%20and%20inductive%20approach&ved=0ahUKEwj00LCk-dThAhWlJrkGHdp8DFkQMwg8KAQwBA&iact=mrc&uact=8

different challenges and unexpected issues that can occur when carrying out the survey in the real manufacturing scenario. Finally, when conducting inductive research seeking to generalize results from observations (which are usually quite specific), it is important to take into account that the resulting inferences are not always accurate enough, having the inductive approach the disadvantage of being more limited, in terms of accuracy, than the deductive approach (Creswell, 2014).

5.3.3 Research Strategy

Several research strategies have been proposed in the literature. Figure 5.3 shows some of the most used ones as well as the methods and tools associated with each one of them.

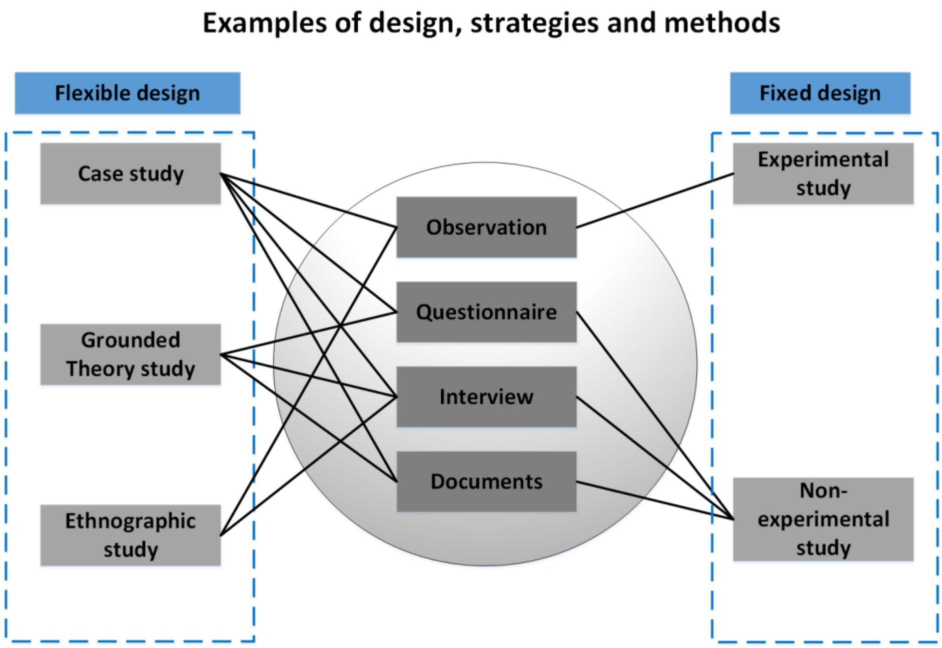

Figure 5.3: Research strategies[49].

In general, the selection of the research strategy is highly based on practical issues, such as, the previous existing knowledge, the available amount of time and data, and the accessibility of the potential participants (Hussey and Hussey, 1997). The conducted research can be associated with a traditional research design, relying on a literature review leading to a set of hypotheses used to develop a model which is finally validated based on experimentation in the real scenario. In this thesis, the experimentation within the real world is performed based on a survey strategy, which is one of the most popular research strategies in the business field (Saunders et al., 2000). The survey is conducted to help the researcher to successfully answer his research questions regarding the

[49] Source: Based on the scheme available at: http://archive.learnhigher.ac.uk/collectthis/main/desstrat3.html

currently implemented lean and green practices, their link with sustainability aspects, and the practitioners' awareness of the need (and actual possibility) for combining them towards improving the sustainability performance. One of the most important reasons for choosing the survey strategy is the fact that it allows the researcher to generalise his findings. This is crucial for the conducted research since the results obtained from the questionnaire need to be capable of generalisation so that the proposed manufacturing framework can be properly validated based on them. Here, it is important to highlight that, in this stage, a case study strategy would also be possible to be implemented. Whether resorting to one, another or both strategies, depends not only on their pros and cons but also on the available time and resources. Within the context of the conducted research, the survey strategy has been selected due to several reasons. On one hand, it provides higher capability of generalisation, which is crucial for the reliability and validity of the proposed manufacturing framework. On the other hand, it provides more freedom to analyse the data once it has already been collected, which is fundamental when having resource and time constraints, as it is the case of the conducted research. In addition, it has the great practical advantage of being easy to distribute, allowing a wide number of respondents to be reached. Moreover, since surveys can be made via email or any social media platform, it is easier to reach more respondents, building larger population samples, obtaining a better generalisation of the results.

5.3.4 Research Choices

Two different methods, namely, quantitative and qualitative, can be chosen to conduct the research. On one hand, qualitative methods are mainly exploratory, being used to understand reasons, opinions and motivations, allowing the researcher to actually be involved in the experience and perform a highly detailed analysis. In general, qualitative research collects data by using unstructured or semi-structured techniques, such as, focus groups and individual interviews, and analyses data by procedures, such as, categorizing data, that support non-numerical data (Saunders, et al., 2000). On the other hand, quantitative research is focused on systematically studying a phenomenon by gathering quantifiable data (numbers) that can be analysed resorting to statistical, mathematical or computational techniques (Saunders et al., 2000). Quantitative data collection methods are usually highly structured, including different types of surveys, such as, online, paper and mobile ones.

Researchers have largely discussed about the pros and cons of using quantitative or qualitative research methods (Creswell, 2003), (Johnson and Christensen, 2000), (Punch, 2000), (Shaffer, 1989), (Williams, 2007), (Ochieng, 2009). In Table 5-1, a summary of the main strengths and weaknesses of each one of them is shown. The research conducted in this thesis includes the analysis of secondary data collected by SLRs, which is a qualitative analysis, as well as the analysis of primary data collected by a survey, which can be performed either resorting to a qualitative or a quantitative approach. The aim of the conducted survey is to validate the proposed lean-green manufacturing framework, being crucial for the analysis of the collected data to provide an in-depth insight into the practitioners' personal experiences when implementing lean and green practices, their perceptions about the different sustainability aspects improved by these practices and their feelings regarding how they should be integrated into a combined manufacturing framework. In this line, the survey data collection and analysis is mainly conducted via a qualitative approach which allows exploring in detail the views of the participants. In particular, the survey includes both close-ended (Likert scale) questions as well as open-ended (textual) questions. On one hand, close-ended (Likert scale) questions allows for and easier and less time-consuming data collection and analysis, at the expense of providing less detail. On the other hand, open-ended (textual questions) give the survey participant more freedom to answer, containing more detailed information, at the expense of harder and more time-consuming data collection and analysis. It is also the researcher's intention to conduct interviews with experts to further analyse the textual answers to the open-ended questions.

Table 5-1: Quantitative vs. Qualitative methods: Strengths and weaknesses (Greene et al., 1989) [50]

	Strengths	Weaknesses
Quantitative	• Quick and cheap • Simple • Helpful when used as a prelude for qualitative research	• Subjectivity • Requires skills for interpretation • Bias could be high • Statistical accuracy can be reduced
Qualitative	• Better accuracy • Detailed results • Allows calculating the margin of error • Good range for prediction	• Slow • Relatively expensive • Complexity • Low response rate

Although the conducted research is mainly qualitative, the researcher is well aware of the fact that qualitative and quantitative methods can support each other, and their combination can help to address the research problem from multiple perspectives,

[50] Source: Based on the table presented in (Marsh et al., 1988).

positions and viewpoints, providing a wider perception and more flexibility to the research. In addition, within the adopted pragmatist framework, which supports combining different methods and techniques, the use of qualitative and quantitative methods in a collaborative context is a suitable choice (Oberiri, 2017), (Teddlie and Tashakkori, 2009), (Bryman, 2006), (Yauch and Steudel, 2003). In this line, in this thesis a quantitative approach is also carried out to analyse the collected data from the survey in order to support the qualitative findings by providing a different analysis perspective and allowing numerical evaluation when needed. In addition, using both methods allows the researcher drawing general conclusions through triangulation, increasing the validity of the study, as well as checking the accuracy of the findings by validating data, *i.e.* analyzing its convergence; complementing data in terms of further explaining the obtained results; and developing data, *i.e.* collecting, sampling or analyzing further data (Teddlie & Tashakkori, 2009), (Bryman, 2006).

5.3.5 Time Horizons

Depending on the available time and the purpose of the research, researchers can choose to conduct cross-sectional research, where different variables are evaluated at a particular point in time, or longitudinal research, where it is possible to analyse different variables at different intervals of time in order to observe changes across the time (Marsh et al., 1988). The main aim of the conducted research is to give an in-depth insight into the current trends and the actual practical situation of lean, green and lean-green practices within the real manufacturing scenario. In this context, since the conducted research is aimed at studying the current picture, to conduct a cross-sectional approach is enough to achieve the research objectives.

5.3.6 Techniques and Procedures

As introduced in Section 5.1, in this thesis the research has been conducted following three main steps:

- Secondary data collection and analysis:
    - Three different SLRs about lean, green and lean-green are carried out.
    - The data collected from the SLRs is analysed in order to identify different patterns and research gaps.
- Development of the lean-green manufacturing framework:

    - Different hypotheses regarding how lean, green and lean-green practices can collaborate to each other and how they influence in the different sustainability aspects of the company, are derived.
- Primary data collection:
    - A survey including closed- and open-ended questions is held in different Saudi manufacturing companies.
    - A qualitative analysis of the collected data is performed towards identifying useful patterns and generating knowledge that can help to validate the proposed lean-green manufacturing framework.
    - A quantitative analysis of the collected data is also performed to support the results obtained from the qualitative analysis giving a different point of view.

In order to ensure the data collected via the conducted survey is statistical significant, as well as to ensure the obtained results from the corresponding data analyses are acceptable, valid, meaningful and, even more important, generalizable, it is mandatory to validate the performed survey (Saunders et al., 2000). In this line, the questions included in the questionnaires used for collecting the data are validated for assessing their dependability. This validation process includes, on one hand, the pre-process of the collected data from the questionnaires in order to properly prepare it to be analysed and, on the other hand, the data analysis based on carefully selected statistical methods so that the reliability of the results can be ensured (Collingridge, 2014). In order to do so, the researcher follows the six steps suggested in (Collingridge, 2014):

- Face validity: The survey is reviewed by two different parties. On one hand, the questions included in the questionnaire are reviewed by experts in the research field capable of evaluating whether they are suitable for successfully capturing the research interest in order to give an in-depth insight into the current lean and green manufacturing situation within the real scenario. On the other hand, the questionnaire is evaluated by an expert on question construction, in order to eliminate common errors, such as, leading, confusing or double-barrelled questions.
- Pilot test: In this stage a pilot study is run on a separated sample of the survey participants to detect irrelevant or poorly formulated questions so that they can be replaced, eliminated, or reformulated.

- Clean collected data: In order to be able to analyse the collected data, the data is pre-processed according to the following steps:
    - Data entering: In order to minimise the risk of errors, one person reads the values aloud while another enters them into the spreadsheet.
    - Reverse code negatively phrased questions: Whether responses from careful respondents evidence a correspondence between negatively and positively phrased questions is evaluated.
    - Minimum and maximum values are double-checked for all the collected data to find errors in data entry.
- Use Principal Components Analysis (PCA): The main aim of this step is validating what the survey is actually measuring. In the conducted research, a PCA analysis is used to identify the underlying elements measured by the survey, determining the most representative themes addressed by the questions. The particular selection of the PCA analysis relies in the fact that PCA is a simple, efficient and non-computationally expensive statistic tool, capable of representing large sets of data by smaller and easier-to-digest ones that can be more rapidly and readily analysed. In this way, only the most important (principal) elements of the survey are left to be further analysed, avoiding the analysis of unnecessary elements.
- Check Internal Consistency: In this step, the internal consistency of the questionnaire is evaluated through the standard Cronbach's Alpha (CA) test, in order to test the reliability of the questions as well as to ensure their answers are consistent.
- Revise the survey: The final step consists in revising the survey based on the results of the PCA and CA analyses to decide whether to eliminate or reformulate questions that do not belong to the principal themes or that are not consistent.

5.3.7 Summary of the Adopted Research Methodology

In this thesis, the conducted research is aimed at filling the research gaps regarding the actual lean-green combined approach implementation within the real manufacturing scenario by providing researchers and practitioners creative tools towards achieving the currently required levels of sustainability keeping the balance among economic, environmental and social performances. The methodological approach followed to do so can be summarised as follows:

- The research is conducted within the pragmatist philosophy. In this way, the researcher has the freedom to focus on the research problem and resort to different approaches to collect the data.
- The research is conducted in an inductive way, begining with the observation of the phenomenon by collecting secondary data (SLRs in Chapters 2, 3 and 4), following with the analysis of the found patterns to establish their relationship and develop a model (lean-green manufacturing framework), ending with the manufacturing framework validation based on the primary data collected via a survey held in different Saudi manufacturing companies.
- The conducted cross-sectional survey, includes close- and open-ended questions. The reliability of the conducted survey is validated following the steps suggested in (Collingridge, 2014).
- The primary data collected by the survey is analysed mainly based in a qualitative approach. In this way, the researcher is allowed to identify patterns from the practitioners perceptions, feelings and personal experiences regarding lean and green applications, their benefits, limitations, how can they be implemented together and how they can contribute to the different aspects of the companies' sustainability performance. In addition, a quantitative analysis is also perfomed of the primary data in order to complement the qualitative analysis by providing a different perspective and allowing numerical evaluation when needed.

5.4 Chapter Summary

Research methodology is the systematic approach used by researchers to conduct their research within a particular paradigm or theoretical framework (Collingridge, 2014) in order to solve the research problem. In this chapter, the research methodology adopted to conduct the present research has been introduced, each one of its stages has been described, and the particular research choices that have been made towards achieving the conducted research objectives have been discussed.

In Chapter 6, the proposed combination framework for combining lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and disguising their weaknesses, for the sake of achieving the currently required level of sustainability, in terms of economic, environmental and social aspects, is introduced.

6 THEORETICAL FRAMEWORK

6.1 Introduction

In Chapters 2, 3 and 4 SLRs have been conducted on the current trends in the literature regarding lean, green and lean-green practices, paying special attention on their link with each of the three pillars of sustainability performance, *viz.*, economic, environmental and social ones, depicted in Figure 2.13. Based on the analysis of the gathered information via the conducted SLRs, the research gap regarding the lack of lean-green combination approaches in the literature has been highlighted. In fact, although some examples of lean-green solutions have been found, such as the ones based on waste management methods (Dües et al., 2012), (Bergmiller and McCright, 2099), (Bashkite and Karaulova, 2012), (Fercoq et al., 2013), (Kurdve et al., 2014), or the ones using lean culture as a catalyst of green practices (Cobra et al., 2015), (Pampanelli et al., 2014), (Chiarini, 2014), (Ng et al., 2015), (Dhingraa et al., 2014), (Venkat and Wakeland, 2006), most of them are highly customised aimed at fulfilling particular needs of the companies, related with local culture, policies and regulations. In addition, in most of the analysed cases, the influence of the proposed approach on the companies' sustainability performance has not been extensively studied. In this chapter, a novel theoretical manufacturing framework is developed based on the different patterns that have been identified in the SLRs of Chapters 2, 3 and 4 towards combining lean, green and lean-green approaches within a synergetic environment. The main objective of the proposed approach is to provide reseacrhers and practitioners a solid theoretical basis to properly and advantageously combine them. In addition, the proposed manufacturing framework has the advantage of being generic and flexible, providing the possibility of being adapted to any manufacturing context by selecting the best suited lean, green and lean-green techniques in each case. Finally, it is important to highlight that, although the practical implementation of the proposed lean-green theoretical manufacturing framework is out of the scope of this thesis, a survey is conducted in different Saudi manufacturing companies in order to test and validate the developed theoretical framework and give some insight into its applicability. This survey is expected to give the researcher valuable information to set the basis for future research directions towards actually implementing the proposed lean-green manufacturing framework in a real world company.

The remaining of the chapter is organised as follows. In Section 6.2, the proposed theoretical framework is presented. In Section 6.3, the main constructs (variables) involved in the proposed theoretical framework, *viz.*, the lean and green practices, the considered sustainability performances (economic, environmental and social), and the control variables are introduced, a brief theoretical background on each one of them is provided, and the nature and direction of the relationship among them is explained. Section 6.4 provides an overview of the theoretical perspectives that underlay the proposed theoretical framework. Section 6.5 presents the research hypotheses described in the theoretical framework. Finally, in Section 6.6 the chapter summary is provided.

6.2 Theoretical Framework Overview

In this section, the theoretical manufacturing framework proposed for combining lean and green practices towards achieving a superior level of sustainability is introduced. In particular, the proposed theoretical framework has been developed by following the methodology described in Chapter 5, further summarised in Figure 5.4. In Figure 6.1, a flowchart showing the different steps followed to develop the proposed theoretical framework is depicted. According to this flowchart, the first step in the process is to collect data by conducting the SLRs presented in Chapters 2, 3 and 4 regarding the current trends in lean, green and lean-green practices, respectively, making special focus on their actual impacts on sustainability aspects. Then, the collected data is processed and analysed in order to identify the relevant findings and the current research gaps in the field presented in Table 4-5 and Table 4-6, respectively. On one hand, how lean and green practices contribute individually to the economic, environmental and social performances has been studied. On the other hand, how their interaction can contribute to such performances has also been studied. Based on them, different research gaps have been identified pointing out the most concerning issues that the manufacturing framework should help to address. In addition, relevant patterns have also been identified allowing setting the basis for the theoretical framework design. More specifically, based on the SLRs analyses, different hypotheses regarding how lean, green and lean-green approaches can contribute towards improving sustainability in terms of economic, environmental and social performances, are set towards supporting the theoretical lean-green manufacturing framework. These hypotheses and their interactions are then modelled and combined into the theoretical manufacturing framework. Once the theoretical framework has already been developed, a survey is conducted within the Saudi manufacturing scenario to collect data towards testing the proposed hypotheses in order to validate it. As a result of the described process, illustrated in the flowchart of Figure 6.1, the theoretical manufacturing framework presented in Figure 6.2 is proposed.

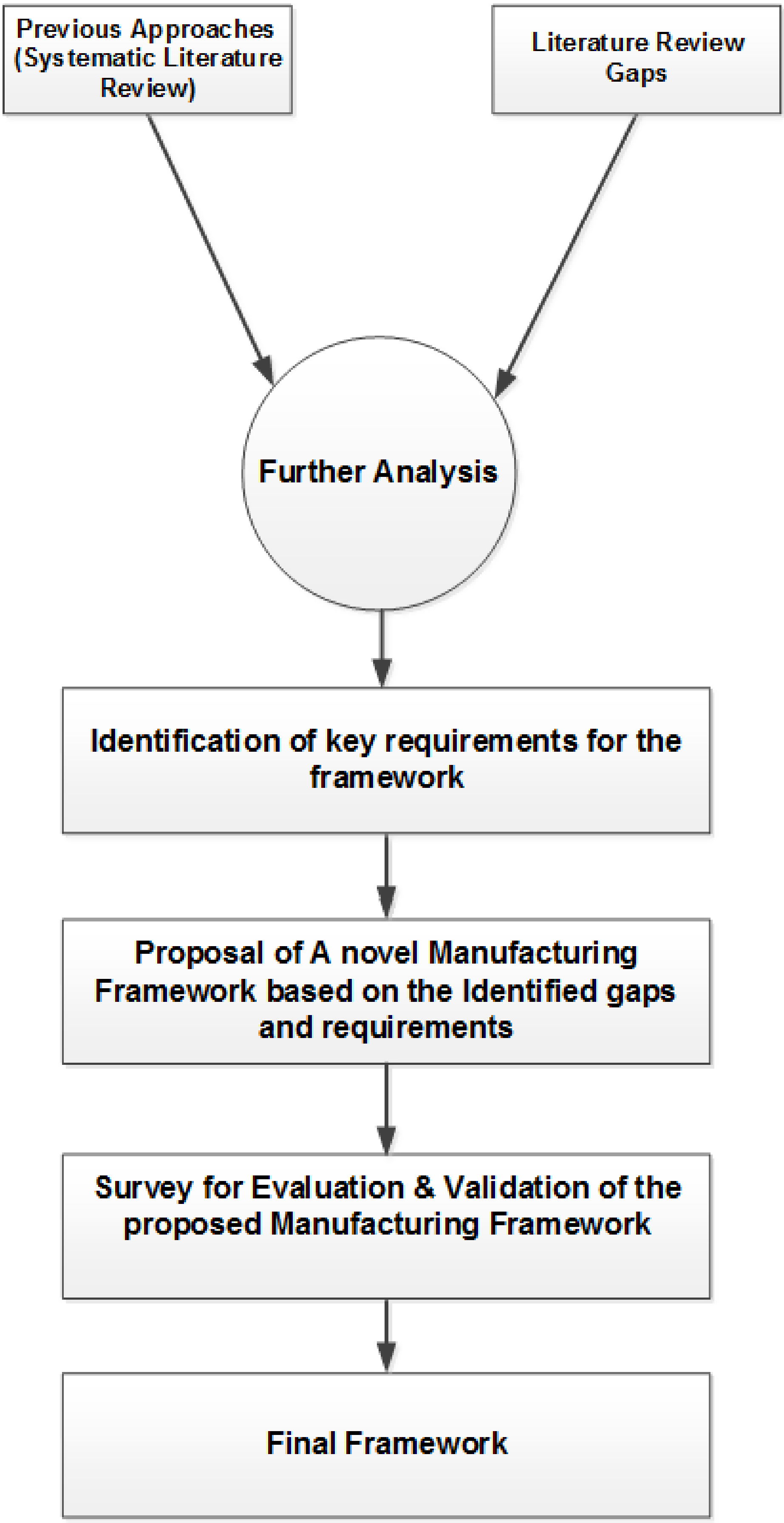

Figure 6.1: Flowchart of the theoretical framework development.

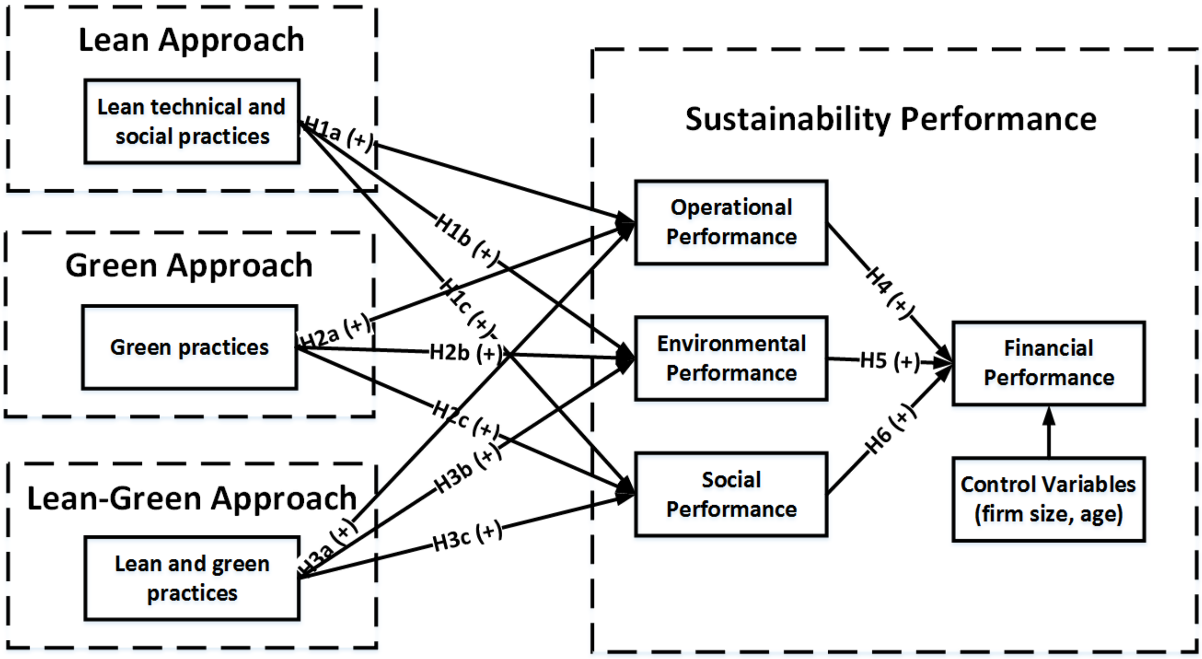

Figure 6.2: Proposed theoretical manufacturing framework.

The proposed manufacturing theoretical framework is aimed at establishing the relationship between lean, green and lean-green practices, and the firms' sustainability performance. As throughout the whole analysis conducted within the context of the present research, the TBL concept of sustainability, first introduced by (Ng et al., 2015) and depicted in Figure 2.13, is used to model the sustainability performance in terms of economic, environmental and social performances. In addition, within the proposed framework context, the economic performance is broken down into two types of performances, namely, operational and financial performances. Once the sustainability model has already been set, how each one of the considered manufacturing practices, *viz.*, lean, green and lean-green ones, contributes to it is taken into account. In this line, on one hand, based on the discussion carried out in Chapter 2, the theoretical framework suggests that lean practices (both social and technical ones) can positively influence operational (Elkington, 1998), (Chunguang et al., 2018) environmental (Belekoukias, 2014), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), social (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018) and financial performances (Bortolotti et al., 2015), (Hofer et al., 2012). On the other hand, based on the discussion carried out in Chapter 3, the proposed framework suggests that green practices can also positively influence operational (Camuffo and Gerli, 2014), environmental (Zhu and Sarkis, 2004), (Alonso et al., 2017), (Thoo et al., 2015), (Cagno et al., 2005), social (Govindrajulu and Daily, 2004), (Alonso et al., 2017) and financial performances (Hicks and Dietmar, 2007), (Bohringer et al., 2008), (Miroshnychenko et al., 2017). In this context, where lean as well as green practices are capable of positively influencing each of the considered aspects of the sustainability performance, the next question arises: how to efficiently combine them, in the sense of enhancing their strengths while mitigating their weaknesses towards achieving the next level of sustainability (Rao and Holt, 2005)?

The logic of the complementary theory advances that the interaction effect of the parts of a system is greater than the effect of the sum of individual parts. This so-called synergy phenomenon, is due to the fact that each part of the system may be deficient on its own, in the sense that is only able to cover one aspect of the work of the system, and therefore, each part will need to be complemented by other part (at the same time that will complement it) (Garza Reyes, 2015b). Based on this idea, several researchers have particularly study the synergic nature of lean and green practices (Latash, 2008), (Kumar and Sanchez Rodrigues, 2018), showing that both practices can be concurrent in the sense that implementing them together can effectively generate a synergy regarding waste reduction, energy, material and time consumption, supply chain management and product life cycle optimisation (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), (Galeazzo et al., 2014), (Garza Reyes, 2015b), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Bortolini et al., 2016). Based on the promising results in the literature regarding the lean and green practices synergy, the idea of using the complementary theory principles regarding synergy as one of the pillars of the proposed manufacturing framework arises (Pampanelli et al., 2014), (Ketchen and Hult, 2011), (Yakimtsov, 2015). In this line, the proposed theoretical framework suggests that both lean and green practices should be implemented together in order to realise higher level and simultaneously improvement of the operational, environmental, social and financial performances, as shown in Figure 6.2.

In addition, the proposed framework is also supported by the Socio-Technical System (STS) theory (Martin Holubčík and Jakub Soviar, 2016), which has already been studied within the context of lean (Sadok and Welch, 2017), (Dankbaar, 1997), (Niepce and Molleman, 1998) and green (Raja, 2011) manufacturing. Moreover, several researchers have proposed the implementation of different STS theory principles to make the transition towards more sustainable manufacturing obtaining promising results (O'Neill and Gibbs, 2014), (Lawhon and Murphy, 2011). According to the STS theory, any system consists in sub-systems that interact among each other, highlighting that the success of complex systems, such as firms, is only reached based on the proper interaction between social and technical aspects. Then, based on the STS theory principles regarding the interdependency and interaction between social and technical practices as a crucial aspect towards improving the firms' performance as well as the complementary theory principles regarding the synergy that these practices can achieve, the proposed theoretical framework intends to enhance the combined (socio-technical effect) implementation of lean (both technical and social) and green (by nature combining technical and social aspects) practices by potentiating (synergy effect) their strengths and disguising (complementary effect) their weaknesses.

Based on the STS and synergy theories, the theoretical manufacturing framework presented in this chapter propose to model the contributions of lean, green and a combined approach of lean-green practices to the different considered aspects of sustainability, *viz.*, operational, environmental and social aspects, by a set of hypotheses, H1a, b and c, H2a, b and c, and H3a, b and c, respectively, as shown in Figure 6.2. In addition, the proposed conceptual framework suggests that these contributions are translated to the final financial performance of the company via the contributions of the operational, environmental and social performances modelled by the hypotheses H4, H5 and H6, respectively. Finally, several works in the literature demonstrate that specific demographic variables of the firms, such as, size and age, can also have an influence in their sustainability performance, acting as regulation variables (O'Neill and Gibbs, 2014), (Kipesha, 2013), (Artin et al., 2015), (Trencansky and Tsaparlidis, 2014), (Majumdar, 1997). In this context, it is crucial to control these variables in order to be aware of their regulation effects and uncover whether the improvements in the firms' sustainability performance can actually be attributed to the implementation of lean and green practices. Then, the proposed theoretical framework includes the size and age variables as control variables in order to take into account their influence in the firms' sustainability performance.

6.3 Lean Practices, Green Practices and Sustainability Performance

In this section, the main selected constructs to be included in the proposed theoretical manufacturing framework, *viz.*, lean and green practices, all the considered types of sustainability performance, and the proposed control variables are identified and described.

6.3.1 Lean Practices

The SLR conducted in Chapter 2 identified a wide array of lean practices that have received a considerable empirical examination. According to (Ling et al., 2007), the identification and classification of lean practices can be a quite challenging task given the lack of agreement on the nature of such practices. On one hand, this can be attributed to the fact that these practices do share similar practices with other operational excellence approaches such as TQM and JIT (Hadid and Afshin Mansouri, 2014). On the other hand, it can be attributed to the fact that lean management share practices with different practices within different fields of the organisation and business literature, such as, Human Resources Management (HRM) (Shah and Ward, 2003). In fact, in the seminal paper (Shah and Ward, 2003), a toolbox for lean management is proposed in which four main bundles of practices including TQM, JIT, TPM and HRM practices are identified. In this way, it is stablished that lean practices involve not only technical but also social practices as shown in Figure 6.3 (Shah and Ward, 2003), (Vadivel and Sequeira, 2017), (Shah and Ward, 2003), (Dombrowskia and Mielke, 2013), (Bortolotti et al., 2015). Nevertheless, although researchers agree that to take into account social practices within the lean context is crucial in order to generate a synergetic environment capable of maximising the lean benefits (Wong and Wong, 2014), (Dombrowskia and Mielke, 2013), (Bortolotti et al., 2015), the SLR conducted in Chapter 2 shows that little attention has been paid to such practices compared with technical ones. Table 6-3 and Table 6-4 summarise the most popular technical and social lean practices identified in the SLR conducted in Chapter 2, respectively.

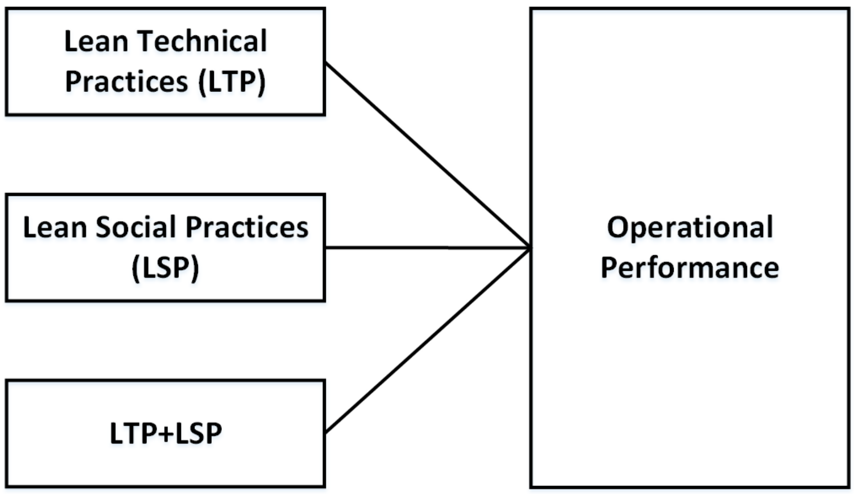

Figure 6.3: Lean technical and social practices interaction according to (Wong and Wong, 2014)[51].

[51] Source: Based on the scheme presented in (Vadivel and Sequeira, 2017).

Table 6-1: Main Lean Technical Practices[52].

No.	Lean Technical Practice	Definition and Source	Studies addressing the examined practice
1	Five Ss	5Ss stands for sort, set in order, shine, standardise and sustain: • Sort: To stablish which elements belong to each working area, avoiding the existence of elements that belong to another working area. • Set in order: Make the most useful and frequently used elements to be closest to the corresponding work area. • Shine: Ensure the elements and the working area are clean. • Standardise: Stablish and document standard work routines, including indications of machine and resources management. • Sustain: Ensure stablished standards are followed.	(Vadivel and Sequeira, 2017), (Arlbjørn et al., 2011), (Markovitz, 2012), (Chadha et al., 2012), (Radnor et al., 2012)
2	Automation	The automation makes specific machinery and equipment to be able to replace what was previously done by humans.	(Burgess and Radnor, 2010), (Bortolotti and Romano, 2012)
3	Group Technology	Similar production processes are grouped into cells in order to avoid unnecessary transportation and reduce production time.	(Carter et al., 2011), (Arlbjørn et al., 2011)
4	Changing the Facility Layout	Ensure the designed layout flows in an optimal operational way.	(Burgess and Radnor, 2010)
5	Continuous Improvement	Daily activities aimed at making the improvements demanded by the marketplace.	(Suarez Barraza et al., 2009), (Emiliani, 2004), (Alagaraja, 2010), (Kuriger et al., 2011), (Qudrat-Ullah et al., 2012), (Dickson et al., 2009a)

[52] Source: Combined by the Author.

6	Just in Time	Delivering what is needed, where it is needed and the time it is needed.	(Hagan, 2011), (Alagaraja, 2010), (Kuriger et al., 2011), (Dickson et al., 2009a)
7	Kaizen blitz	Improvements implemented in a specific area based on short-term process improvement projects.	(Hagan, 2011), (Emiliani, 2004), (Arlbjørn et al., 2011), (Holden, 2010)
8	Kanban	Information system used to ensure the proper sequential flow of the activities.	(Burgess and Radnor, 2010), (Manos et al., 2006), (Arlbjørn et al., 2011)
9	Mistakes Proofing/Poka-Yoke	It is aimed at minimising the situations that can lead to mistakes.	(Alagaraja, 2010), (Manos et al., 2006), (Alagaraja, 2010)
10	Policy Deployment/Hoshin Karni	Connect corporate strategy to the key manufacturing objectives and resources.	(Doman, 2011), (Emiliani, 2004)
11	Pull System	Products are produced provided the costumer request so.	(Qudrat-Ullah et al., 2012)
12	Process Redesign	Improving a process or design by redefining it.	(Manos et al., 2006)
13	Quality Function Deployment	Using a multidisciplinary team for decision-making about products' specifications based on customer requirements.	(Yavas and Yasin, 2001)
14	Quick Set up Time	To quickly re setup the specific tasks developed in a working area.	(Alagaraja, 2010)
15	Root Cause Analysis	To identify the actual source of a problem and the possible ways of avoiding its future occurrence.	(Maguad, 2007)
16	Small Lots	To reduce the process information batch.	(Emiliani, 2004)
17	Standardisation	It is an agreed-upon set of work procedures that establish the best and most reliable methods and sequences for each process and each worker.	(Arbos, 2002)

18	Takt Time	Established by the customer demand frequency. It helps to estimate the workplace activities time based on the customer demand time.	(Kosuge et al., 2011),
19	TPM	Keep the needed equipment in a good and ready-to-use condition.	(Emiliani, 2004)
20	VSM	Visual picture of the current or future material, process or information flows.	(Mirehei et al., 2011)
21	Visualisation	Visual information to provide an easy and fast way of communication.	(Alagaraja, 2010)
22	Work Load Balancing	Distribute the assigned amount of work load in a fair way among the employees.	(Emiliani, 2004), (Mirehei et al., 2011), (Middleton et al., 2005)

Table 6-2: Main lean social practices (Kuriger et al., 2011) [53].

No.	Lean Social Practice	Definition and Source	Studies addressing the examined practice
1	Small group problem solving	The use of small group problem solving allows taking employees' suggestions more seriously, encouraging them to involve themselves and propose improvements not only to their own tasks but also to the whole system (Bortolotti et al., 2015).	(Forza, 1996), (Shah and Ward, 2003), (Rahman et al., 2013), (Fotopoulos and Psomas, 2009)
2	Training employees	Empowering and educating the employees facilitates their self-development(Prajogo and McDermott, 2005).	(Haddad and Jaaron, 2012),(Shah and Ward, 2003) , (Fotopoulos and Psomas, 2009)
3	Top management leadership for quality	The lean leadership is based on three main principles: • Go see • Ask why • Show respect	(Prajogo and McDermott, 2005),(Shah and Ward, 2003) , (Fotopoulos and Psomas, 2009)
4	Supplier partnership	The supplier partnership involves (Prajogo and McDermott, 2005): • Commitment over an extended time period • Sharing of information • Sharing of the risks and rewards of the relationship	(Cali, 1993),(Shah and Ward, 2003) , (Fotopoulos and Psomas, 2009)
5	Customer involvement	The needs of customers are identified and taken into account throughout the whole production process.	(Prajogo and McDermott, 2005),(Shah and Ward, 2003) , (Fotopoulos and Psomas, 2009)

[53] Source: Based on the table presented in (Bortolotti et al., 2015).

Although lean practices have shown to lead to sustainable results (Prajogo and McDermott, 2005), (Fliedner, 2008), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013) they have not been particularly aimed at doing so (Chiappetta Jabbour et al., 2013), being mainly focused in the economic aspect of the organisation, which is only one of the three sustainability pillars in the TBL sustainability model (Fliedner, 2008). Regarding the other two pillars, namely, the social and environmental ones, some observations can be done. On one hand, the implementation of lean social practices helps to achieve improvements regarding the social aspect of the sustainability performance, including workers' empowerment by training them so that they are encouraged to get involved, solve problems and propose improvements. In fact, continuous improvement practices, which are one of the most important practices towards lean manufacturing success, are highly correlated with human resources management, including training, empowering, evaluating and rewarding employees, either individually or as team members (Elkington, 1998). On the other hand, lean manufacturing considers wastes definitions from a time and cost perspectives, rather than from an environmental perspective. For instance, although a lean practice like 5S can reduce the raw material consumption and wastage (by keeping it ordered and clean), having a positive impact on the environment, this positive impact would be not enough to reach an environmentally optimised raw material management. This is due to the fact that, in order to reach so, it is not only necessary to reduce raw material consumption and waste, but also to avoid the use of hazardous materials, use renewable resources and environmentally-friendly materials, eliminate the emissions and reduce the supply chain footprint, which are not lean objectives. Examples like this abound in the real manufacturing world showing that, although lean practices are in the right path towards achieving greener results through waste elimination, they are usually not enough to address such an issue when implemented individually, making it necessary to resort to different and new complementary strategies in order to help them to widen their interpretation of wastes. In addition, there are researchers that agree that, from a lean point of view, practices focused on the environment can even result in problems regarding products, services, designs and production processes. Then, although lean practices, which are mainly focused on improving operational and financial aspects of the organisations, are also capable to address social aspects, they seem to be not enough to ensure the environmental aspects are properly addressed. In this context, it is necessary to complement lean practices with other specific practices focused on environmental issues, such as the green ones, in order to be able to actually reach sustainable results addressing economic, environmental and social aspects simultaneously.

6.3.2 Green Practices

The SLR conducted in Chapter 3 identified different green practices that are mainly aimed at reducing the environmental footprint of the whole product life cycle. The most popular green practices in the literature include assessment oriented methods, such as LCA, which are used to evaluate the environmental impact of each process in order to make a diagnosis of their environmental efficiency, as well as improvement oriented methods, which, based on the results of the assessment methods, propose different DfE or EOL strategies to address the found issues. Table 6-5 summarises the main green practices discussed in Chapter 3.

In addition, in Chapter 3 the link between green practices and sustainability performance, in terms of economic, environmental and social performances, has been studied. Green practices are specially committed to addressing environmental issues, which represent one of the three pillars of sustainability defined by (Blackburn and Rosen, 1993). Nevertheless, it is important to be highlighted that this environmental commitment implies a social commitment as well, since green practices do, by nature, consider the social aspects within their main objectives, in the sense that they seek to eliminate emissions and hazardous substances in order to provide a healthier, safer and cleaner life not only for employees but also for the whole community. Regarding the economic aspect, the positive correlation between this aspect of the sustainability and the green practices has historically been called into question. Moreover, green practices have largely been resisted by many industry owners since they have a high cost, and require a huge investment, considering environmental standards and regulations as a burden for production and achieving profits. In this context, although some economic benefits, such as, reduction of energy and material consumption (Elkington, 1998), (Sun et al., 2003) could be attributed to the implementation of green practices, they are not enough to ensure the whole company profitability. Then, in order to comply the environmental regulations, as well as to remain being competitive, companies need to be creative and propose new strategies which can complement the green practices to enhance their profitability (Cabral et al., 2012), (Karp, 2005).

Table 6-3: Main Green Practices.

No.	Green Practice	Definition and Source	Studies addressing the examined practice
1	Green Design	Combines LCA, DfE and Process Planning to design the green product (Fercoq et al., 2013). • LCA: The LCA is an internationally standardised method under ISO 14040 and ISO 14004 that can be used to identify and quantify the environmental and resource-related impact associated with a particular product throughout its entire life cycle, that is, from its design to its EOL (Rehman, 2013). • DfE: DfE is a set of rules to take into account the design performance regarding environmental, health, and safety objectives over the entire product and process life cycle from its very beginning in order to plan strategies that allow reducing the product footprint and handle its EOL. In this way, DfE is intended to optimise the relationship between environmental and economic systems, so that the produced products can fulfil customer's needs while their environmental and social impacts can be reduced (Zhang et al., 1997). • Process Planning: Green process planning can complement the product design with the process design by selecting the process elements, optimising the process flow, and evaluating the process project (Fiksel, 1996).	(Yan et al., 2007), (Rehman, 2013), (Yan et al., 2007), (Zhang et al., 1997)
2	EOL Strategies	One of the key aspects in Green Manufacturing is to be responsible for the product and its environmental impact throughout the entire product life cycle including the concept of product EOL into the product life cycle (Fiksel, 1996), (Yang et al., 2015). The most popular EOL strategies are: • Remanufacturing: Making an already used product to work as if it was new, guaranteeing that it works as well as the actually new ones. • Reconditioning/refurbishing: Reconditioning is aimed at rebuilding or repairing the principal components of a used product (even when there is no reported fault of such components) to return it to a satisfactory working condition.	(Rose et al., 1998), (Yang et al., 2015),

		• Reuse: To use an already used product at its EOL stage for the same purpose for what it has been produced to be used at its usage stage. • Repurposing: Giving a used product (or some part of it) a new purpose (different from the one it has been designed for). • Repair: To make a broken product (or component) be usable again. • Recycling: Processing waste materials so that they can be used either for their original purpose or for a new one. • Incineration: The incineration is the combustion process of organic wastes. This procedure generates energy, which can be recovered in order to produce heat or electric power, or not. • Landfill: Landfill is the process of waste disposing by burial.	
3	GSCM	Takes into account the influence of implementing different green practices within different stages of the product life cycle, such as, product design, material selection and purchasing, manufacturing processes, delivery, and EOL strategies, on the GSCM (Rose et al., 1998).	(Shrivastava, 2007)
4	Reverse Logistic	Reverse logistics is a process that allows closing the loop of the product life cycle by applying EOL strategies, such as, reusing, remanufacturing or recycling the waste materials.	
5	Green Purchasing	Green purchasing is focused on choosing and buying eco-friendly products, in an attempt to reduce the consumption of products that have a negative impact on the environment (Shrivastava, 2007).	(Chan, 2001), (Chan, 2001)
6	Green Marketing	Green marketing includes all the activities focused on selling green products by doing special emphasis on the credibility of the product as well as the consumer value and knowledge (Syrek and Gul, 2017b).	(Syrek and Gul, 2017b)

6.3.3 Sustainability Performance

In its report *Our Common Future* (also known as Brundtland's report) in 1987, the WCED defines sustainability as *"the development that meets the needs of the present without compromising the ability of future generations to meet their needs"*. Although this definition has been praised and, as such, have been widely accepted by researchers, practitioners, leaders, stakeholders and policy makers, it provides a macro view of the nature of what actually "needs" of generations means (Syrek and Gul, 2017b). In this sense, this definition can be considered a problematic definition since provides little guidance for practitioners on the scope and nature of the "needs" that should be preserved while achieving the firms' business objectives. In order to fill this gap, scholarly and managerial efforts have been carried out in the last decades to provide a narrower view of what "needs" actually means. The TBL conceptualisation of sustainability illustrated in Figure 2.13 (Gimenez et al., 2012) is one of the main and most widely accepted contributions towards providing a micro understanding regarding the "needs" referred to in the WCED report.

In the proposed theoretical manufacturing framework presented in this chapter, the main idea consists in the fact that, in order to reach the sustainability performance in terms of the TBL model in Figure 2.13 (Elkington, 1998), different, simultaneous and complementary (synergistic) contributions are needed from lean, green and lean-green approaches. In this sense, each of these practices would impact in its particular way on each one of the three pillars of the sustainability performance, making a necessary and interdependent contribution to the whole performance improvements. As mentioned in Section 6.3, in the proposed theoretical manufacturing framework the sustainability performance is modelled in terms of the operational, environmental and social performances, and the hypotheses H3, H4 and H5, which relate them with the financial performance, respectively, as shown in Figure 6.2. In the following sections the different pillars of the TBL sustainability model are defined and how lean and green practices can contribute to each one of them is analysed. Finally, how combining lean and green practices can improve each one of the considered performances is also discussed.

6.3.3.1 Environmental Performance

Environmental performance can be evaluated in terms of the efficiency of a company to eliminate the CO2 emissions in the whole product life cycle (including transportation and delivery), minimise water, energy and resource consumption, reduce the use of hazard substances, produce eco-friendly products or services, be responsible for their product until its EOL, apply an environmental-friendly EOL strategy, ensure a safe, clean and healthy workplace, etc. All of these practices help to reduce the environmental footprint of the product and its manufacturing process throughout the entire product life cycle, which is the main objective of a company towards improving its environmental performance. At this point, the avid reader would have identified several aims of the green manufacturing practices among the described objectives. On the other hand, it results more difficult to identify lean objectives among them. Nevertheless, although they have not been created with green aims, lean practices can also contribute towards reaching these objectives (see Table 2-4) by generating a proper working environment to implement greener practices and improve their results, such as, a cultural background that allows waste reduction and pollution prevention (Elkington, 1998), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). In this regard, lean practices allow employees to be more engaged and, as such, more willing to adopt different practices in order to improve their working conditions. At the same time, lean employees are well-trained, being capable to learn and adopt new techniques in order to improve the manufacturing process and the quality of the final product. In addition, lean technical practices, such as 5S, cell manufacturing, VSM and standardisation, among many others, make it easier to implement modifications into the process, providing a well-organised, modular, flexible and documented process flow. In this way, companies working under lean conditions will be able to take more advantages of the implementation of green practices, taking environmental performance to a higher level, making it crucial to implement both practices in a combined framework for the sake of a more sustainable environmental performance.

6.3.3.2 Social Performance

Although the social aspect is contemplated, to a certain extent, within the lean and green contexts, the SLRs conducted in Chapters 2, 3 and 4 show that there is still little research regarding this particular aspect of the sustainability, either from the lean (Chiappetta Jabbour et al., 2013), (Dombrowskia and Mielke, 2013), (Bortolotti et al., 2015) or from the green (Wong and Wong, 2014), (Chan, 2005) points of view, being the less studied of the considered sustainability aspects. In addition, most of the available studies in the literature evaluate the social performance from a qualitative perspective since, due to its subjective nature, there is a lack of tools capable of quantifying it. In order to fill this gap, in recent years the Global Reporting Initiative (GRI)[54] has developed some guidelines for reporting companies' social performances.

[54] https://www.globalreporting.org/Pages/default.aspx

To fulfil the social aspects of sustainability, manufacturing practices should be able to create a well-being atmosphere not only for employees, but also for suppliers, stakeholders, customers and the whole community. Generally speaking, social performance is related to a wide range of desired outcomes, including employee training, empowerment and engagement, supplier and stakeholder commitment, safety and healthy working environment, clean emissions, society's safety and health, interaction with the community, and improved costumer experience, among others. Some of these objectives, such as, employee training, empowerment and engagement, can be addressed by lean practices, while some others, such as, ensuring cleaner emissions and a safer and healthier working environment, can be addressed by green practices. In addition, there are some others, like the costumer experience, that can be improved by lean practices regarding the cost, quality and delivery time, while green practices can improve them by providing more eco-friendly products. Then, while lean social practices are more focused in the employees' development and customer satisfaction, green practices are more focused in the safety and health of the society as a whole, being both necessary to improve the social image of the company and achieve the social responsibility level that sustainable companies require (Sezen and Cankaya, 2013), (Hartini and Ciptomulyono, 2015), (Glover et al., 2011).

6.3.3.3 Economic Performance

The economic performance is the main focus of lean practices. It can be broken down into two types of performances, namely, the operational and the financial performance. The operational performance captures the degree to which firms can achieve cost reduction, improved quality, delivery and flexibility as a result of implementing manufacturing practices. There is plenty of literature addressing operational performance from the lean perspective (Bocken et al., 2014), (Doraa et al., 2013), since lean practices, by nature, are aimed at improving this aspect of the firms. Moreover, as discussed in Chapter 2, there is a well-stablished set of lean technical tools and methods addressing operational issues. On the other hand, there exists a literature gap regarding widely accepted and applied green methods and tools focused on the operational aspects of the firm (Chavez et al., 2015). In fact, although it has been demonstrated that green design practices, including DfE and process planning, could lead to operational improvements (Rehman, 2013), (Fiksel, 1996), (Jeswiet and Hauschild, 2008), (Naderi, 1996), according to (Tseng et al., 2013), operational and production processing aspects have largely been overlooked by researchers in the green field. In addition, green solutions tend to be customised (He et al., 2008), since they strongly depend on the local regulations. These are probably the main reasons why the influence of green practices regarding operational performance has largely been called into question, making practitioners to even consider the environmental regulations as a burden for production and achieving profits. Nevertheless, there exist also reasons to think that the strongly operational profile of lean practices can be enhanced by the implementation of green practices. On one hand, green practices propose an holistic point of view (Rehman, 2013), (Rehman, 2013), (Deif, 2011) developing green models capable to address the manufacturing issues considering all the companies' activities as a unified working system (Roman and Bras, 2005), (Rehman, 2013), (Deif, 2011). In this way, lean manufacturing activities, which are mainly focused on one sector at a time, can be improved by taking into account the manufacturing system as a whole. On the other hand, the green need for customisation regarding local regulations can improve the local firm's image and get the firm closer to local people.

The financial performance is strictly related to the overall profits (and loses) of the firms. In this case, there is also a vast lean literature (Roman and Bras, 2005), (Meade et al., 2006), (Hofer et al., 2012). This is due to the fact that lean practices are strongly committed to financial issues since they are based on premises like reducing wastes (in terms of eliminating any non-value added activity), optimising resources, energy and time consumption, which are unequivocally aimed at reaching financial benefits. On the other hand, although several efforts have been made in last years to demonstrate that green practices can yield profitability improvements, such as, for instance, costs savings through a more efficient system leading to a positive impact on the ROI (Kocakulah, 2004), practitioners are still reluctant to the idea of relating green practices with financial improvements. In this context, although lean practices may seem more efficient to reach financial performance improvements, green practices can help to go further in this direction. For instance, green practices can positively contribute to improve certain social aspects, such as, the organisational culture and the local people engagement, improving the firm's image which can yield financial benefits (Paul et al., 2014). In addition, the implementation of green practices can make firms comply with local and standard regulations, avoiding paying high taxes and financial punishments.

6.3.4 Control Variables

When evaluating the performance of a firm, there exist several factors that should be taken into account. In this line, it is not enough to guarantee that the chosen practices (lean, green and lean-green in the case of the proposed theoretical framework) are properly implemented to reach the desired results, but it is also necessary to take into account to which extent and how different variables, such as, firm's age and size, are influencing in the overall firm's performance. Regarding the firms' size, the literature reviews conducted in Chapters 2, 3 and 4 suggest that bigger companies usually have more resources, in terms of economic, infrastructure and human resources, to implement lean and green practices in comparison to smaller ones (Lopes Negrao et al., 2017), (Shah and Ward, 2003), (Shahrukh, 2011). This is probably due to the fact that large companies have a greater capability of investing in new technologies, as well as of principle formalisation, making it easier the implementation of new strategies of manufacturing and management (either lean or green) that can achieve performance improvements while complying international standards and governmental regulations (Matt and Rauch, 2013), (Ciocci and Pecht, 2006), (Bhasin, 2012). In fact, only a few examples have been found in the literature reviews presented in Chapters 2 and 3 regarding lean (Doolen and Hacker, 2005), (Bhamu and Sangwan, 2014), (Yusof and Elaine Aspinwall, 1999), (Bhasin, 2012), (Karim, 2011), (Rahman et al., 2013), (Doraa et al., 2013), (Matt and Rauch, 2013) as well as green (Belhadi et al., 2016), (Chen, 2008), (Ilomaki and Melanen, 2001), (Andrews et al., 2002), (Thoo et al., 2015) successful implementations in small, medium and SMEs organisations, respectively. Regarding the firms' age, older firms, which have been in industry for years, have accumulated knowledge and experience in doing business as opposed to younger firms (Hicks and Dietmar, 2007). Then, on one hand, the know-how, skills and capabilities that old firms have developed over the years make them better in running their operations more efficiently than younger firms resulting in higher performance (Coad et al., 2013). On the other hand, they can experiment a higher resistance to change than younger ones (Rossi, 2016), (Kipesha, 2013), (Trencansky and Tsaparlidis, 2014), (Majumdar, 1997). Then, in order to take into account firm's size and age influences on the performance, the theoretical framework presented in this chapter proposes to include such variables as control variables. In this way, it would be possible to distinguish whether a particular perceived performance improvement comes from the lean, green or lean-green contributions, or it should be simply attributed to the firm's age or size (Ling et al., 2007), (Kipesha, 2013), (Artin et al., 2015), (Trencansky and Tsaparlidis, 2014), (Majumdar, 1997).

6.4 Theoretical Foundations of the Proposed Manufacturing Framework

While several researchers agree that it is crucial to combine and integrate lean and green practices in order to enhance the sustainability performance, lesser consensus is found regarding which is the best strategy to combine them. The theoretical argument of the proposed conceptual framework in this chapter is consistent with the logic of two well-established theoretical perspectives, namely, the STS theory, which stablishes that taking into account the interdependency and interaction between social and technical practices is a crucial aspect towards improving the companies' performance; and the complementary theory, which seeks for the synergistic effects of combining different manufacturing practices. The proposed theoretical framework intends to enhance the combined (socio-technical effect) implementation of lean (both technical and social) and green (by nature combining technical and social aspects) practices by potentiating (synergy effect) their strengths and disguising (complementary effect) their weaknesses. The following subsections provide a brief overview of these theories and illustrate how they support the argument being made in the proposed conceptual framework presented here.

6.4.1 Socio-Technical System Theory

The STS theory recognises that organisations consist of two interdependent systems, namely, technical and social systems, as shown in Figure 6.4. On one hand, the technical system includes physical elements, such as, tools, equipment, machines, hardware, software and processes, as well as working tasks, such as, methodologies. On the other hand, the social system consists in the organisational structure and culture, as well as the employees' development and society engagement (Ling et al., 2007). In particular, the main premise of the STS theory is that the adoption and enhancement of technical practices towards meeting operational and financial improvements are likely to be more effective provided the social systems receive similar attention (Trist, 1981).

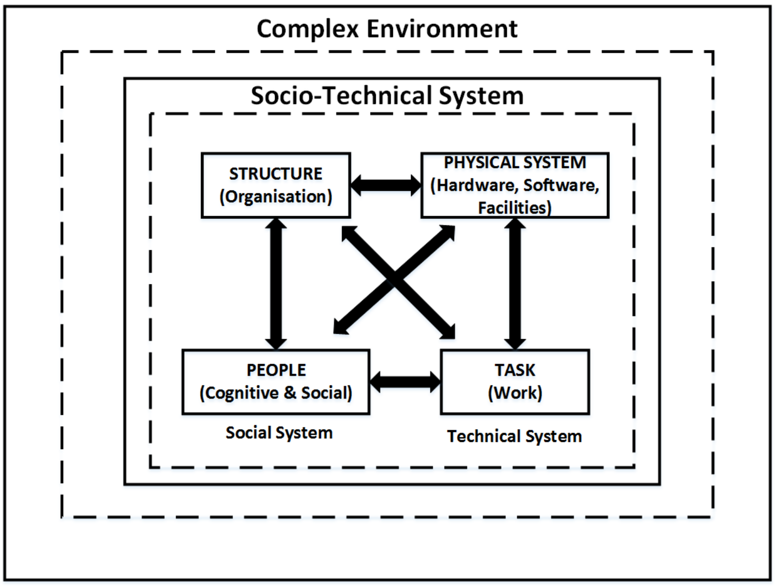

Figure 6.4: STS theory overview (Trist, 1981)[55].

[55] Source: Based on the scheme presented in (Osthuizen and Pretorius, 2016).

The STS theory has already been studied within the context of lean (Oosthuizen and Pretorius, 2016), (Dankbaar, 1997), (Niepce and Molleman, 1998) and green (Raja, 2011), manufacturing, obtaining promising results, especially in the case of lean practices (O'Neill and Gibbs, 2014), (Dankbaar, 1997), (Niepce and Molleman, 1998). Nevertheless, although there exist some works in the literature addressing the implementation of different STS theory principles to make the transition towards more sustainable manufacturing (Raja, 2011), (Lawhon and Murphy, 2011), the actual potential of integrating lean and green practices based on the STS theory principles has not been deeply explored yet. In the theoretical framework proposed in this chapter, there exists interdependence between social and technical aspects, in the sense that social performance improvements, either obtained by lean or green practices, do have impact on the technical aspects, being also true the other way around. Then, the idea of using STS theory principles within the context of the proposed theoretical framework is to take into account both technical and social aspects with the same degree of importance in order to combine lean and green practices into an integrated model capable of taking advantage of this interdependence by enhancing the positive impact that technical aspects can have on the social aspects and vice versa. For instance, if a company pays attention to the employees' empowerment, which is a social lean aspect, a positive impact on lean technical aspects, such as, the way in which the tools and equipment are used, can be obtained. In addition, such employee empowerment, may lead employees to be more willing to be committed with the green aspects of the processes, improving the green efficiency (technical aspect) and the public image of the company (social aspect). Finally, this interaction flow will generate a positive feedback to the company performance, by increasing the sales, engaging customers and suppliers, making a continuous interaction cycle. This is just a simple example to illustrate how, based on the STS theory which encourages companies to pay similar attention to social and technical aspects, a suitable framework to combine and integrate the lean and green practices in a beneficial way can be generated. When practically implementing the proposed theoretical framework, the suitable lean, green and lean-green practices should be selected in order to maximise the potential benefits of their interdependence.

6.4.2 The 'Synergism Hypothesis' Perspective

The logic of complementary theory defines the synergy phenomenon as the interaction effect of the parts of a system being greater than the effect of the sum of the individual parts. It is based on the idea that each part of the system can only cover one aspect of the work of the system, and therefore, each part will need to be complemented by other part (at the same time that will complement it) (O'Neill and Gibbs, 2014). On the contrary of the case of the STS theory, researchers have largely discussed about the synergistic effects of lean and green practices. In this line, although there are the ones that argue that since lean and green approaches differ in their main objectives they may not always be able to reach a synergistic effect (Latash, 2008), (Mollenkopf et al., 2010), most of them agree that both practices can be concurrent in the sense that implementing them together can effectively generate a synergy regarding waste reduction, energy, material and time consumption, supply chain management and product life cycle optimisation (Kleindorfer et al., 2005), (Garza Reyes et al., 2014), (Saunders et al., 2000), (Dües et al., 2012), (Galeazzo et al., 2014), (Garza Reyes, 2015b), (Bergmiller and McCright, 2009), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Bortolini et al., 2016).

The in-depth analyses conducted within the framework of this thesis allow identifying the differences as well as the similarities between lean and green practices, which have mainly been summarised in Table 4-2. To be aware about these differences and similarities is crucial for reaching a synergistic manufacturing environment. Moreover, despite the (many) differences that both practices can have, the fact that there exist a similar structure for the implementation of successful lean and green practices makes the synergism hypothesis to be suitable (Pampanelli et al., 2014). Then, provided the suitability of the synergism hypothesis is ensured, the synergistic effect will be achieved when the differences between both practices can be disguised, while the similarities can be potentiated. In this sense, since both practices can have different impacts on the different considered aspects of the sustainability performance, the synergistic principles of the complementary theory seems to be well-suited to combine them. Then, the proposed conceptual framework is based on the idea that if both practices have a positive effect on a particular performance, they should be combined in such a way that their effects are potentiated in order to generate a higher improvement than in the case of being implemented individually. On the other hand, if both practices have different impact of a particular performance, they should be combined in such a way that the positive impact is higher (have more influence) than the negative one; while if both practices have a negative impact, they should be combined in such a way that the negative impact is minimised. Finally, the actual advantages and limitations of the particular lean, green and lean-green practices selected to actually be included into the practical implementation of the proposed theoretical framework will determine the best way in which they will have to be combined and integrated in order to achieve the described synergistic effect.

Several successful synergistic examples in the literature, such as the ones in (Dawood and Abdullah, 2017), (Galeazzo et al., 2014) and (Pampanelli et al., 2014), can be mentioned to support the inclusion of this theory in the proposed conceptual framework of this chapter. In (Bortolini et al., 2016), green and lean practices are applied, either simultaneously or sequentially, within the context of different pollution prevention projects outperforming the implementation of each one of the practices implemented individually. In (Galeazzo et al., 2014), green practices are used in a cell production application, resulting in significant reduction of resource wastage, in terms of lean as well as green perspectives. Finally, a significant example of how a conflicting point between lean and green practices, such as the replenishment frequency (Pampanelli et al., 2014), can be addressed by combining them in a synergistic way can be found in (Venkat and Wakeland, 2006), where a novel framework to integrate lean and green practices into the supply chain management is proposed showing promising results.

6.5 Hypotheses Development

The proposed conceptual framework introduced in this chapter and shown in Figure 6.2 proposes to model the contributions of lean, green and lean-green practices to the different considered aspects of sustainability, *viz.*, operational, environmental and social aspects, by a set of hypotheses. One of the main research findings identified from the SLRs conducted in Chapters 2, 3 and 4 is the need for measuring the actual practical gap between achieving the lean and green aims when applying each practice individually, before designing the lean-green approach. In this way, it is intended that being aware of the gap's depth could lead to develop a combination strategy that address the problem and fill this gap in a smooth way. In this line, in order to estimate to what extent lean and green aims are actually reached by lean and green practices, hypotheses (H1a-c) and (H2a-c) model the contributions of lean and green practices to the operational, social and environmental performances, respectively. Once these contributions have properly been analysed, the suitable combined framework for the lean-green approach can be defined. Then, hypotheses (H3a-c) will model the contribution of the proposed lean-green approach towards the operational, social and environmental performances, respectively. Finally, hypotheses H3, H4 and H5 relate the operational, social and environmental performances with the financial performance, respectively. In the following sections, each set of hypotheses is described.

6.5.1 Lean Practices and Sustainability Performance

Operational performance improvements are, by nature, the main focus of lean social and technical practices, since they consist in a widely accepted and implemented set of practical manufacturing tools, techniques and methods, such as the ones listed in Table

6-3 and Table 6-4, focused on reducing costs and improving product and delivery qualities from customers' point of view. In fact, there is plenty of literature addressing operational performance from the lean perspective (Bortolini et al., 2016), (Khanchanapong et al., 2014), (Doraa et al., 2013). In this context, it is straightforward to state that:

H1a: Lean technical and social practices positively influence operational performance.

Although lean practices have not been aimed at doing so, they can lead to different environmental benefits. Figure 6.5 illustrates how the successful achievement of lean objectives can lead to environmental performance improvements. In this regard, some observations can be made. On one hand, it is important to highlight that this improvements can often be interpreted as spin-offs being subjected to different factors, such as, the actual success in reaching all the required lean objectives that combined contribute towards improving a particular environmental issue. In addition, these potential environmental improvements are usually not enough to fulfil the environmental standards and local regulations (Chavez et al., 2015). On the other hand, social lean practices, focused in training and engaging employees, as well as technical lean practices, focused on organising and cleaning the working area, do generate a proper working environment to reach greener results, such as, a cultural background that allows waste reduction and pollution prevention (Kurdve et al., 2011), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). In this sense, the following hypothesis can be made:

H1b: Lean technical and social practices positively influence environmental performance.

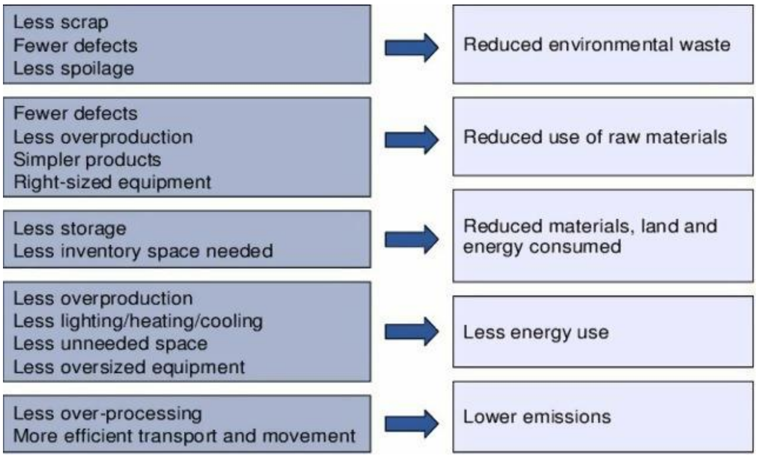

Figure 6.5: Lean contributions towards environmental performance (Chiappetta Jabbour et al., 2013) [56].

[56] Source: Based on the scheme presented in (Kurdve et al., 2011).

Lean practices, either social or technical, promote employees, suppliers and customers' engagement. Regarding employees' engagement, lean practices, such as continuous improvement, are highly correlated with human resources management, including training, empowering, evaluating and rewarding employees, either individually or as a team (Kurdve et al., 2011), facilitating employees' self-development (Prajogo and McDermott, 2005). In this context, techniques like small group problem solving encourage them to get involved in decision making processes, giving them the power to propose improvements not only to their own tasks but also to the whole production process (Bortolotti et al., 2015), (Forza, 1996), (Shah and Ward, 2003), (Rahman et al., 2013), (Fotopoulos and Psomas, 2009). In addition, some other lean practices, such as 5S help employees by providing a healthier and safer working environment. Regarding supplier partnership, the lean environtment favours information sharing, commitment over an extended time period and sharing the risks and rewards of the relationship (Cali, 1993), (Shah and Ward, 2003), (Fotopoulos and Psomas, 2009). Regarding customers, lean practices identify their needs and take them into account throughout the whole production process (Prajogo and McDermott, 2005), (Shah and Ward, 2003), (Fotopoulos and Psomas, 2009). The following hypothesis can then be stated:

H1c: Lean technical and social practices positively influence social performance.

6.5.2 Green Practices and Sustainability Performance

Green practices are mainly aimed at improving the environmental performance of the firms. In this context, the correlation between green practices and operational performance has not been properly addressed in the literature (Blackburn and Rosen, 1993). Despite this literature gap, there some green practices, such as the ones devoted to the product design like DfE and process planning, that can be positively correlated to the operational performance improvements. In this sense, the following hypothesis can be made:

H2a: Green practices positively influence operational performance.

Green practices are aimed at reducing the environmental footprint throughout the entire product life cycle, being responsible for their product until its EOL. In particular, green practices include eliminating CO2 emissions and hazard substances, minimising water, energy and resource consumption, producing eco-friendly products, applying environmental-friendly EOL strategies, and ensuring a safe, clean and healthy workplace, among others. In this context, it is straightforward to state that:

H2b: Green practices positively influence environmental performance.

Green practices are focused in the safety and health of the society as a whole as well as in being responsible for the product footprint throughout its entire life cycle. Green practices can help companies' social performance from both the external and internal points of view. On one hand, adopting environmentally friendy practices improves the companies' positive image and reputation. This increases the sales, since brand reputation plays a crucial role in consumer decisions in the sense that environmetantally conscious consumers are more willing to buy eco-friendly products and tend to engage with companies that produced them (Syrek and Gul, 2017b). On the other hand, since green practices aim at reducing material wastage and hazardous emissions, they can provide employees a healthier, cleaner and safer workplace, and local society a healthier environment. It is then possible to state that:

H2c: Green practices positively influence social performance.

6.5.3 The Joint Effect of Lean and Green Practices on Sustainability Performance

In the previous sections, the positive influence of lean and green practices applied individually on the operational, environmental and social aspects of the sustainability performance has been discussed. The proposed theoretical framework proposes a set of hypotheses (H1a-c and H2a-c) to model and estimate the actual impact of lean and green practices on the different sustainability aspects when applied individually. Although positive, the contributions of both practices towards the different considered sustainability aspects are not enough. In order to realise simultaneously higher performance improvements in all the considered sustainability dimensions, the proposed theoretical framework states that it is necessary to resort to the joint implementation of both lean and green practices. The actual strategy for combining both practices will depend on the existing gap's depth regarding the already achieved lean and green objectives and the particular lean and green techniques chosen for practically implementing the practices. In particular, according to the SLRs conducted in Chapters 2, 3 and 4, the main aspects that should be taken into account in order to synchronise lean and green practices into an integrated framework are:

- Waste minimisation
- Environmental management
- Resource management
- Elimination of unnecessary processes

As discussed in Section 6.5, the combination will be based on the STS theory and the synergism principles, which support the idea that a superior level of improvements can be achieved when both practices are applied together in a collaborative environment. In this line, the hypotheses modelling the actual impact that the joint implementation of lean and green practices do have on the different sustainability performances are stated in terms of a moderating effect of lean practices on green practices performances.

Operational performance is evaluated in terms of the cost reduction, improved quality, delivery and flexibility as a result of implementing manufacturing practices. Researchers have largely discussed about the actual impact of green practices on the operational performance (He et al., 2008), (Ahemad and Shrivastava, 2013), (He et al., 2008). In particular, although in the case of green practices there is a lack of a widely accepted set of methods and techniques aimed at addressing specific operational aspects of the firm in contrast to the case of lean practices, green practices have an holistic perspective, developing green models capable of addressing the manufacturing issues considering all the companies' activities as a unified working system (Rehman, 2013), (Rehman, 2013), (Deif, 2011). In this way, the implementation of specific lean manufacturing techniques within a green context, can lead to improvements in specific operational aspects. In such a situation, lean practices will moderate the operational performance (by implementing more specific techniques) of the green practices, yielding to further improvements, making the following hypothesis feasible:

H3a: Lean practices moderates the relationship between green practices and operational performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.

Environmental performance can be evaluated in terms of the efficiency of a company to reduce the environmental footprint throughout the entire product life cycle. Although this is an objective that can be reached by applying green practices, lean practices can help towards generating a proper organisational culture and a suitable working environment allowing a more efficient implementation of such green practices and enhancing their results (Roman and Bras, 2005), (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). In this context, lean practices can act as moderating factors towards reaching further improvements, since lean employees are empowered being more willing to adopt different and new practices, while lean working places and processes are more flexible making it easier to modify them. Then, companies working under lean conditions will be able to take more advantages of the implementation of green practices, making it important to implement them in a combined and synergistic framework in order to reach better and more sustainable environmental performance. Based on these comments, the following hypothesis can be stated:

H3b: Lean practices moderates the relationship between green practices and environmental performance in such a way that the positive impact of green practices on environmental performance is stronger when lean practices are implemented.

Green practices which aim to reduce wastes and hazardous emmisions help to improve employees' working environment making it safer and healthier. If these practices are implemented within a lean culture where the work is standardise, the processes are efficient, the individual and team tasks are fairly distributed, and the working areas are well-organised according to the 5S, making them ordered and clean, it is likely to obtain further improvements in comparison with the ones obtained in a working environment that is not lean. In addition, green practices also contribute with the local community quality of life in terms of reducing emissions, preventing pollution, DfE and taking care of the environmental impact of the products until their EoL. For instance, lean practices, which allow product modularization and parts standardization, simplify the production process, helping to reduce wastes and energy consumption contributing towards the eco-friendly nature of the produced products. In addition, lean practices promote face-to-face planning and communication with suppliers which helps companies to be responsible for suppliers' environmental issues. Finally, lean practices are highly costumer oriented, keeping a healthy interaction with costumers aimed at satisfying their needs. In this line, lean practices can not only help to identify to what extent customers are willing to buy green products, but also to the diffusion of the companies' green initiatives. Then, the following hypothesis can be made:

H3c: Lean practices moderates the relationship between green practices and social performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.

6.5.4 The Interrelationship among Sustainability Performance

The proposed theoretical framework models the sustainability performance in terms on the TBL sustainability model taking into account the economic, environmental and social performances. In addition, to break down the economic performance into two performances, namely, the operational and the financial performances, is proposed. Finally, in order to model the sustainability performance as a whole, the contributions of the operational, environmental and social performances to the financial performance are taken into account by hypotheses H4, H5, H6, respectively, as shown in Figure 6.2. These hypotheses are described as follows.

The relationship between the operational performance and the financial performance has largely been studied (Chiappetta Jabbour et al., 2013), being almost straightforward. In general, the more efficient the operational aspects of a firm are, in terms of resource, time, and energy consumption, the higher the cost savings and the better the quality of the produced product is. More specifically, improvements in the operational performance in terms of improvements in processes and equipments, such as the use of "error proof" equipment, cycle time reduction, availability and reliability of machines, and use of cellular manufacturing, avoid incorrect processing and over-processing. This helps to produce higher quality products and reduce the material and energy usage as well as the waste production, reducing the production costs making companies more competitive and profitable, improving the company's financial performance. In addition, improvements in the operational performance in terms of improvements in planning and control strategies, such as pull-flow control, overlapped production, visual control of the shop floor, small lot sizing, scheduling, levelled production, and inventory reduction contribute to reduce wastes in overproduction. In particular, planning and control practices allow reducing the materials and components used throughout the manufacturing operations, reducing the work in process and floor space utilization, and reducing the damaged products without affecting the delivery time. In this way, planning and control practices can lead to higher financial performance by reducing in-process wastes, faulty materials and improving the work scheduling. In this line, the following hypothesis can be done:

H4: Operational performance is positively related to financial performance.

The profitability of practices that allow improving the environmental performance has largely been called into question by practitioners. Nevertheless, there are the ones that agree that improvements in the environmental performance can lead to improvements in the financial aspects in terms of cost savings through a more efficient system leading to a positive impact on the ROI (García Hernández et al., 2012) and through avoiding paying high taxes and punishments applied by local regulations and international standards. In addition, an improved environmental performance would result in a better firm's image making it more competitive and, consequently, more profitable. Then, the following hypothesis can be stated:

H5: Environmental performance is positively related to financial performance.

Social performance can be evaluated from the employees' point of view and from the community point of view. In the first case, if employees are trained, involved and empowered, they will be able to work more efficiently, being willing to learn and adopt new manufacturing strategies, and even to propose their own ideas to improve the manufacturing processes. In the second case, if the firm interacts with the community, adding value to their culture and daily life, the image of the firm will be improved and the community will be engaged with the firm's principles and will buy its products. In both cases, the described socially improved contexts will lead to financial improvements. In this sense, it can be stated that:

H6: Social performance is positively related to financial performance.

6.5.5 Summary of the Research Hypotheses

Table 6-6 shows a summary of the research hypotheses included in the proposed conceptual framework shown in Figure 6.2 to model the different contributions of the lean, green and lean-green practices towards the different considered aspects of the sustainability performance, *viz.*, operational, environmental and social, as well as the contributions among these sustainability aspects, and the financial performance.

Table 6-4: Summary of research hypotheses.

No.	Hypothesis	Type of hypothesised relationship
H1a	Lean technical and social practices positively influence operational performance.	Direct (+)
H1b	Lean technical and social practices positively influence environmental performance.	Direct (+)
H1c	Lean technical and social practices positively influence social performance.	Direct (+)
H2a	Green practices positively influence operational performance.	Direct (+)
H2b	Green practices positively influence environmental performance.	Direct (+)
H2c	Green practices positively influence social performance.	Direct (+)
H3a	Lean practices moderate the relationship between green practices and operational performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.	Interaction (+)
H3b	Lean practices moderate the relationship between green practices and environmental performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.	Interaction (+)
H3c	Lean practices moderate the relationship between green practices and social performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.	Interaction (+)
H4	Operational performance is positively related to economic performance.	Direct (+)
H5	Environmental performance is positively related to economic performance.	Direct (+)
H6	Social performance is positively related to economic performance.	Direct (+)

6.6 Chapter Summary

In this chapter, the design and development of the proposed theoretical manufacturing framework to combine lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and disguising their weaknesses, towards filling some of the currently most concerning research gaps identified via the conducted SLRs in Chapters 2, 3 and 4 is introduced. In particular, the proposed theoretical manufacturing framework is supported by the STS theory and the synergistic concept. In this way, it is intended to integrate lean, green and lean-green tools by taking into account their interaction, either direct or indirect, as well as their contributions to the different aspects of sustainability, modelled by operational, environmental and social ones, which, for their part, contribute to the financial aspect, through different hypotheses developed based on the analysis of the gathered information by the SLRs. In addition, in order to test the validity of the proposed theoretical manufacturing framework in this chapter, a survey has been conducted within the real manufacturing scenario. In this way, the researcher intends to analyse the ideas, perceptions, thoughts and feelings of the practitioners regarding the proposed theoretical manufacturing framework in order to explore and understand its practical value and implications. In particular, in Chapter 7, a quantitative analysis of the gathered data via the conducted survey is presented.

7 SURVEY MECHANISM AND DESIGN

7.1 Introduction

It is a well-known fact that the industry and production of a country are great economic indicators of its development, as well as important indicators of its autonomy and position at world level. In Saudi Arabia, modernisation and industrial diversification are taking place at a rapid pace, accompanying the modernisation of the country. In addition, the bet in new sectors as well as the greater intervention of the population in the country decisions has also contributed to the industrial modernisation. However, the increased industrialisation has contributed to increased environmental and sustainability concerns. While the global market urges to move towards superior manufacturing practices, including the implementation of lean, green and lean-green practices, such practices are just in their early stages in most of Saudi companies (Creswell, 2003). In this context, the lean-green combined theoretical manufacturing framework proposed in this thesis is intended to encourage Saudi companies to move towards implementing new and innovative manufacturing procedures, providing them useful tools to actually improve their economic, environmental and social performances. In this line, a survey is conducted towards practically testing and validating the lean-green theoretical manufacturing framework proposed in Chapter 6 (Figure 6.2) by studying, describing and evaluating the perception of Saudi practitioners regarding the introduction of lean, green or lean-green approaches in their business, their expected benefits and issues, and their impact on the outcomes in terms of economic (operational and financial, as modelled in the proposed theoretical framework (Figure 6.2)), environmental and social performances. In this chapter, the conducted survey is described in detail and its validity, in terms of its statistical significance, has been analysed towards ensuring the reliability of the obtained results.

The remaining of the chapter is organised as follows. Section 7.2 describes the general survey structure. The following sections are focused on describing the methods used for descriptive statistics. Section 7.3 is devoted to the quantitative pre-process of the data, Section 7.4 analysis the used sample, Section 7.5 describes the methodology used to validate the survey, in terms of testing the assumption, testing the common method bias and non-response bias, and evaluating the measurement model. Finally, the chapter is summarised in Section 7.6.

7.2 Survey Structure

The conducted survey is based on an *ad-hoc* designed questionnaire including 273 questions (*x* multiple choice Likert scale questions and *y* open text questions) addressing five main aspects:

- Personal and business information
- Impact of lean practices on business outcomes
- Impact of green practices on business outcomes
- Knowledge about lean-green practices as well as their impact on business outcomes
- Impact of operational, environmental and social performances on financial performance

7.3 Quantitative Pre-process of the Data

Based on a PCA analysis (described in Section 5.3.1.6), Likert scale questions have 5 possible answers, containing 13 principal components for their further analysis. Table 7-1 shows a summary of the 13 main components and the number of questions that account for each one of them.

Table 7-1: Thirteen principal components used for data analysis.

Lean practices towards Operational Performance → 27 questions
Lean practices towards Environmental Performance → 17 questions
Lean Practices towards Social Performance → 27 questions
Green Practices towards Operational Performance → 26 questions
Green practices towards Environmental Performance → 29 questions
Green Practices towards Social Performance → 15 questions
Lean-Green Approach: Understanding → 49 questions
Lean-Green Approach towards Operational Performance → 12 questions
Lean-Green Approach towards Environmental Performance → 6 questions
Lean-Green Approach towards Social Performance → 10 questions
Operational Performance towards Financial Performance → 9 questions
Environmental Performance towards Financial Performance → 4 questions
Social Performance towards Financial Performance → 8 questions

7.4 Sample Description

The sample population surveyed in this study is composed by 102 employees from 14 different companies in Saudi Arabia. Table 7-2 shows a list of the companies where the surveyed took place.

Table 7-2: Description of the surveyed companies.

Company	Sector	Location
Maimani Red Bricks Factory	Red Bricks Factory	Madina, Saudi Arabia
Azel Rockwool Insulation Factory	Insulation Factory	Yanbu, Saudi Arabia
Taiba Water Factory	Water Factory	Madina, Saudi Arabia

Eastern Petrochemical Company	Petrochemical Company	Al Jubail, Saudi Arabia
Advanced Petrochemical Company	Petrochemical Company	Al Jubail, Saudi Arabia
Safco-Saudi Arabian Fertilizer Company	Petrochemical Company	Al Jubail, Saudi Arabia
Sabic Yanbet	Petrochemical Company	Yanbu, Saudi Arabia
Sadaf-Saudi Petrochemical Company	Petrochemical Company	Al Jubail, Saudi Arabia
The Saudi Chevron Phillips Company (SCP)	Petrochemical Company	Al Jubail, Saudi Arabia
Sahara-Petrochemical Company	Petrochemical Company	Al Jubail, Saudi Arabia
Arabian Petrochemical Company (PETROKEMIA)	Petrochemical Company	Al Jubail, Saudi Arabia
MAAdDEN Saudi Arabian Mining Company	Mining Company	Riyadh, Saudi Arabia
Tasnee- Petrochemical Company	Petrochemical Company	Yanbu, Saudi Arabia
Sabic NATBET	Petrochemical Company	Yanbu, Saudi Arabia

The survey was distributed to different employees of the companies described in Table 7-2 working in a wide range of job positions as shown in Table 7-3.

Table 7-3: Job position of surveyed respondents among all businesses.

Job Position	Count	N %
Tech Engineer	25	24.5%
Chemical Analyst	3	2.9%
Department Chief	3	2.9%
Production	21	20.6%
Engineer	14	13.7%
Manager	7	6.9%
Operations	17	16.7%
Department Manager	2	2.0%
Account	2	2.0%
Assistant	2	2.0%
Driver	2	2.0%
Technician	4	3.9%

To have a wide range of business activities included in the sample is crucial in order for the survey to cover the real business scenario as much as possible. In particular, the conducted survey includes employees from 14 Saudi companies. It is important to highlight, however that, although the surveyed companies are focused in different business activities, not all the activities are equally represented in the survey, being most of the respondents from the chemistry, petroleum, rubber and food industries. The wood and paper industries, on the other hand, are the business activities with the lowest representation. All the business activities represented in the conducted survey are shown in Figure 7.1.

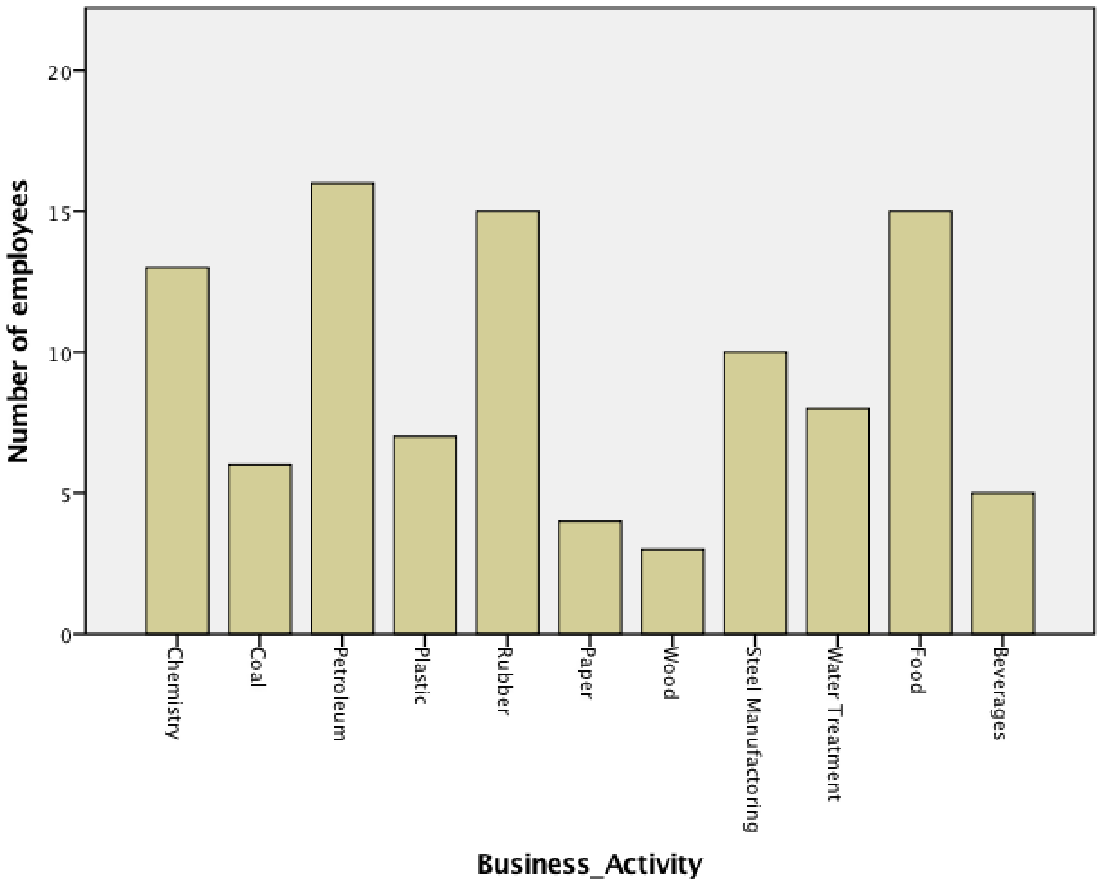

Figure 7.1: Business activities included in the survey.

The proposed theoretical framework in Chapter 6 is intended to be useful not only to big companies but also to SMEs. In this line, during sample selection, a big effort has been made towards obtaining questionnaires returned from a representative sample, in terms of size, of Saudi businesses. This would result in both SMEs and big businesses to be equally represented in the survey. Nevertheless, in the practice, several issues, such as, employees refusing to fil the questionnaire, as well as different constraints during sample selection and questionnaire distribution, made it not possible to obtain a similar number of questionnaires from all businesses' sizes. In general, the business size can be assessed by the number of employees. In particular, the surveyed businesses have a number of employees varying from 5 to 70. From each one of them, the number of obtained surveys varies from 3 to 10. The exact number of surveys obtained according to the number of employees in each business, *i.e.*, according to the business size, is shown Table 7-4.

Table 7-4: Number of surveys obtained according to the number of employees in business.

Number of employees in business	Number of surveys from business

5	3
6	5
7	8
8	7
9	6
12	5
13	7
14	9
16	10
24	8
39	9
43	8
47	4
50	7
70	6

In addition, employees surveyed within the context of the different business have reported different years of professional experience in the job as well as in the corresponding business, as shown in Figure 7.2. From Figure 7.2, it can be seen that most of the surveyed employees have broad experience in their job positions, having worked there for several years, in particular, between 11 and 15 or even more than 21. In this sense, it can be said that the sampled employees should be able to respond to the questionnaire based on a deep know-how of their business activities.

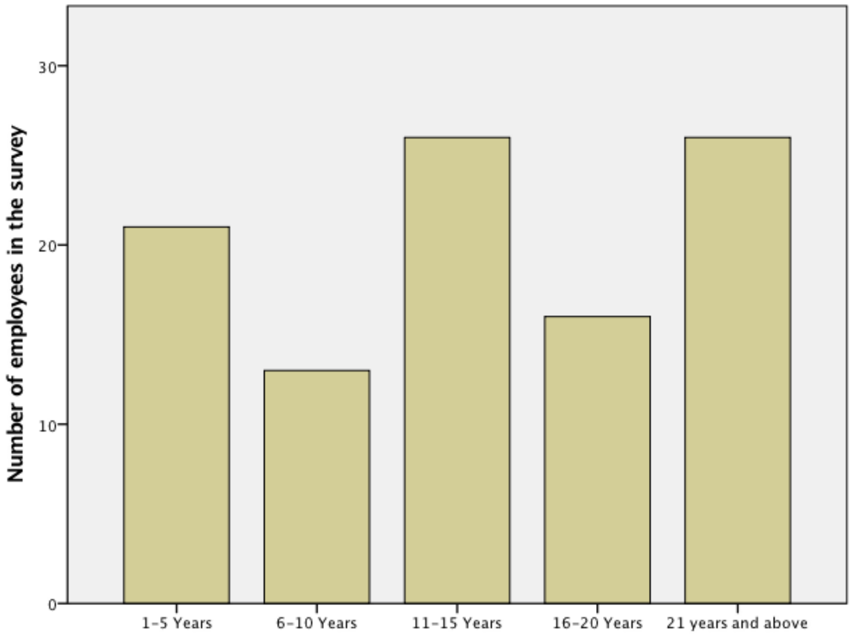

Figure 7.2: Years of professional experience for all employees surveyed across all business.

Regarding the production volume level of the surveyed businesses, the majority of the employees, in particular, 64.7% of the total respondents, reported it to be high. On the other hand, about 24% of the total respondents reported the volume level as medium, while the rest of the respondents reported it as low. In Figure 7.3, this distribution is illustrated by a pie chart.

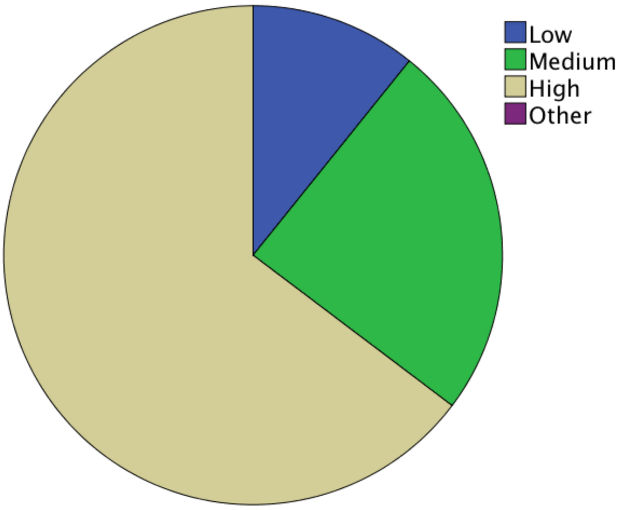

Figure 7.3: Volume level of production across all surveyed employees for all businesses.

With a similar distribution, most of the surveyed businesses work exclusively with retailers (63.7%), while only 26.5% of them sell their products directly to end users, as shown in the pie chart of Figure 7.4.

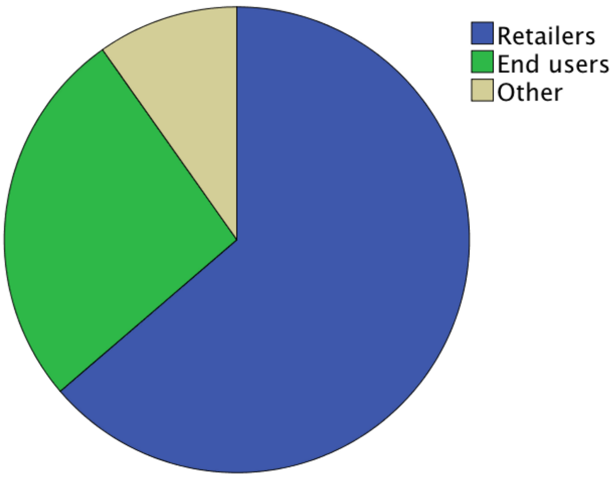

Figure 7.4: Distribution of business users for the total of 102 respondents.

The questionnaire data for all the included questions is summarised, based on a PCA analysis, according to 13 principal components aiming to access specific questions regarding the lean, green and lean-green approaches. In this way, while individual questions are set using a Likert scale with 5 possible options (Strongly Agree=1, Agree=2, Don’t Know=3, Disagree=4 and Strongly Disagree=5), the 13 main components are the average score for all sub-questions of the main components. In Table 7-5, the 13 principal components of the questionnaire, referred to as dependent variables, are listed.

Table 7-5: Main components assessed by the questionnaire that were used for data analysis hypothesis testing.

Dependent Variable (DV) description	DV number
Lean practices towards Operational Performance	DV1
Lean practices towards Environmental Performance	DV2
Lean Practices towards Social Performance	DV3
Green Practices towards Operational Performance	DV4
Green practices towards Environmental Performance	DV5
Green Practices towards Social Performance	DV6
Lean-Green Approach: Understanding	DV7
Lean-Green Approach towards Operational Performance	DV8
Lean-Green Approach towards Environmental Performance	DV9
Lean-Green Approach towards Social Performance	DV10
Operational Performance towards Financial Performance	DV11
Environmental Performance towards Financial Performance	DV12
Social Performance towards Financial Performance	DV13

7.5 Survey Validity

In order to ensure the reliability of the results, the survey is practically conducted following a series of steps listed in Section 7.5.1 as well as its statistical significance is evaluated as described in Section 7.5.2.

7.5.1 Survey implementation

As discussed in Section 5.3.4, the analysis of the primary data collected by the survey is performed mainly based on a qualitative approach. Nevertheless, a quantitative analysis of the data is also performed in an attempt to complement the findigns and provide numerical support when needed. In addition, using both qualitative and quantitative analysis allows for triangulation which helps increasing the validity of the survey and further evaluating the accuracy of the findings by validating data through:

- Analysing data from different perspectives
- Analysing the convergence of the obtained results
- Further explaining the obtained results

In addition, for the sake of a reliable data collection, in the practice, the survey is conducted following the principles listed here:

- Prolonged and persistent field work: Allows interim data analysis and corroboration to ensure match between findings and participants' reality.
- Participant language verbatim accounts: Obtain literal statements of participants and quotations from documents.
- Low-inference descriptors: Record precise, almost literal, and detailed descriptions of people and situations.

- Multiple researchers: Agreement on the descriptive data collected by the research team.
- Participant researcher: Use of participants recorded perceptions in diaries or anecdotal records for corroboration.
- Member checking: Check informally with participants for accuracy during data collection frequently done in participant observation studies.
- Participant review: Ask participants to review researcher's synthesis of interviews with person for accuracy of representation frequently done in interview studies.
- Negative or discrepant data: Actively search for record, analyze, and report negative or discrepant data that are an exception to patterns or that modify patterns found in data.

7.5.2 Testing the Assumption

Statistical tests usually require assumptions to be fulfilled in order to prove their validity. Among them, assuming the sample is normally distributed or large enough (usually higher than 30 individuals or observations), are the most common ones. In addition, the linearity assumption is also important in the case of linear regression modelling since, in such a case, the outliners can have a significant impact on the models. Finally, the homoscedasticity assumption is also helpful to simplify the mathematical computation. In Sections 7.5.1.1, 7.5.1.2 and 7.5.1.3, normality, linearity and homoscedasticity are tested.

7.5.2.1 Normality

In general, the larger the sample size, the closer the distribution to the normal one. In particular, most statistical and mathematical tests are based on the central limit theorem which indicates that, provided the sample size is large enough, the means of samples obtained using a random sampling with replacement are distributed normally, regardless of the population distribution. To access normality of data distribution for the 13 main components of the questionnaire, the four most common tests of normality, *viz.*, Skewness, Kurtosis (Saja et al., 2015), Kolmogorov-Smirnov, and Shapiro-Wilk (Kim, 2013), are used. The results of these tests are shown in Table 7-6. From Table 7-6, it can be seen that, when evaluating the variable distribution based on the Skewness and Kurtosis tests, most of them result to be not normally distributed. This is not surprising, since they are the mean value of a Likert scale, in which the central measure (Don't know=3) is the less likely to occur. On the other hand, when evaluating the variable distribution based on the Kolmogorov-Smirnov and Shapiro-Wilk tests, data can be considered as normal distributed ($p<0.05$ for all variables). These findings based on the results shown in Table 7-6 are probably due to the sample size ($n=102$) rather than due to a "perfect" normal distribution (Razali and Wah, 2011).

Table 7-6: Normality tests for the 13 dependent variables in the study.

	Skewness			Kurtosis			Kolmogorov-Smirnov	Shapiro-Wilk
	Statistic	**Std. Error**	**Z-score**	**Statistic**	**Std. Error**	**Z-score**	**Sig. (p-value)**	**Sig. (p-value)**
DV1	-0.578	0.239	-2.410	1.171	0.474	2.470	<0.001	<0.001
DV2	-0.790	0.239	-3.305	0.149	0.474	_**0.314***_	<0.001	<0.001
DV3	-0.221	0.239	_**-0.925***_	1.596	0.474	3.367	<0.001	<0.001
DV4	-1.047	0.239	-4.381	0.844	0.474	_**1.781***_	<0.001	<0.001
DV5	-0.843	0.239	-3.527	1.070	0.474	2.258	<0.001	<0.001
DV6	0.015	0.239	_**0.063***_	0.008	0.474	_**0.017***_	<0.001	0.015
DV7	-0.446	0.239	_**-1.866***_	1.445	0.474	3.049	<0.001	<0.001
DV8	2.019	0.239	8.448	12.142	0.474	25.616	<0.001	<0.001
DV9	-0.003	0.239	_**-0.013***_	0.543	0.474	_**1.146***_	<0.001	0.01
DV10	-0.735	0.239	-3.075	0.826	0.474	_**1.743***_	<0.001	<0.001
DV11	-0.481	0.239	-2.013	1.346	0.474	2.840	<0.001	<0.001
DV12	0.141	0.239	_**0.590***_	1.746	0.474	3.684	<0.001	<0.001
DV13	-0.337	0.239	_**-1.410***_	0.669	0.474	1.411	<0.001	<0.001

*Significant values p<0.05

7.5.2.2 Linearity

To test for linearity a correlation matrix was constructed using Pearson's Bivariate Correlation among all the 13 variables. The obtained correlation coefficients are shown in Table 7-7. From Table 7-7, it can be seen that, with exception to only 3 correlations (highlighted in boldface in Table 7-7), all the variables are significant and positively correlated, with p<0.05.

Table 7-7: Linearity test using Pearson's Bivariate Correlation among the 13 variables.

Kendall's tau	DV2	DV3	DV4	DV5	DV6	DV7	DV8	DV9	DV10	DV11	DV12	DV13
DV1	0.317	0.646	0.334	0.374	0.445	0.232	0.425	0.270	0.652	0.313	0.345	0.312
DV2		0.433	0.524	0.479	0.372	0.421	0.500	0.557	0.393	0.442	0.209	0.472
DV3			0.363	0.434	0.422	0.301	0.562	0.338	0.676	0.458	0.442	0.246
DV4				0.584	0.262	0.474	0.296	0.350	0.401	0.237	0.437	0.387
DV5					_**0.133**_	0.436	0.450	0.416	0.279	0.335	0.312	0.287
DV6						0.424	0.297	0.438	0.577	0.585	0.250	0.558
DV7							_**0.096**_	0.496	0.214	0.415	0.240	0.323
DV8								0.478	0.461	0.418	0.283	0.446
DV9									0.306	0.394	_**-0.051**_	0.441
DV10										0.452	0.529	0.357
DV11											0.363	0.570
DV12												0.228
DV13												

7.5.2.3 Homoscedasticity

Homoscedasticity is accessed, for the 13 variables, using their residuals. Residuals are the differences between the values predicted assuming normal distribution and the values obtained from the real data. In particular, homoscedastic data should have residual values normally distributed. In order to test so, standardised z-score values are calculated for each of the 13 variables, and then the normality of these standardised values is accessed. Here, it is important to highlight that, although the data corresponding to the residuals is not perfectly parametric, parametric tests can still be employed since the size of the used sample is big enough. The obtained results regarding the residual values distribution are shown in Table 7-8. For the Skewness and Kurtosis tests, a z-score value between -1.96 and 1.96 is associated with normal distributed data. Values in this interval are highlighted in boldface in Table 7-8. According to the results shown in Table 7-8 for the Kolmogorov-Smirnov and Shapiro-Wilk tests, where a p<0.05 is associated with a normal distribution, most of the residual values are normally distributed.

Table 7-8: Normality tests for the residuals of all 13 variables in the study.

	Skewness			Kurtosis			Kolmogorov-Smirnov	Shapiro-Wilk
	Statistic	Std. Error	Z-score	Statistic	Std. Error	Z-score	Sig. (p-value)	Sig. (p-value)
DV1	-0.578	0.239	-2.410	1.171	0.474	2.470	<0.001	<0.001
DV2	-0.790	0.239	-3.305	0.149	0.474	***0.314****	<0.001	<0.001
DV3	-0.221	0.239	***-0.925****	1.596	0.474	3.367	<0.001	<0.001
DV4	-1.047	0.239	-4.381	0.844	0.474	***1.781****	<0.001	<0.001
DV5	-0.843	0.239	-3.527	1.070	0.474	2.258	<0.001	<0.001
DV6	0.015	0.239	***0.063****	0.008	0.474	***0.017****	<0.001	0.015
DV7	-0.446	0.239	***-1.866****	1.445	0.474	3.049	<0.001	<0.001
DV8	2.019	0.239	8.448	12.142	0.474	25.616	<0.001	<0.001
DV9	-0.003	0.239	***-0.013****	0.543	0.474	***1.146****	<0.001	0.01
DV10	-0.735	0.239	-3.075	0.826	0.474	***1.743****	<0.001	<0.001
DV11	-0.481	0.239	-2.013	1.346	0.474	2.840	<0.001	<0.001
DV12	0.141	0.239	***0.590****	1.746	0.474	3.684	<0.001	<0.001
DV13	-0.337	0.239	***-1.410****	0.669	0.474	1.411	<0.001	<0.001

7.5.3 Testing Common Method Bias and Non-response Bias

In the estimation of structural models, it is common to use data obtained from surveys, as in the case of the research conducted within the framework of this thesis. When data from exogenous and endogenous variables are obtained from the same source (same respondents, same format of responses, same form of collection, etc.), as it is the case of the conducted survey, the common method bias can occur. The common method bias, which is a bias of underestimation or overestimation of measure, is associated with the error that occurs when respondents of a questionnaire have the will to provide positive answers to the researcher in order to better suit the research objectives. In particular, the common method bias can be detected based on a principle that establishes that variations in responses are caused by the instrument rather than by the actual predisposition of the respondents (Ghasemi and Zahediasl, 2012). Based on this principle, the Harman test, which is not capable of directly testing (or controlling) the method bias, but allows testing the respondents' response bias, can still be used to test for common method bias.

7.5.3.1 Harman's Single Factor

According to the Harman test, bias is considered to occur either when the solution results in a single extracted factor or when a single factor extracts most of the variance from the set of variables. The Harman one-factor analysis is then used to test for common method bias by testing whether a single factor is accountable for variance in all the data set or not. In the analysis performed in this chapter, the Harman test is performed by using PCA as the extraction method (Tehseen et al., 2017). Table 7-9 shows the results of the Haman's single factor test.

Table 7-9: Harman's single factor for total variance explained using principal component analysis as extraction method.

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Factor	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	9.832	75.628	75.628	**9.602**	**73.865**	**73.865**
2	.851	6.549	82.178			
3	.633	4.873	87.050			
4	.469	3.606	90.656			
5	.348	2.680	93.336			
6	.220	1.689	95.025			
7	.192	1.476	96.501			
8	.133	1.024	97.526			
9	.127	.981	98.506			
10	.092	.711	99.217			
11	.045	.346	99.562			
12	.033	.256	99.818			
13	.024	.182	100.000			

From Table 7-9, it can be seen that only one factor (number 1) is responsible for more than 75% of the variance in the tests. This suggests that respondents may have answered with the aim of fulfilling the study objectives or may have claimed some interests or personal views rather than a truthful report of the actual business situation.

7.5.4 Evaluating the Measurement Model Value

To evaluate the model measurement value, the reliability and validity of the questionnaire is assessed. In particular, the reliability of the measurement model, discussed in Section 7.5.3.1, is tested using statistical methods, while its validity, discussed in Section 7.5.3.2, is addressed from an empirical point of view.

7.5.4.1 Reliability

According to the survey validation process introduced in (Tehseen et al., 2017) and presented in Section 5.3.1.6, an analysis based on carefully selected statistical methods should be used to test the reliability of the survey. In the case of the conducted survey, reliability is accessed based on the well-known Cronbach's Alpha test. In general, reliability tests aim to access whether two observations in the same study or questionnaire equivalent to each other in terms of the construct and measurement tools, lead to an equivalent outcome when comparing their outcomes to each other. In order to do so, the Cronbach's Alpha test splits data in two equal parts and compares variations in these two parts. The Cronbach's Alpha test results in reliability values varying between 0 and 1, being values higher than 0.7 usually considered acceptable for Likert scale data (Collingridge, 2014). For the conducted survey, a Cronbach's Alpha value of 0.972 has been obtained, as shown in Table 7-10, demonstrating an excellent reliability of the measurement tool.

Table 7-10: Reliability analysis using Cronbach's Alpha.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.962	**0.972**	13

In order to further prove the reliability of the conducted survey, the Cronbach's Alpha test is strengthened by performing it "if item deleted". In this case, the obtained results still remain higher than 0.9, suggesting an excellent reliability of the survey, even if only one item is analysed. Table 7-11 shows all the results obtained in the case of one item deleted, performed for all the main components in the analysis.

Table 7-11: Reliability analysis using Cronbach's Alpha if item deleted.

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Lean practices towards Operational Performance	35.1870	57.730	0.897	**0.958**
Lean practices towards Environmental Performance	35.1123	56.950	0.853	**0.958**
Lean Practices towards Social Performance	35.3104	57.473	0.923	**0.957**
Green Practices towards Operational Performance	35.0186	56.807	0.866	**0.958**
Green practices towards Environmental Performance	35.1188	57.099	0.888	**0.958**
Green Practices towards Social Performance	35.3410	57.393	0.804	**0.959**
Lean-Green Approach: Understanding	35.1664	56.580	0.906	**0.957**
Lean-Green Approach towards Operational Performance	35.1428	53.086	0.664	**0.969**
Lean-Green Approach towards Environmental Performance	35.2081	56.653	0.796	**0.959**
Lean-Green Approach towards Social Performance	35.0409	55.578	0.924	**0.956**
Operational Performance towards Financial Performance	35.1302	55.837	0.916	**0.957**
Environmental Performance towards Financial Performance	34.7318	56.724	0.574	**0.967**
Social Performance towards Financial Performance	35.2441	56.580	0.861	**0.958**

7.5.4.2 Validity

The process of analysing the validity of an instrument depends, among other factors, on the variables to be validated, on the objectives of the measuring instrument and on the population that the instrument has to measure. Different types of validity, such as, content, discriminant and convergent validity, can be tested. Not every type of validity supports statistical analysis. For instance, the validation of content is usually performed based on the judgment of the researcher or expert regarding the content of the instrument. The discriminant validity, on the other hand, checks the extent to which the construct does not correlate with other constructs that differ from it, while convergent validity measures consistency and uniformity among similar individuals. In Sections 7.5.3.2.1, 7.5.3.2.2 and 7.5.3.2.3, the content, discriminant and convergent validity are analysed, respectively.

7.5.4.2.1 Content Validity

Content validity refers to the degree to which the content of an instrument adequately reflects the construct that is being measured, that is, it evaluates to what extent a sample of items is representative of a defined universe or domain of a content. For instance, an instrument that assesses satisfaction should include not only satisfaction but also other variables related to it, such as, remuneration, promotion, relations with colleagues work, among others (Gliem, 2003). Since there is no specific statistical test for evaluating content validity, a qualitative approach, based on the judgement of the researcher or of a committee of experts, is usually used. In the case of the conducted survey, the questionnaire has been specially designed by the researcher in order to validate the proposed theoretical manufacturing framework combining lean, green and lean-green practices. Then, in this case, questions included in the questionnaire are strictly focused on providing a deep insight into the current real situation of lean, green and lean-green practices in Saudi companies.

7.5.4.2.2 Discriminant Validity

Discriminant validity tests the hypothesis that the target measures are not unduly related with different constructs, *i.e.*, with variables from which they should diverge. For instance, an instrument that assesses motivation should have low correlations with an instrument that measures self-efficacy. In general, correlation tests are used to measure discriminant validity between variables that must have opposite variance values. In the questionnaire used to conduct the present survey, all the questions have been designed in such a way that a positive measure of its impact is given. In this context, it is not possible to test the divergence of correlation between the different questions (or main components) of the questionnaire (Rubio et al., 2003).

7.5.4.2.3 Convergent Validity

The convergent validity is obtained by the correlation of the focal instrument with another instrument that evaluates a similar construct, expecting to obtain a high correlation between them (Cable and DeRue, 2002). For instance, in the application of two instruments that evaluate job satisfaction, it is expected that strong correlations will be obtained. In order to evaluate the convergent validity of the questionnaire used to conduct the present survey, the correlation matrix among all the main components presented in Table 7-7 can be used. Based on this correlation matrix, it can be proved that all the main components have a convergent validity among them.

7.6 Chapter Summary

The main objective of the conducted survey is to identify and evaluate the perception of industrial workers in Saudi Arabia regarding the introduction of lean, green and lean-green approaches in their business, as well as the expected (or already achieved) effects on crucial sustainability aspects, such as, operational environmental and social ones. In addition, a secondary objective, focused on testing the perception of Saudi workers about the influence of operational, environmental and social performances on the financial performance is also pursued. In order to achieve such objectives, the survey is based on an *ad-hoc* designed questionnaire applied to 102 employees from 14 different Saudi companies. In this chapter, the conducted survey has been described in detail and its validaty, in terms of statistical significance, has been evaluated in order to ensure the reliability of the results. In Chapter 8 the main results of the conducted survey are analysed and discussed.

8 DISCUSSION AND ANALYSIS

8.1 Introduction

The current global market situation have largely demonstrated that companies are urged to move towards superior manufacturing practices that can maintain a healthy balance among the three pillars of sustainability performance, *viz.*, economic, environmental and social ones. In this line, many researchers in the field of manufacturing have suggested to take advantage of the synergetic effects that can be obtained by integrating lean and green practices. Nevertheless, although the great efforts that have been done in the last years, there are still several research gaps regarding the actual implementation of such a combined strategy (Paul et al., 2014). The research conducted within the framework of this thesis is aimed at developing a novel manufacturing framework to combine lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and disguising their weaknesses. In this way, it is intended to provide researchers and practitioners an innovative lean-green manufacturing tool capable of achieving the currently required level of sustainability, in terms of improving economic, environmental and social aspects simultaneously. In order to do so, the methodology described in Chapter 5 is adopted. More specifically, in order to develop the proposed theoretical manufacturing framework, the flowchart in Figure 6.1 is followed. According to it, the first step in the research is to conduct an extent literature review in order to obtain an in-depth insight into the current situation regarding lean and green practices adoption, the awareness regarding the need for combining them towards improving the sustainability level and the actual possibility of implementing such combination. In this line, three SLRs have been carried out and presented in Chapters 2, 3 and 4 analysing the current trends in lean, green and lean-green practices, respectively, and doing special focus on their link with sustainability. Based on the research gaps identified by the conducted SLRs, the novel theoretical manufacturing framework presented in Chapter 6 and depicted in Figure 6.2, has been proposed, designed and developed. Once the theoretical manufacturing framework has already been introduced, the next step in the present research, according to the research outline in Figure 6.1, is to validate and test it. In order to do so, primary data is collected via the survey described in Chapter 7 including close- and open-ended questions conducted in different Saudi manufacturing companies following the guidelines described in Sections 5.3.3 and 5.3.6. Then, the analysis of the collected primary data is performed mainly based on a qualitative approach. In this way, the researcher can explore the practitioners' personal experiences when implementing lean and green practices, their perceptions about the different sustainability aspects improved by these practices and their feelings regarding how they should be integrated into a combined manufacturing framework. In this thesis, this qualitative analysis is performed based on the NVIVO 12[57] analysis. In addition, as discussed in Section 5.3.4, according to several researchers, the use of both qualitative and quantitative approaches when analysing the collected data can lead to a deeper understanding of the subject under study by complementing each other (McWilliams and Siegel, 2000), (Teddlie and Tashakkori, 2009), (Bryman, 2006). In this chapter, a quantitative analysis of the primary data is also carried out to support the qualitative findings by providing a different analysis perspective and allowing numerical evaluation. In particular, the proposed quantitative analysis conducted in this thesis is focused on validating the hypotheses supporting the theoretical manufacturing framework presented in Figure 6.2 based on a statistical analysis conducted using IBM SPSS version 23[58].

The remaining of the chapter is organised as follows. In Section 8.2, the qualitative analysis of the survey results is presented. In particular, a thematic analysis of the collected data is performed in Section 8.2.1, in terms of the three main identified themes, *viz.*, lean, green and lean-green approaches, which are addressed in Sections 8.2.1.1, 8.2.1.2 and 8.2.1.3, respectively. In Section 8.3, the complementary quantitative analysis of the survey results is presented. In particular, in Section 8.3.1 the validation of the proposed lean-green theoretical manufacturing framework presented in Chapter 6 (shown in Figure 6.2) is evaluated by testing its hypotheses. Finally, a chapter summary is provided in Section 8.4.

8.2 Qualitative Analysis

The main objective of the qualitative exploratory analysis presented in this chapter is to account for the views of the Saudi employees regarding the implementation of lean and green practices, their benefits, issues and barriers, and the actual possibility of integrating them towards achieving a higher level of sustainability. The qualitative approach accepts reality as a construct of human interactions, experiences and knowledge. Within the context of the conducted survey, such kind of information is intended to be generated based on the interaction between the experiences of the respondents and their ideas, thoughts, opinions and feelings about each of the topics addressed in the questionnaire.

8.2.1 Thematic Analysis

A NVIVO 12 analysis has been carried out towards separating demographic data from the data corresponding to the answers in the questionnaire aiming to review personal opinions and experiences regarding the implementation of lean, green and lean-green

[57] https://www.qsrinternational.com/nvivo/home
[58] Available at: https://www-01.ibm.com/support/docview.wss?uid=swg24038592

approaches towards sustainability in the real Saudi manufacturing world. In addition, a data categorisation has also been performed in order to identify further and new findings by constructing different themes, *i.e.*, by grouping concepts connected with different phenomena. In this way, it is intended to capture the respondents' views and identify meaningful information patterns. In particular, the identified themes are associated with the experiences of employees from different industries that can contribute to answer the main research question of this thesis regarding whether it is possible to achieve a superior sustainability performance in terms of improving economic, environmental and social performances simultaneously by resorting to a combination of lean and green practices, as well as which would be the best strategy to do so. The different themes have been modelled in order to capture the different experiences of the respondents in their daily manufacturing practice and the perceived gaps, advantages, disadvantages, challenges and issues regarding the following three different categories:

- Category 1 - The Lean Approach
- Category 2 - The Green Practices
- Category 3 - The Lean-Green Approach.

In this way, the result of the qualitative analysis conducted in this chapter should be a synthesis allowing defining different and meaningful patterns of experience within the framework of the three categories defined above. In addition, common characteristics between the following demographic characteristics of the respondents are also evaluated:

- Business activity of the company
- Years of professional experience in the company
- Profession

Here, it is important to highlight that the role of the local "institutional context" in explaining industrial districts performance and local views of the development of lean and green approaches has also been taken into account when defining the themes, linking the debate about institutional capacity and its particular view regarding sustainability based on previously constructed questions. This is possibly due to the fact that themes are flexible, allowing the researcher to modify them whenever he deems it necessary, for instance, in the case of significant data occurrence.

8.2.1.1 Category 1 - Lean Approach and Operations

The first stage of the thematic analysis conducted here consists in studying the first defined category, namely, the one corresponding to the impact of lean practices in business. This is accessed by a set of questions directly associated with the identified success factors and the encountered barriers when implementing lean practices, as well as with the perceived benefits for business, environment and society. In the qualitative analysis conducted here, special focus is done on the opinions and feelings of Saudi employees about the adoption and implementation of lean practices, the perceived benefits, issues and barriers, as well as the actual possibility of achieving sustainable results in terms not only of economic, but also of environmental and social aspects. In order to do so, the general climate in Saudi companies regarding the lean approach is evaluated using the matrix developed by NVIVO 12 considering the number of repeated words and their connection with demographic data. Figure 8.1 shows a diagram based on the query results (NVIVO 12) from the questions regarding the barriers and conflicts associated with the lean approach implementation. The obtained results of such analysis show that Saudi employees are highly concerned about the (many) challenges that the implementation of lean practices implies. From Figure 8.1, it can be clearly seen that the identified challenges associated to the lean implementation by Saudi employees are quite diverse, raging from financial aspects and lack of leadership to technical and personal barriers. Then, in order to be able to properly analyse this category, a further division is performed towards taking into account the different themes related to the different obstacles implied by the lean approach implementation mentioned by the respondents. In particular, three further themes are defined, *viz.*, lack of management and leadership, personal barriers and lack of resources, described in Sections 8.2.1.1.1, 8.2.1.1.2 and 8.2.1.1.3, respectively.

Figure 8.1: NVIVO 12 diagram for Category 1 - Lean Approach and Operations.

8.2.1.1.1 Theme 1. Lack of Management and Leadership

The first theme, referred to as “lack of management and leadership”, is the result of narrowing the focus to the most available repeated codes, such as, *lack of management*, *lack of leadership*, *lack of business culture or vision* and *no training for employees*. This theme accounts for the institutional level, in the sense of defining the company as the place or location where institutional problems (regarding the implementation of lean practices) can be detected. According to the obtained results shown in Table 8-1, a vast majority of the respondents does not recognise their companies among the ones where the quality of the implementation of lean practices has been improved. This is particularly emphasized in the case of participants working in the rubber and the steel manufacturing industries. In this context, they argue that the current Saudi manufacturing strategies are not capable to achieve the expected lean results because of a lack of proper leadership and management engagement. In this line, they suggest top managers to adopt lean leadership strategies towards improving lean implementation.

Table 8-1: Lack of management and leadership according to the type of business activity.

Demographic	Lean approach_lack of management and leadership	Total (Unique)
...in_activity = chemistry *(n=3)*	0	0
..._activity = chesmistry *(n=2)*	2	2
..._activity = petroleum *(n=16)*	2	2
...ss_main_activity = coal *(n=6)*	0	0
...main_activity = plastic *(n=7)*	1	1
...ain_activity = Rubber *(n=15)*	4	4
..._main_activity = paper *(n=4)*	2	2
..._main_activity = wood *(n=3)*	1	1
...steel manufactoring *(n=10)*	4	4
...ivity = water treatment *(n=8)*	2	2
..._main_activity = Food *(n=15)*	1	1
...in_activity = Beverage *(n=5)*	2	2
...in_activity = Chemical *(n=8)*	2	2
Total *(n=102)*	23	23

8.2.1.1.2 Theme 2. Personal Barriers

The results of the conducted survey not only show that there exist institutional level barriers regarding the implementation of lean practices, but also show that there exist personal barriers delaying such implementation. In particular, a generalised consensus has been found among the surveyed employees highlighting that the lack of personal characteristics and capabilities constitute a huge barrier towards the implementation of the lean approach. Moreover, this theme, pointed out by the respondents resorting to expressions code as *resistance to change*, *no motivation*, *fear to failure*, *no security* and *additional pressure*, as shown in the diagram of Figure 8.2, is the most common theme among all the surveyed business activities. These results indicate that Saudi companies should improve their internal communication as well as provide employees a better training. Regarding communication, companies should give employees the proper information to keep them updated and make them understand what changes are being done and, even more important, why they are necessary. In this way, employees will not only be aware of what is happening at an institutional and technical level, but they will also be more willing to accept the changes by being aware of their benefits, not only for the company, in terms of operational and financial improvements, but also for themselves, in terms of better training and improved working conditions. This can improve employees' engagement with the change, making it smoother. Regarding employees training, companies should provide employees all the required knowledge to deal with the new technologies needed for lean implementation. In this way, employees will be more confident when adoping the new practices, avoiding extra pressures, such as the fear of losing their jobs or making mistakes. Here, it is important to highlight that, in the same way that the individual capabilities of the employees do positively correlate with the institutional potential of achieving sustainability, the individual barriers can make the institutional potential to decrease. In this sense, it is not only crucial to improve the institutional structure and culture, developing new and innovative management strategies and demonstrating a good and healthy leadership, but it is also crucial to keep employees engaged, stimulated, focused and well-trained. Finally, Table 8-2 shows the results obtained for the theme analysed in this section in terms of the years of professional experience. From Table 8-2, it can be seen that most of the employees reporting personal barriers have 5 years of experience in their current job position, representing the 37% of the whole surveyed employees. This suggests that employees with 5 (or less) years of experience may have a tendency to attribute the barriers to their lack of training rather than to an institutional issue. These result show that new employees tend to feel more insecure about their personal capabilities, making it crucial to train them in order to raise their confidence, and that they are not confortable with highlighting institutional failures. On the other hand, employees with more experience attribute the barriers not only to individual issues but also to a lack of management and leadership in combination with a general difficulty to overcome the change within the already established institutional framework.

Figure 8.2: Lack of management and leadership: NVIVO 12 diagram.

Table 8-2: Years of experience: Barriers to a lean approach.

Demographic	Lean approach_individual barriers	Lean approach_lack of management and leadership	Lean approach_lack of resources	Total
...sional_experience = 1 *(n=22)*	7	8	3	**18**
...sional_experience = 4 *(n=16)*	4	5	3	**12**
...sional_experience = 5 *(n=38)*	18	7	3	**28**
...sional_experience = 3 *(n=26)*	10	4	8	**22**
Total *(n=102)*	**39**	**24**	**17**	**80**

8.2.1.1.3 Theme 3. Lack of Resources

The third theme, which NVIVO 12 diagram is shown in Figure 8.3, refers to material and non-material resources, such as time, money and skills. According to the results of the conducted survey, employees of the petroleum area are the most concerned about this theme.

Figure 8.3: Lack of resources: NVIVO 12 diagram.

Generally speaking, many benefits regarding the lean approach implementation and its effect on sustainability aspects have been mentioned by the employees, characterised by codes such as *effectiveness*, *improvement*, *implementation*, *collaboration*, *alternatives*, *satisfaction and possibilities*, *progress*, *commitment* and *opportunities*, as shown in the diagram of Figure 8.4. In this regard, the most popular answers among employees are: *minimising waste, reducing inventory, improving quality, equipment effectiveness, automated processes* and *real market demand.* Neverteless, it is important to highlight that most of the "optimistic" views about lean practices corresponds to the less experienced employees, whereas employees with more experience tend to think that there exist a conflict of interests between the lean approach objectives and the environmental performance, as highlighted in Table 8-3. This disagreement between less and more experienced employees shows that employees that have been working in the company for more time, which have better knowledge about the company's culture and operational processes, are more aware of the actual barriers for implementing lean practices than the newer ones. In addition, the fact that the more experienced employees call into question the compatibility between the lean approach and the environmental performance shows that they have long been influenced by the top management's point of view, which considers green practices as a burden for production and achieving profits.

Table 8-3: Conflicts for the lean approach according to the years of experience.

Demographic	Lean Approach_conflicts	Lean approach for environment_ no conflicts	Lean aproach for sustainability_does not apply	Total (Unique)
...sional_experience = 1 *(n=22)*	6	3	4	**13**
...sional_experience = 4 *(n=16)*	7	2	2	**11**
...sional_experience = 5 *(n=38)*	16	5	9	**29**
...sional_experience = 3 *(n=26)*	9	3	2	**14**
Total *(n=102)*	**38**	**13**	**17**	**67**

Figure 8.4: NVIVO 12 sustainability benefits of lean practices.

In addition, going deeper in the thematic analysis, the surveyed companies can be divided into two categories in terms of which benefits achieved by the lean approach are perceived, and how they are perceived. Table 8-4 shows the highlighted lean benefit in terms of the business activity of the company. On one hand, most of the companies, including the ones focused on petroleum, wood, water treatment, food and chemical products, recognise business benefits in terms of cost reduction, increased productivity and profit, *i.e.*, strictly in economic (operational and financial) terms. On the other hand, only a few companies, including the ones focused on plastic, chemestry and beverages, mention waste reduction and management as the main advantages, making more emphasis in environmental aspects. In this line, it is clear that, although employees are beginning to recognise that lean practices can achieve benefits in terms of production and financial performance, they are not so convinced about the potential environmental benefits that lean practices can achieve. According to the available literature, the majority of the environmental impact of business processes comes from the materials used in business, being global warming, soil acidification, carcinogenesis material usage, respiratory effects or smog, common indicators. In addition, different studies, such as the one in (Karim, 2011), state that transportation, equipment manufacturing and combustion are the major contributors only for ozone depletion. In Saudi Arabia, most industries use raw material in their production, being the surveyed companies not the exception. Previous findings published in the literature for this particular kind of industries have shown that a highly efficient implementation of lean practices is needed towards achieving a significant impact on the environmental performance. The fact that most of the surveyed companies cannot identify environmental benefits when implementing lean practices could be indicating that the lean manufacturing implementation is still inefficient and has to be improved towards being able to perceive such benefits.

Table 8-4: Type of business activity: Lean approach for waste management.

Demographic	Lean approach_production and profit	Lean approach_waste management	Total (Unique)
...in_activity = chemistry *(n=3)*	0	1	**1**
..._activity = chesmistry *(n=2)*	0	0	**0**
..._activity = petroleum *(n=16)*	1	0	**1**
...ss_main_activity = coal *(n=6)*	0	0	**0**
...main_activity = plastic *(n=7)*	0	1	**1**
...ain_activity = Rubber *(n=15)*	0	0	**0**
..._main_activity = paper *(n=4)*	0	1	**1**
..._main_activity = wood *(n=3)*	1	0	**1**
...steel manufactoring *(n=10)*	0	0	**0**
...ivity = water treatment *(n=8)*	1	0	**1**
..._main_activity = Food *(n=15)*	3	0	**3**
...in_activity = Beverage *(n=5)*	0	1	**1**
...in_activity = Chemical *(n=8)*	1	0	**1**
Total *(n=102)*	**7**	**4**	**11**

8.2.1.1.4 Category 1: Summary

The results obtained from the conducted survey show that respondents from different Saudi companies do recognise the lean approach impact on the production and financial performances of the companies. On the other hand, their opinions regarding whether lean practices can lead environmental improvements are diverse. In this line, newer employees tend to consider that lean practices can achieve sustainable results, whereas more experienced employees are still calling into question the compatibility between lean practices and environmental performance. In addition, employees are concerned about the operational, cultural, institutional and personal barriers to implement lean manufacturing. In this line, they highlight the need for further developing management and individual skills, being the failure in the lean implementation of the lean approach attributed to the former by the newer employees and the latter by the older employees, but probably due to the combination of both. In this line, they highlight that, on one hand, it is necessary to develop effective systems on the institutional level, urging leaders and top managers to get more involved and adopt lean management strategies. On the other hand, it is also necessary to develop those individual characteristics that are essential for overcoming the personal barriers in order to make employees willing and capable to face the upcoming changes. In particular, surveyed employees have widely agreed that, in order to move towards leaner practices seeking for improving sustainable results, companies should ensure three principal elements:

- Security: Provided employees have adequate and safe working conditions, they will be able to adopt lean practices and see sustainability as an opportunity.
- Change management: A systematic approach capable of helping employees to experience the change towards leaner solutions, including a better internal communication giving employees relevant information so that they can understand the main goals of the changes, and the new processes and procedures being implemented.
- Lean training: Training employees would not only give employees confidence making them willing and capable of implementing the new technologies, but also would increase the value of the lean approach for them as well as for the whole company, at an institutional level.

Finally, the lack of resources has also been pointed out as one of the main responsible for the failure of the lean implementation. According to the STS theory described in Section 6.5.1, companies are only successful if they can keep a healthy interaction between technical and social aspects. In this regard, lean implementation as well as its positive impact on the sustainability aspects are more likely to occur within the framework of a well-defined and robust institutional culture, where management and employees skills are enhanced, their interaction is improved by the ensuring the three identified elements listed above, and the resource usage and its impact on social aspects are optimised.

8.2.1.2 Category 2 - Green Practices and Sustainability

The set of questions under Section 3 of the questionnaire aims to explore and understand respondents' ideas, perceptions, thoughts, opinions and feelings regarding the implementation of green practices, the actual possibility of becoming greener, the potential benefits this can carry and the current barriers encountered towards doing so. In particular, special focus is made on the green practices impact in the operational performance, as well as on how companies deal with environmental regulations, including international and local standards and policies. In order to analyse employees' answers to these questions, three themes, *viz.*, green practices opportunities, obstacles, and its relationship with the communities, are defined and generally discussed in Sections 8.2.1.2.1, 8.2.1.2.2 and 8.2.1.2.3, respectively.

8.2.1.2.1 Theme 1. Green Practices and Opportunities

The first theme discussed within this category is related to the opportunities that the implementation of green practices can imply. In particular, since, as discussed in Chapter 3, green practices highly depend on the business activities, the institutional culture, and the local regulations, being usually highly customised, it is important to collect, analyse and understand the perceptions and feelings of employees from different companies regarding the (potential) positive impact that such an implementation can have in the whole performance of the company. In order to do so, Figure 8.5 shows the different opportunities identified by employees working in industries focused on different business activities. According to Figure 8.5, the petroleum industry is the one that considers green practices are more promising, whereas the chemical industry is the one that considers them less interesting.

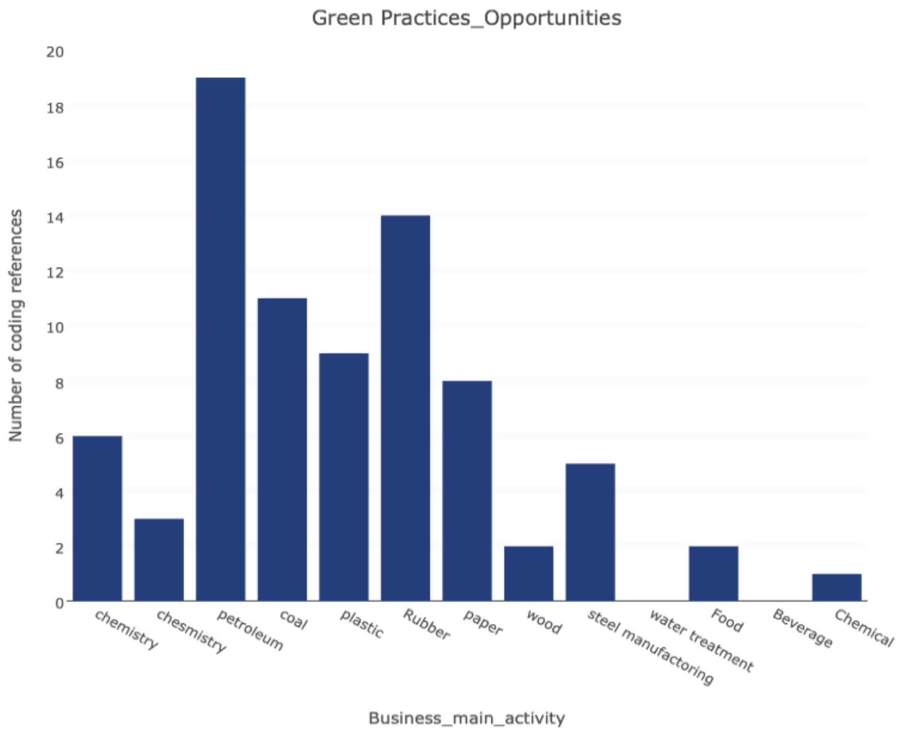

Figure 8.5: Type business activity: Identified opportunities for green practices.

In particular, the opportunities that the surveyed employees associate with the green approach implementation have been coded in 80 references, according to the results obtained from the NVIVO 12 analysis shown in Figure 8.6.

Figure 8.6: NVIVO 12 analysis for the green approach opportunities.

Among the most relevant opportunities reported by employees shown in Figure 8.6, the following ones have been particularly recurrent:

- Standardisation of processes
- Political lobbying
- Regular internal auditing to check compliance and implement change
- Manufacturing and volume flexibility
- Citizen action
- Improve efficiency
- Help to reduce CO2
- Making communities and business more resilient
- Interdisciplinary research
- Preventing and minimising waste
- Re-using
- Recycling
- Anticipating costs with regulatory affairs
- Use waste to generate new energy
- Inspire people to go green
- Recycling excess production
- Create a greater awareness of global issues
- Change political policies to be able to combat climate change
- Reducing trash production

As it can be seen from the list of the most recurrent green opportunities identified when analysing the employees answers, they believe that green practices can have positive impacts regarding environmental aspects, such as, reducing CO2 emissions, preventing and minimising waste, re-using, recycling, reducing trash production, and combating climate change; operational aspects, such as, standardising of processes and improving efficiency in terms of manufacturing and volume; financial aspects, such as, anticipating costs with regulatory affairs; and social aspects, such as, citizen action, and political lobbying. Nevertheless, it is important to highlight that, the most popular answers among employees, regardless the business area in which they work, are the ones corresponding to reducing CO2 emissions and recycling, suggesting that Saudi employees tend to strongly associate green practices with environmental opportunities, being the other mentioned associations still not strong. In this context, Saudi companies trying to become greener should not only develop an adequate system based on specific tools and techniques to activate the identified environmental opportunities, but also make especial efforts to take care of their internal culture and external politics towards also perceiving benefits not strictly related to environmental issues.

8.2.1.2.2 Theme 2. Green Practices Obstacles

The second theme identified for green practices is associated with the obstacles that employees have experienced when implementing such practices or think the implementation of such practices can imply. According to the surveyed employees' answers, the main barrier for implementing green practices is its financial cost. This is in line with the generalised opinion of top managers that has already been discussed throughout the thesis who consider that environmental regulations are a burden for profit. In this line, most of the surveyed employees agree that Saudi companies has not currently have the financial ability to comply with all the regulatory specifications, making the costs associated with environmental requirements to limit competitiveness. In addition, they have also highlighted that green practices implementation carries great difficulties related to operational aspects, since it requires to work with new technologies that are not only difficult to afford but also require specific know-how that employees don't usually have. Finally, in addition to the strict regulations and the operational difficulties, respondents have reported that the commonly used techniques for estimating green cost and benefits tend to overestimate costs, discouraging companies to become greener. Figure 8.7 shows a diagram based on the NVIVO 12 analysis for the current theme.

Figure 8.7: NVIVO 12 analysis of green obstacles.

Among the most recurrent identified obstacles, the following ones can be mentioned:

- Compliance cost is too high
- Misinformed public, questionable integrity of the regulatory system
- Regulations are too strict
- Management is responsible for all decisions
- Lack of civil, public and political support for the business
- Inaccurate cost and benefit estimates
- Social impacts and return are higher than the financial gain of an investment
- Environmental regulation is detrimental for economic performance
- Payment for the use of specific resources
- No ROI from making business green
- The ability of industries to compete

As discussed above, most of the employees agree that the main barrier to implement green practices is their cost. In order to analyse whether this perception is influenced by the employees' job position, Table 8-5 shows how green opportunities and obstacles are perceived by employees working in different job positions. From Table 8-5, it can be seen that employees working as engineers and production specialists, tend to have a more positive view towards implementing green practices, highlighting the opportunities rather than the obstacles they can carry. On the other hand, managers tend to have a more conservative view of green practices taking into account opportunities and obstacles in the same proportion.

Table 8-5: Job position: Obstacles and opportunities for green practices.

Demographic	Green Practices_Obstacles	Green Practices_Opportunities	Total (Unique)
..._position = Tech eng (n=22)	3	9	**9**
...sition = Chem Analyst (n=3)	0	2	**2**
...= Departmente Chief (n=3)	0	1	**1**
...position = Production (n=18)	5	7	**8**
Job_position = Eng (n=14)	3	8	**8**
Job_position = Tech eg (n=3)	0	1	**1**
...b_position = prodution (n=3)	1	1	**1**
Job_position = Manager (n=3)	1	1	**1**
...position = operations (n=13)	3	6	**6**
...b_position = Managaer (n=2)	1	1	**1**
...Department manager (n=2)	1	1	**1**
Job_position = Account (n=2)	0	1	**1**
Job_position = Assistant (n=2)	0	0	**0**
...b_position = Operation (n=2)	0	0	**0**
Job_position = driver (n=2)	0	1	**1**
Job_position = tech (n=4)	0	2	**2**
..._position = Managger (n=2)	0	0	**0**
...osition = Operatations (n=2)	0	1	**1**
Total (n=102)	**18**	**43**	**44**

As pointed out in the list of barriers identified by the surveyed employees, Saudi companies do not have a strong governmental support, being no clear legislation regarding green standards. In this context, companies tend to adopt green practices by choice rather than by the stakeholders' pressure (Mariotti, Kadasah, & Abdulghaffar, 2014). In other words, the uncertain regulatory situation allows top managers of business activities where green practices are either hard to implement or do not achieve the expected ROI to avoid their implementation. This can lead employees working on companies focused on different business activities to perceive the influence of green practices in a different way. In order to give a further insight in this direction, Table 8-6 shows how green opportunities and obstacles are perceived by employees working in industries focused on different business activities.

Table 8-6: Business activity: Obstacles and opportunities for green practices.

Demographic	Green Practices_Obstacles	Green Practices_Opportunities	Total (Unique)
...in_activity = chemistry (n=3)	0	3	3
..._activity = chesmistry (n=2)	0	2	2
..._activity = petroleum (n=16)	3	7	7
...ss_main_activity = coal (n=6)	4	6	6
...main_activity = plastic (n=7)	5	6	6
...ain_activity = Rubber (n=15)	4	6	6
..._main_activity = paper (n=4)	1	4	4
..._main_activity = wood (n=3)	0	2	2
...steel manufactoring (n=10)	0	4	4
...ivity = water treatment (n=8)	1	0	1
..._main_activity = Food (n=15)	0	2	2
...in_activity = Beverage (n=5)	0	0	0
...in_activity = Chemical (n=8)	0	1	1
Total (n=102)	**18**	**43**	**44**

The results in Table 8-6 show that, in fact, the positive view of Saudi employees regarding the benefits of green practices strongly depends on the business activity. This can be seen as a reflection of the current situation of Saudi companies, in terms of arbitrary top management decisions, lack of governmental support and lack of stakeholder involvement. In this context, it is not surprising that, as suggested from the results in Table 8-5, environmental concerns are not yet the main priority for Saudi business management. The results in Table 8-6 reaffirm this observation showing that the wood and chemical industries do not consider green practices can lead to great business opportunities, whereas the plastic, rubber and coal industries identify several barriers to implement them. Nevertheless, results in Table 8-6 can be also seen from a more optimistic point of view, since they show that the perception of green practices is changing for some business activities like petroleum, paper, steel manufacturing and food.

Finally, as in the case of the answers analysed within the framework of the category corresponding to the lean approach, employees with more experience resulted to be more willing and capable of explaining their experiences, ideas, thoughts and feelings regarding green practices opportunities and obstacles in a more detailed way, as shown in Table 8-7. This confirms that employees with longer time in their jobs can (naturally) have more practical experience, being more capable of explaining practical phenomena, issues and potential opportunities. In addition, these results can further suggest that more experienced employees are more confident about the role they play within the company structure, feeling free to express their thoughts and feelings in a more open way than less less experienced ones.

Table 8-7: Years of experience: Obstacles and opportunities for green practices.

Demographic	Green Practices_Obstacles	Green Practices_Opportunities	Total (Unique)
...sional_experience = 1 *(n=22)*	3	7	**8**
...sional_experience = 4 *(n=16)*	3	8	**8**
...sional_experience = 5 *(n=38)*	10	18	**18**
...sional_experience = 3 *(n=26)*	2	10	**10**
Total *(n=102)*	**18**	**43**	**44**

8.2.1.2.3 Theme 3. Green Practice and Community

It is widely known that the social impact of a business is not only related to its impact on its employees, but also on the region and community that are near to the business location. In Saudi Arabia, the existence of business and production facilities is synonymous of employment for many people, as well as a valuable contribution to the economic development of nearby regions. In several developing countries, such as, China (Mandurah et al., 2012) and Turkey (Wu et al., 2015), the application of eco-innovation and green manufacturing has shown to have an important impact in improving business social and environmental performances. Unfortunately, in Saudi Arabia, data about the relation between green implementation and community well-being is still scarce. The third identified theme, which addresses the link between green practices and the community from the employees' point of view, can shed some light into this relationship. Figure 8.8 shows a diagram based on the NVIVO 12 analysis for the current theme.

Figure 8.8: NVIVO 12 analysis of green practices and their link with community.

According to the diagram shown in Figure 8.8, the surveyed employees agree that the relationship between green practices and the community is strongly associated to concepts such as the ones that follow:

- A sustainable local economy
- Educating women and involving women
- Sustainable development
- Communities feel safe
- Know how the business effect
- Job opportunities and employment
- Projects for natural conservation
- Technology can help to achieve more green practices, comparing to traditional business
- Employment
- Quality of life of the employees
- Better infrastructure facilities

It is a well-known fact that the social impact of any business activity is not only limited to its employees, but it is also extended to the local community. Although this is true for any kind of business activity, in the case of green practices this impact is particularly notorious. In this context, the implementation of greener solutions should help to improve the living conditions of the local community by, for instance, reducing air, water and soil pollution, contributing to build a safer and healthier environment. The results presented in Figure 8.8, further summarised in the list above, agree with this vision, showing that Saudi employees do feel that green practices are tightly related with the community well-being, promoting not only the conservation of the environment, but also providing new, safer and healthier job opportunities, in an attempt to achieve a sustainable local economy. Finally, Table 8-8 shows that this vision is mainly shared by technical engineers, production and operation specialists, being managers more reluctant to agree with it.

Table 8-8: Profession: Green practices for the local community.

Demographic	Green Practices and Local Community	Total (Unique)
..._position = Tech eng *(n=22)*	4	4
...sition = Chem Analyst *(n=3)*	0	0
...= Departmente Chief *(n=3)*	0	0
...position = Production *(n=18)*	4	4
Job_position = Eng *(n=14)*	1	1
Job_position = Tech eg *(n=3)*	1	1
...b_position = prodution *(n=3)*	1	1
Job_position = Manager *(n=3)*	1	1
...position = operations *(n=13)*	4	4
...b_position = Managaer *(n=2)*	1	1
...Department manager *(n=2)*	1	1
Job_position = Account *(n=2)*	0	0
Job_position = Assistant *(n=2)*	0	0
...b_position = Operation *(n=2)*	0	0
Job_position = driver *(n=2)*	0	0
Job_position = tech *(n=4)*	0	0
..._position = Managger *(n=2)*	0	0
...osition = Operatations *(n=2)*	1	1
Total *(n=102)*	19	19

8.2.1.2.4 Category 2: Summary

Green practices are currently worldwide recognised to be crucial as they consider the needs of both present and future generations. Nevertheless, they have largely been resisted based on practitioners' fears related to processes, procedures and outcomes within ecosystem and company limits, such as, costs, work conditions and lack of support of the economic, political and social sectors. The particular situation of Saudi companies regarding green practices is not the exception. The results analysed in this section show that, although employees working on specific technical activities do believe that green practices can lead to great business opportunities and social benefits, managers do not necessarily share the same vision because of the high cost green solutions imply. In fact, according to the results, Saudi employees agree that the main barriers to implement green practices are their costs. On one hand, employees are highly concerned about the high investment green solutions require, and the poor ROI they seem to provide. On the other hand, they claim for a lack of governmental support. In particular, since regulations are too strict and the compliance costs are too high, Saudi employees believe that, without this support, managers will continue being reluctant to implement green solutions. In addition to these main barriers, the respondents have also reported that the commonly used techniques for estimating green costs and benefits tend to overestimate costs, discouraging (even more) companies to become greener.

Finally, Saudi companies, such as the petroleum, rubber and chemical ones, which highly depend on raw material and can produce high rates of pollution, are urged to overcome the above mentioned barriers towards implementing green practices to reduce their environmental impact and improve the community living conditions, in terms of quality of life and well-being. In this context, the qualitative findings analysed here showing that employees' are not only aware about the business opportunities that the green approach can lead, but also willing to implement it, can be used to encourage top managers to get more involved beginning to see green practices from a more positive point of view.

8.2.1.3 Category 3 - Lean-green Practices and Sustainability

The set of questions included in Section 4 of the questionnaire, including questions 4.1.2, 4.2.3, 4.3.3, and 4.4, has been designed to explore and understand respondents' ideas, perceptions, thoughts, opinions and feelings regarding the need for combining lean and green practices towards achieving superior sustainability results, as well as which are the actual possibilities, according to their experience, of practically implementing such a combination within the real organisational context of Saudi companies. Since the combination of lean and green practices is a relatively new idea, not only in Saudi Arabia, but also in most of the developing countries, the answers collected for this category are rather general, allowing to be further divide only into two big themes, namely, issues and strategies, discussed in Sections 8.2.1.3.1 and 8.2.1.3.2, respectively.

8.2.1.3.1 Theme 1. Lean-Green Approach Issues

The results of the conducted survey show that, in general, Saudi employees believe that integrating lean and green practices is a very complex and challenging task, implying many obstacles and problems at different levels of the company. In particular, from Table

8-9, it can be seen that this feeling is shared by employees working in all the surveyed business areas, except for the ones working in the water treatment and beverage industries.

Table 8-9: Type of industry: Issues detected for Lean Green Approach.

Demographic	Lean Green Approach _ Issues	Total (Unique)
...in_activity = chemistry *(n=3)*	3	3
..._activity = chesmistry *(n=2)*	2	2
..._activity = petroleum *(n=16)*	7	7
...ss_main_activity = coal *(n=6)*	2	2
...main_activity = plastic *(n=7)*	4	4
...ain_activity = Rubber *(n=15)*	5	5
..._main_activity = paper *(n=4)*	1	1
..._main_activity = wood *(n=3)*	1	1
...steel manufactoring *(n=10)*	6	6
...ivity = water treatment *(n=8)*	0	0
..._main_activity = Food *(n=15)*	2	2
...in_activity = Beverage *(n=5)*	0	0
...in_activity = Chemical *(n=8)*	2	2
Total *(n=102)*	35	35

In addition, as it can be seen from Table 8-10, practitioners playing leading roles in the operational processes of the above mentioned industries, such as, engineers, production managers and chiefs, are the most concerned regarding the obstacles towards implementing the lean-green approach as well as the potential problems such implementation may cause. In particular, based on their answers to the survey questions, two different kind of issues have been identified. On one hand, employees have highlighted obstacles at an institutional level whereas, on the other hand, they have also highlighted obstacles at an individual level. In Figure 8.9, the main identified issues at institutional as well as individual levels, according to the engineers, production managers and chiefs of all the surveyed industries (except for water treatment and beverage ones), are summarised.

Table 8-10: Profession: Issues detected for Lean Green Approach.

Demographic	Lean Green Approach _ Issues	Total (Unique)
..._position = Tech eng *(n=22)*	10	**10**
...sition = Chem Analyst *(n=3)*	1	**1**
...= Departmente Chief *(n=3)*	2	**2**
...position = Production *(n=18)*	6	**6**
Job_position = Eng *(n=14)*	7	**7**
Job_position = Tech eg *(n=3)*	0	**0**
...b_position = prodution *(n=3)*	0	**0**
Job_position = Manager *(n=3)*	1	**1**
...position = operations *(n=13)*	3	**3**
...b_position = Managaer *(n=2)*	1	**1**
...Department manager *(n=2)*	1	**1**
Job_position = Account *(n=2)*	1	**1**
Job_position = Assistant *(n=2)*	0	**0**
...b_position = Operation *(n=2)*	1	**1**
Job_position = driver *(n=2)*	0	**0**
Job_position = tech *(n=4)*	1	**1**
..._position = Managger *(n=2)*	0	**0**
...osition = Operatations *(n=2)*	0	**0**
Total *(n=102)*	**35**	**35**

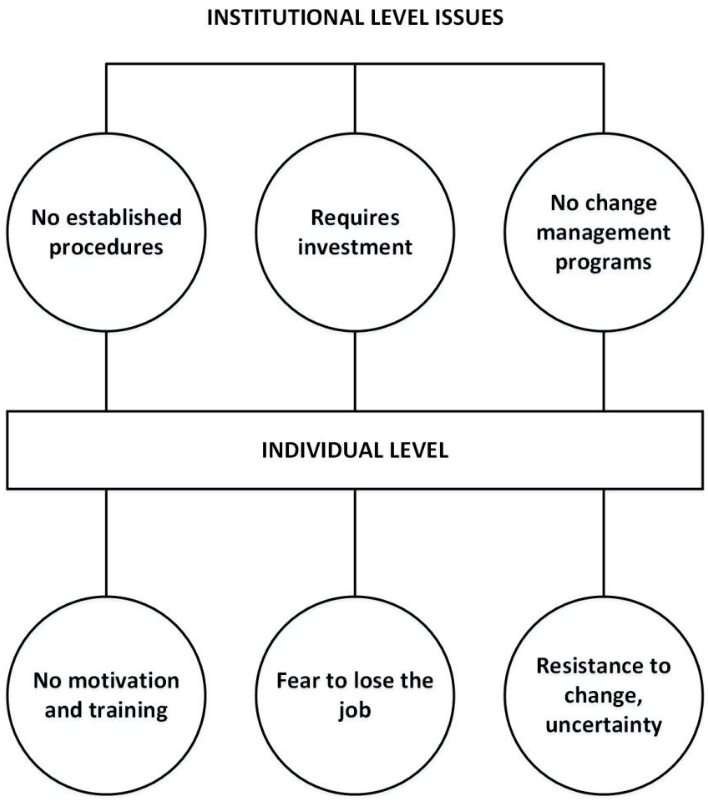

Figure 8.9: Lean Green Approach Issues themes.

From Figure 8.9, it can be seen that the huge investment the implementation of the combined approach requires is not the only concern at institutional level, but also the lack of well-stablished procedures to do so (this has been discussed in detail in the SLR presented in Chapter 4) and the lack of change management programs are highlighted as critical issues. These institutional issues are the same that employees have highlighted in the case of implementing lean practices discussed in Section 8.2.1.1. In this line, it can be suggested that an institutional change towards a leaner culture, management and leadership could benefit the combination of lean and green approaches. Regarding individual level issues, employees report to be neither motivated nor well-trained to deal with the implementation of new manufacturing strategies. In such a context, it is natural that employees tend to resist the change, considering the uncertainty as a threat to their jobs. This has been also discussed in Sections 8.2.1.1 and 8.2.1.2, being particularly notorious in the case of employees with less experience in their jobs.

Finally, as depicted in Figure 8.9, institutional and individual issues are strongly interconnected, in the sense that:

- No established procedures at the institutional level can lead to demotivation of the employees, making them not willing to learn new techniques towards implementing the lean-green combined approach.
- The need for a huge investment at institutional level in order to implement the lean-green approach can make employees to fear of losing their jobs.
- The lack of change management programs makes the employees to be neither well-motivated nor well-trained to deal with the challenging changes the implementation of the lean-green approach requires. This context leads to a generalised uncertainty contributing to employees’ change resistance.

8.2.1.3.2 Theme 2. Lean-Green Approach Strategies

In this section the collected answers of the surveyed employees suggesting strategies towards implementing the combination of lean and green practices are analysed, grouping them in a theme referred to as “Lean-green approach strategies”. This theme helps to understand how employees can contribute to implement the lean-green combined approach by proposing their own ideas and strategies. Figure 8.10 shows that Saudi employees consider that companies should change their currently organisational culture, in terms of their employed processes at the institutional level, in order to be able to move towards a new manufacturing approach like the combined lean-green one. In particular, the surveyed employees suggest that companies should:

- Reduce the number (and complexity) of the currently used manufacturing processes.
- Simplify the productive and administrative procedures making them more efficient
- Promote educational programs for employees, in terms of preparing them for the change and train them towards adopting innovative manufacturing techniques
- Improve employees' working conditions, in terms of safety, health and salary, so that they can be more engaged and willing to learn new strategies and implement them

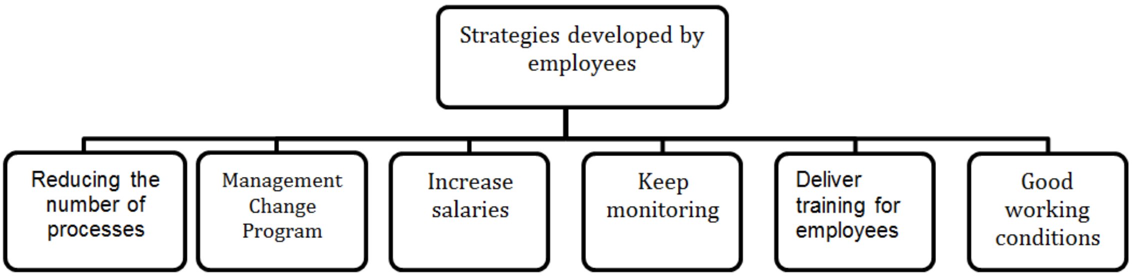

Figure 8.10: Lean-green approach strategies.

8.2.1.3.3 Category 3: Summary

The results analysed in this section show that respondents from most of the surveyed Saudi companies, except for the water treatment and beverage industries, are highly concerned about the challenges that the implementation of a lean-green combined approach can lead at institutional as well as individual levels of the companies. In particular, the most concerned about these issues are the employees working in job positions responsible for decision-making, such as, engineers, chiefs and production managers. This further reflects the Saudi Arabia situation regarding the adoption of new technologies, making it clear that managers are still more focused on the problems and obstacles they can carry than on the potential benefits they can achieve.

Fortunately, the surveyed employees, especially the more experienced ones, have also shown that they are in the position of proposing different ideas and strategies towards addressing the encountered issues. In this line, employees agree that companies should make not only a huge investment but also great efforts towards designing a well-planned strategy to improve the organisational culture as well as the currently used processes in order to be able to deal with the changes of implementing a combined approach, as well as to give employees the tools to deal with it. In this regard, surveyed employees suggest that it is crucial to take into account the impact that such a change can have on the companies' as well as the communities' realities, taking special care of individuals (employees, customers and citizens) showing them the great opportunities this change can lead in terms of new and better job positions as well as improved living conditions.

8.3 Complementary Quantitative Analysis

8.3.1 Hypothesis Testing

In order to test the hypotheses supporting the proposed theoretical framework shown in Figure 6.2, the One Sample Binomial test is used to compare the proportion of positive and negative responses to the survey questions. The variables are codified taking into account the nature of the Likert scale. Mean values for the several composite scores are coded as "*Yes*", if respondents mainly respond *Agree* or *Strongly Agree* (mean ranging from 0 to 2.50) to the subset of questions, and "*No*", if respondents mainly respond *Disagree* or *Strongly Disagree* (means ranging from 2.51 to 5) to the subset of questions. The One Sample Binomial test assumes a null hypothesis in which the proportion of positive and negative responses are equal, which means a probability of 0.5 for both "*Yes*" and "*No*" responses. With a p-value lower than 0.05, the null hypothesis must be rejected, being possible to assume that differences in the proportion of positive and negative responses are significantly different.

In addition, the relationship between different business main activities and a positive perception regarding lean, green and lean green has also been tested. In particular, the Chi-square test, which compares the proportions between two or more groups, in order to identify whether, at least one group, is different from the other ones, has been employed. In order to apply such a test, the business activities and the lean, green and lean-green positive perceptions are coded as dichotomous variables, and the Chi-square test is performed.

8.3.1.1 Testing the Impact of Lean Practices

The perception of Saudi employees regarding the implementation of lean practices has been analysed in Section 8.2.1.1, where the lack of management and resources as well as the personal barriers have been pointed out as the main challenges employees face when companies try to move towards to leaner solutions. In order to complement this qualitative analysis, a quantitative analysis of the impact of lean practices in the companies' performance from the employees' point of view is conducted in this section. The main aim of this quantitative analysis is to quantify to what extent employees expect positive outcomes when implementing lean practices in terms of operational, environmental and social performances. This is done by testing the hyphoteses (H1a, H1b and H1c) supporting the theoretical manufacturing framework presented in Figure 6.2.

8.3.1.1.1 H1a: Lean technical and social practices positively influence operational performance

To explore the hypothesis H1a the composite score of the set of questions 2.1 Lean Practices towards Operational Performance is used. The results of the One Sample Binomial test are shown in Figure 8.11. From Figure 8.11, it can be seen that a $p<0.05$ has been obtained, meaning that the null hypothesis should be rejected. This shows that there are significant differences in the counting of positive and negative responses. In addition, by observing the frequency graph in Figure 8.11, it is possible to see that the proportion corresponding to positive responses ("*Yes*") is higher than the one corresponding to negative ones ("*No*"). These results suggest that, according to respondents, lean technical and social practices positively influence operational performance. Then, hypothesis *H1a* is true.

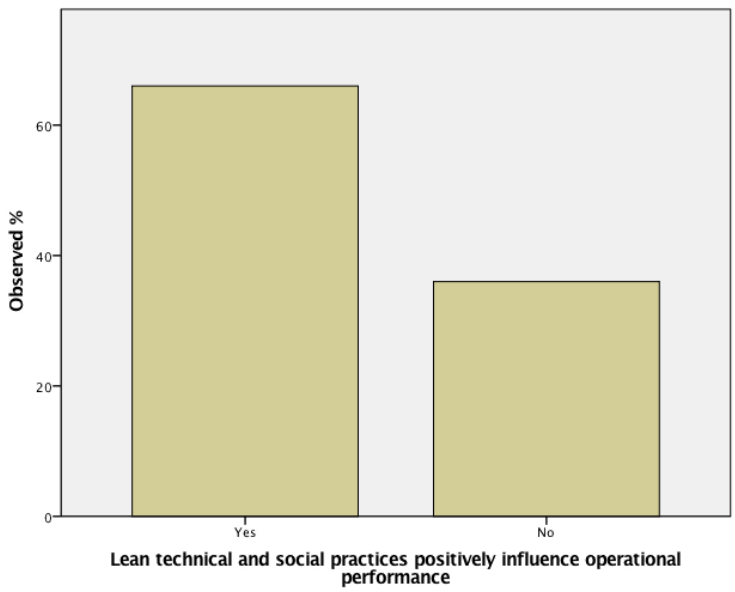

Figure 8.11: One sample binomial test results for *H1a*.

The obtained results regarding how lean practices are perceived within the context of the different business activities are shown, in terms of the Chi-square test, in Table 8-11. Analysing the results in Table 8-11, it is possible to see that most respondents working in activities related to plactic and beverages (85.7% and 80%, respectively) agree that lean technical and social practices positively influence the operational performance, whereas respondents working in activities related to steel manufacturing and paper (70% and 50%, respectively) do not. In addition, it is important to highlight that the results for all the other surveyed business activities resulted to be not statistically significant.

Table 8-11: Chi-square test comparing the proportion of agreement with the statement that Lean technical and social practices positively influence operational performance among different business activities.

		Lean technical and social practices positively influence operational performance	
		Yes %	**No %**
Business Activity	Chemistry	69.2%	30.8%
	Coal	66.7%	33.3%
	Petroleum	68.8%	31.2%
	Plastic	85.7%	14.3%
	Rubber	66.7%	33.3%
	Paper	**50.0%**	**50.0%**
	Wood	66.7%	33.3%
	Steel Manufacturing	**30.0%**	**70.0%**
	Water Treatment	66.5%	37.5%
	Food	66.7%	33.3%
	Beverages	80.0%	20.0%

Pearson Chi-Square Tests Sig. = 0.6451 / Degrees of freedom = 10 / Test statistic = 7.832

Based on the results shown in Figure 8.11 and Table 8-11, it can be noticed that the majority of respondents are aware of the positive effects of lean technical and social practices on the operational performance. These obtained results are in line with the results analysed in Section 8.2.1.1, where it has been found that although being concerned with the several challenges the implementation of lean practices implies, employees do recognise that the lean approach can have a positive impact on the production and financial performances of the companies. In addition, these results are also promising when compared with previous quantitative results published in the literature reporting that only about 20% of Saudi employees have a positive understanding of the influence of lean practices on operational performance (Carlson and Herdman, 2012), (Albliwi et al., 2017). For instance, in (Carlson and Herdman, 2012), where participants from both private and public Saudi organizations were surveyed, it has been found that only less than 10% of them were fully aware of lean benefits. In addition, in (Albliwi et al., 2017) it has been found that productivity and product quality were the least improved variables when implementing lean practices. In this context, the results obtained by the conducted survey show that, in last years, Saudi employees' awareness about the operational benefits of implementing lean practices has increased. These results are very helpful to encourage all Saudi companies, the ones that are already implementing lean practices as well as the ones that are still evaluating to do so, to actually keep their efforts in this direction. As discussed in Section 8.2.1.1, this should be done by planning and implementing a well-defined strategy towards improving their institutional culture, their internal communication and their employees' training.

8.3.1.1.2 H1b: Lean technical and social practices positively influence environmental performance

To explore the hypothesis H1b the composite score of the set of questions 2.2 Lean Practices towards Environmental Performance is used. The results of the One Sample Binomial test are shown in Figure 8.12. From Figure 8.12, it can be seen, on one hand, that the One Sample Binomial test resulted in $p<0.05$ and, on the other hand, that the proportion of positive responses ("*Yes*") in the frequency graph is higher than the one corresponding to the negative ones. Since these results are the same as in the case of *H1a*, the same comments stand, arriving to the conclusion that the hypothesis *H1b* is true. According to Figure 8.12, the majority of the respondents do agree with the fact that lean practices, which mainly aim at waste reduction, can have a positive impact on environmental issues. This is in contrast with the results ontained from the qualitative analysis held in Section 8.2, where 38 out of 67 respondents argue that lean practices are in conflict with green objectives, especially, when dealing with raw material pollution.

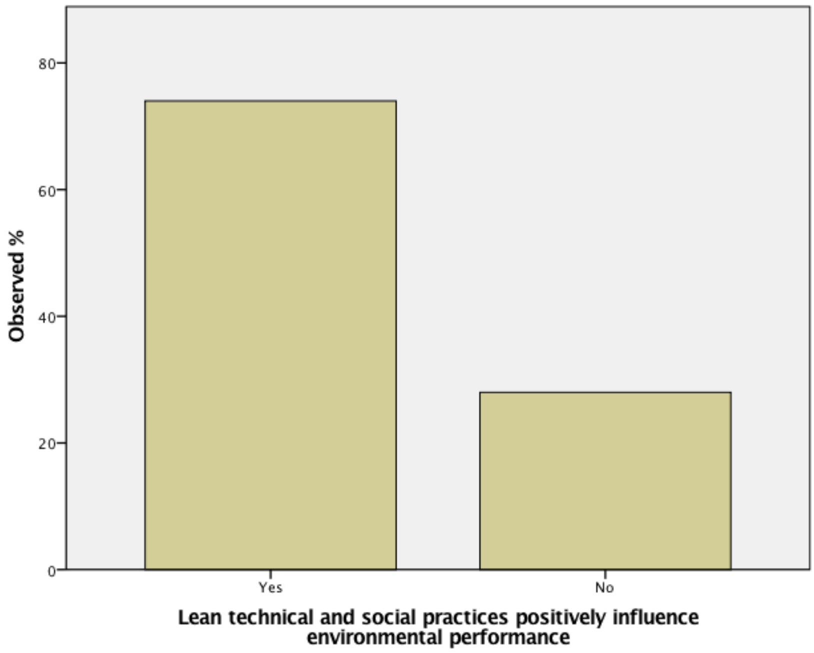

Figure 8.12: One sample binomial test results for *H1b*.

In addition, in Section 8.2 it has been shown that only a few companies, such as the ones focused on plastic, chemestry and beverages, mention waste reduction and management as the main advantages of implementing lean practices. In this way, although waste reduction and management are not strictly related to environmental issues, these companies perceive a potential environmental benefit of lean practices. Nevertheless, when quantitatively evaluating the different perceptions regarding the influence of lean practices in the environmental performance across the different types of business activities based on the Chi-Square test, no significant differences were found (p=0.081).

8.3.1.1.3 H1c: Lean technical and social practices positively influence social performance

To explore the hypothesis *H1c* the composite score of the set of questions *2.3 Lean Practices towards Social Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.14, have a $p<0.05$, while the proportion of positive responses ("*Yes*") in the frequency graph is lower than the one corresponding to the negative ones. In this context, the hypothesis *H1c* is false. In addition, when evaluating the different perceptions regarding the social benefits of implementing lean practices across the different types of business activities based on the Chi-Square test, no significant differences were found (p=0.081).

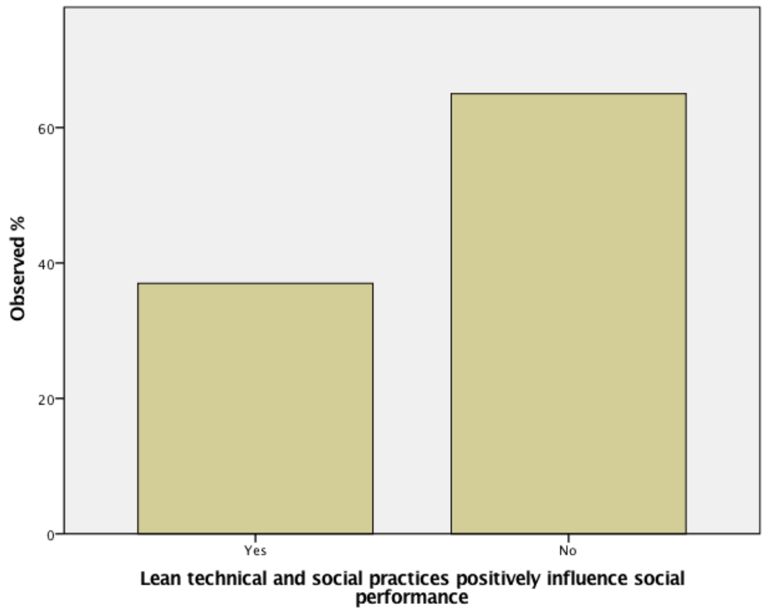

Figure 8.14: One sample binomial test results for *H1c*.

According to the qualitative analysis conducted in Section 8.2, the most concerning issue identified by employees is the lack of leadership and management. In fact, social performance and social responsibility are still a long way to go in Saudi organisations (Banawi and Bilec, 2014). In (Mandurah et al., 2012), it has been found that Saudi intermediate level managers are well aware of social responsibility and its importance to improve social performance. However, top managers do not share the same view about social responsibilities, being less interested in implementing social performance indicators (Mandurah et al., 2012). This causes conflicting expectations when implementing lean solutions. If Saudi top managers implement lean practices only focused on making more profit, it is less probable that they care about fulfilling employees expectations of perceiving the benefits of such implementation, such as improvements in their working conditions. Then, employees do not experiment any significant change in their daily working life when top managers decide to implement lean solutions, so they do not think that lean practices can improve social aspects, which may be an explanation for the poor quantitative results found regarding lean practices influencing the companies' social performance.

8.3.1.2 Testing the Impact of Green Practices

The perception of Saudi employees regarding the implementation of green practices has been analysed in Section 8.2.1.2. According to the results in Section 8.2.1.2, Saudi employees are, on one hand, highly concerned about the cost and operational challenges green practices implementation implies. On the other hand, they believe that, provided the financial and operational barriers can be sorted, green practices can lead to great business opportunities. In order to complement this qualitative analysis, a quantitative analysis of the impact of green practices in the companies' performance from the employees' point of view is conducted in this section. The main aim of this quantitative analysis is to quantify to what extent employees expect positive outcomes when implementing green practices in terms of operational, environmental and social performances. This is done by testing the hyphoteses (H2a, H2b and H2c) supporting the theoretical manufacturing framework presented in Figure 6.2.

8.3.1.2.1 H2a: Green practices positively influence operational performance

To explore the hypothesis *H2a* the composite score of the set of questions *3.1 Green Practices towards Operational Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.15, are the same as in the cases of the hypotheses *H1a* and *H1b*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H2a* is true. This result is showing that, although as discussed in Section 8.2.1.2, Saudi employees are highly concerned about the operational barriers encountered when trying to implement green practices, such as the lack of know-how and the huge investment, they are do recognise that green practices can have a positive impact on some operational aspects, such as standardising of processes and improving efficiency in terms of manufacturing and volume outcomes. In addition, since the results in Section 8.2.1.2 suggest that green practices are perceived differently by employees working on different business activities, Table 8-12 quantifies the different perceptions regarding green practices positive influence on the companies' operational performance, in terms of the Chi-square test.

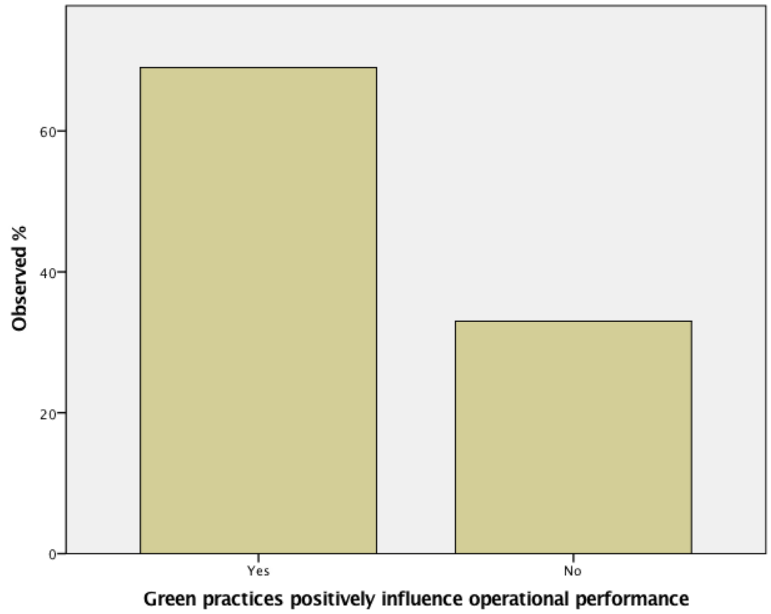

Figure 8.15: One sample binomial test results for *H2a*.

Table 8-12: Chi-square test comparing the proportion of agreement with green practices towards operational performance among different business activities.

		Green technical and social practices positively influence operational performance	
		Yes %	**No %**
Business Activity	Chemistry	76.9%	23.1%
	Coal	**33.3%**	**66.7%**
	Petroleum	81.3%	18.8%
	Plastic	85.7%	14.3%
	Rubber	86.7%	13.3%
	Paper	100.0%	0.0%
	Wood	66.7%	33.3%
	Steel Manufacturing	**10.0%**	**90.0%**
	Water Treatment	100.0%	0.0%
	Food	60.0%	40.0%
	Beverages	**20.0%**	**80.0%**

Pearson Chi-Square Tests Sig. = 0.001 / Degrees of freedom = 10 / Test statistic = 29.409

The results in Table 8-12 not only agree with the findings discussed in Section 8.2.1.2, but also show that the difference between perceptions of employees working on different companies regarding the positive impact of green practices in the operational performance is statistically significant. In particular, analysing the results in Table 8-12, it is possible to see that employees working in activities related to coal, steel manufacturing and beverage do not agree that green practices can positively influence the operational performance. Among them, the steel manufacturing employees are the ones who disagree the most (90%). This is probably due to the fact that the implementation of green practices in the steel manufacturing industry where the main raw materials are carbon and scrap, which are non-green materials, is too difficult to implement, and can make productive processes too complex and time-consuming. On the other hand, employees working on companies focused in paper, water treatment, plastic, rubber and petroleum tend to believe that green practices can improve companies' operational performance. Among them, paper and water treatment companies are the more optimisitic ones (100%). This is probably due to the fact that companies like the water treatment one can take advantage of some green practices to enhance their productive proccess. For instance, a subproduct (gas) of green practices applied to water treatment can be used as fuel to input in some other stages of the process. In this way, water treatment companies do not only recycle organic waste into fuel, reducing costs and environmental damage, but also optimise their productive process making it more efficient and less time consuming, avoiding delays in waiting for external fuel supply.

8.3.1.2.2 H2b: Green practices positively influence environmental performance

To explore the hypothesis *H2b* the composite score of the set of questions *3.2 Green Practices towards Environmental Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.16, are the same as in the cases of the hypotheses *H1a*, *H1b* and *H2a*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H2b* is true. In particular, this result show that a high rate of employees (more than 60%) believe that green practices can have a positive effect on the environmental performance. This is an expected result, since green practices are aimed at improving the environmental aspects of the business and, as such, they should positively influence environmental performance by nature. In addition, this result numerically supports the discussion held in Section 8.2.1.2, where it has been concluded that Saudi employees mainly associate green practices with environmental issues. In particular, most of the identified green opportunities are related to environmental aspects, such as reducing CO2 emissions, preventing and minimising waste, re-using, recycling, reducing trash production, and combating climate change. In addition, since the results in Section 8.2.1.2 suggest that green practices are perceived differently by employees working on different business activities, Table 8-13 quantifies the different perceptions regarding green practices positive influence on the companies' environmental performance, in terms of the Chi-square test.

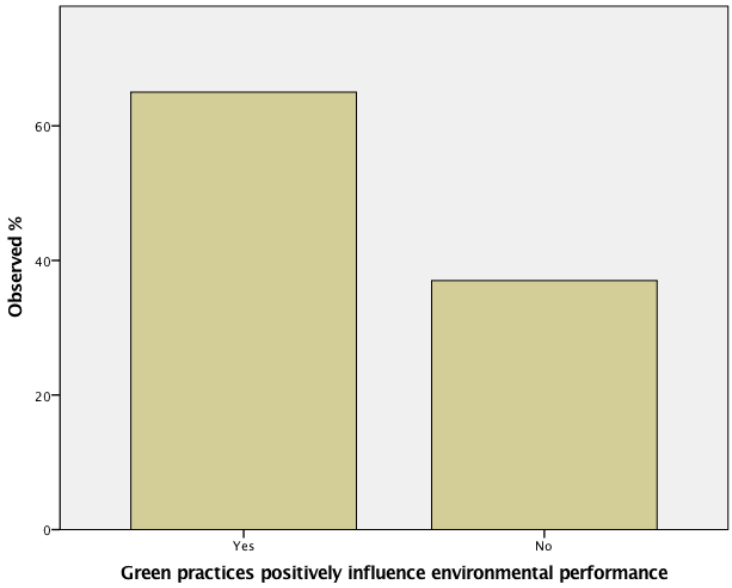

Figure 8.16: One sample binomial test results for H2b.

Table 8-13: Chi-square test comparing the proportion of agreement with green practices towards environmental performance among different business activities.

		Green practices towards Environmental Performance	
		Yes	No
		Row N %	Row N %
Business Activity	Chemistry	38.5%	31.5%
	Coal	100.0%	0.0%
	Petroleum	**43.8%**	**56.3%**
	Plastic	57.1%	42.9%
	Rubber	100.0%	0.0%
	Paper	100.0%	0.0%
	Wood	100.0%	0.0%
	Steel Manufacturing	90.0%	10.0%
	Water Treatment	100.0%	0.0%
	Food	53.3.0%	46.7%
	Beverages	**0.0%**	**100.0%**

Pearson Chi-Square Tests Sig. = 0.001 / Degrees of freedom = 10 / Test statistic = 35.462

The results in Table 8-13, confirms what has been suggested in Section 8.2.1.2 and analysed in Section 8.3.1.1 regarding the different perception of green practices by the employees working in different business activities. In this case, it can be seen that respondents working in activities related to coal, paper, wood, water treatment and steel manufacturing industries do agree that green practices can positively influence the environmental performance, whereas employees from the petroleum and beverages industries do not. In this context, it can be seen that employees tend to recognise green practices can benefit the environmental performance more than the operational performance. Unfortunately, although employees are aware of the potential benefits that green practices can have on the environmental performance, the implementation of such practices is still in its early stages in Saudi companies because of the numerous barriers discussed in Section 8.2.1.2. This, as suggested above, can probably be explained by the fact that most of Saudi companies use raw materials in their production processes. These kinds of businesses are, on one hand, very unlikely to be green and, on the other hand, need a very high investment to improve environmental performance in exchange to a relative small return in achieving this goal.

8.3.1.2.3 H2c: Green practices positively influence social performance

To explore the hypothesis *H2c* the composite score of the set of questions *3.3 Green Practices towards Social Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.17, are the same as in the case of the hypothesis *H1c*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H2c* is false. In addition, when evaluating the different perceptions regarding the green practices influences on social aspects across the different types of business activities based on the Chi-Square test, no significant differences were found (p=0.184).

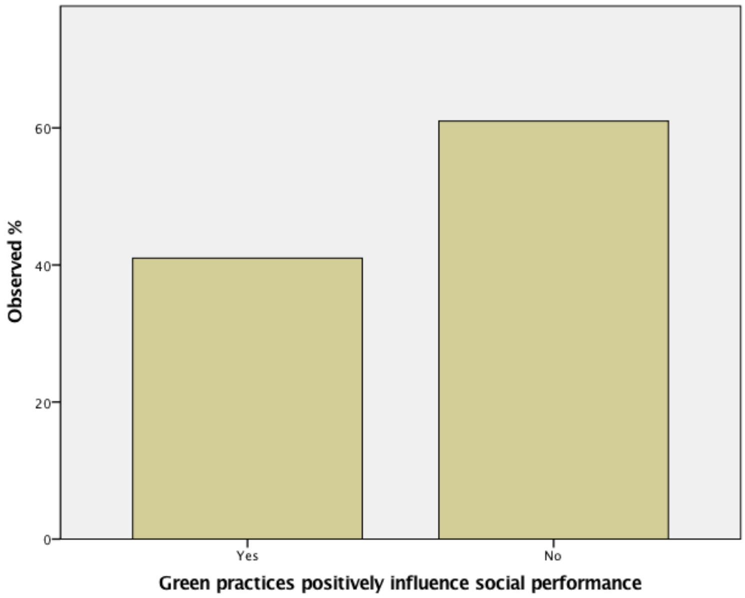

Figure 8.17: One sample binomial test results for *H2c*.

In Section 8.2.1.2, it has been shown that Saudi employees, specially those working in job positions related to technical activities agree that green practices are tighly related to social aspects in terms of achieving a sustainable local economy, educating and involving women, making communities feel safe, providing job opportunities and employment, enhancing the quality of life of the employees, and developing projects for natural conservation. In addition, it has also been highlighted that social responsibility is a critical aspect for Saudi companies. The results shown in Figure 8.17 suggest that, although Saudi employees understand the relationship between green practices and social aspects, they do not believe that they are currently been implemented in such a way that the potential benefits can be perceived. In this context, the results obtained here suggest that companies are urged to implement institutional programs towards improving their employees working condicitons as well as the local community living conditions, making especial focus on vulnerable groups, giving them job opportunities, empowerment and capability to understand and actively participate in the community well-being.

8.3.1.3 Testing the Impact of the Implementation of Lean-green Practices

The perception of Saudi employees regarding the combination of lean and green practices has been analysed in Section 8.2.1.3. According to the results in Section 8.2.1.3, Saudi employees agree that, in order to implement such a complex combination, companies should design a well-planned strategy to improve processes at institutional and individual levels. In this chapter, a complementary quantitative analysis of the impact of the lean-green approach in the companies' performance from the employees' point of view is conducted. The main aim of this quantitative analysis is to quantify to what extent employees understand the need for combining lean and green practices, whether they think the implementation of such combination is feasible within the Saudi manufacturing context, which barriers they perceive and which benefits they expect to achieve. This is done by testing the hyphoteses (H3a, H3b and H3c) supporting the theoretical manufacturing framework presented in Figure 6.2.

8.3.1.3.1 H3a: Lean practices moderate the relationship between green practices and operational performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented

To test the hypothesis *H3a,* a Chi square test is used to compare the proportion of positive answers regarding green practices influencing operational performance with the proportion of positive responses regarding the combined lean-green approach influencing operational performance. The obtained results are shown in Table 8-14. In this case, the null hypothesis for the Chi-square test states that the proportions are equal in both groups (green and lean-green). The alternative hypothesis states that there are significant differences on the proportions of positive and negative responses between the two groups. Finally, a p-value lower than 0.05, is considered to be statistically significant to reject null hypothesis.

Table 8-14: Chi-square test comparing the proportion of agreement respondents regarding Lean-Green approach towards Operational Performance and Green approach towards Operational Performance.

		Lean-Green approach towards Operational Performance		
		Yes	**No**	**Total**
Green approach	**Yes**	63	5	68

towards Operational Performance	**No**	22	12	34
Total		85	16	102

Pearson Chi-Square Tests Sig. = 0.045 / Degrees of freedom = 1 / Test statistic = 48.282

From Table 8-14, it is possible to see that the proportion of positive responses evaluating the lean-green approach influencing the operational performance is higher than the proportion corresponding to the green approach influencing the operational performance (83% vs 66%). This difference is statistically significant since a $p<0.05$ has been obtained. Then, the hypothesis *H3a* is true, meaning that lean practices actually moderate the relationship between green practices and the operational performance in such a way that the positive impact of green practices on the operational performance is stronger when lean practices are implemented.

The fact that green practices implemented together with lean practices are more likely to have a positive effect on the operational performance than green practices implemented individually can be explained as follows. As discussed in Section 8.2.1.2, employees agree that green practices tend to complexify the production process. To implement green practices in combination with some lean practices that are especially focused on improving operational aspects of the companies optimising their production processes, such as cell manufacturing, TPM, and quality at the source, can mitigate the adverse effects of the green practices and improve the operational aspects with respect to the implementation of the green practices individually. In addition, lean practices that are focused on the workplace organisation, such as 5S and visual management, can improve employees working environment and simply their everyday's assignments, giving them more freedom and time to take care of additional tasks implied by the implementation of gree practices. In this way, the implementation of green practices in a lean environment which makes processes more efficient and improves the organisation of the workplace can favour the implementation of the green practices without losing operational efficience.

8.3.1.3.2 H3b: Lean practices moderate the relationship between green practices and environmental performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.

To test the hypothesis *H3b,* a Chi square test is used to compare the proportion of positive answers regarding green practices influencing environmental performance with the proportion of positive responses regarding the combined lean-green approach influencing environmental performance. The obtained results are shown in Table 8-15.

Table 8-15: Chi-square test comparing the proportion of agreement respondents regarding Lean-Green approach towards Environmental Performance and Green approach towards Environmental Performance.

		Lean-Green approach towards Environmental Performance		
		Yes	**No**	**Total**
Green approach towards Environmental Performance	**Yes**	55	10	65
	No	27	10	37
Total		82	20	102

Pearson Chi-Square Tests Sig. = 0.001 / Degrees of freedom = 1 / Test statistic = 23.182

From Table 8-15, it is possible to see that the proportion of positive responses evaluating the lean-green approach influencing the environmental performance (n=82, 80.4%) is higher than the proportion corresponding to the green approach influencing the environmental performance (n=65, 63.7%). This difference is statistically significant since a $p<0.05$ has been obtained. Then, the hypothesis *H3b* is true, meaning that lean practices actually moderate the relationship between green practices and the environmental performance in such a way that the positive impact of green practices on the environmental performance is stronger when lean practices are implemented.

Here, it is possible to see that employees agree that there is a synergetic effect when combining green and lean practices capable of improving environmental results. This can be explained by taking into account the lean culture of waste reduction. Note the reader that if green practices aimed at reducing environmental damage like hazardous emissions, water and soil pollution, are implemented within a lean culture context where all the wastes, including raw material and energy consumption as well as resource wastage, have been reduced, the environmental performance will be potentiated. Finally, the result, together with the one obtained in the case of the hypothesis *H3a*, shows that employees agree on the synergetic effect that lean and green practices can achieve on different aspects of the company’s performance.

8.3.1.3.3 H3c: Lean practices moderate the relationship between green practices and social performance in such a way that the positive impact of green practices on operational performance is stronger when lean practices are implemented.

To test the hypothesis *H3c,* a Chi square test is used to compare the proportion of positive answers regarding green practices influencing environmental performance with the proportion of positive responses regarding the combined lean-green approach influencing environmental performance. The obtained results are shown in Table 8-16.

Table 8-16: Chi-square test comparing the proportion of agreement respondents regarding Lean-Green approach towards Social Performance and Green approach towards Social Performance.

		Lean-Green approach towards Social Performance		
		Yes	**No**	**Total**
Green approach towards Social Performance	**Yes**	7	34	41
	No	8	53	61
Total		15	87	102

Pearson Chi-Square Tests Sig. = 0.580 / Degrees of freedom = 1 / Test statistic = 38.470

From Table 8-16, it is possible to see that the proportion of positive responses evaluating the lean-green approach influencing the social performance (n=15, 14.7%) is lower than the proportion corresponding to the green approach influencing the social performance (n=41, 40.2%). This difference is not statistically significant since a p>0.05 has been obtained. Then, the hypothesis *H3c* is false, meaning that lean practices are not able to moderate the relationship between green practices and the social performance in such a way that the positive impact of green practices on the social performance could be stronger when lean practices are implemented.

Contrastingly to the previous findings regarding *H3a* and *H3b*, where synergetic effects between lean and green practices have been perceived by the surveyed employees, the results obtained in this case show that they do not believe synergy occurs when dealing with social aspects. This reflects the current uncertain Saudi situation regarding social aspects of businesses. In addition, the lack of social indicators makes it difficult to measure and compare social performances. This result, which is in line with the discussion in Section 8.2.1.3, where employees have highlighted several issues at institutional and individual level that companies should solve, further show that social aspects are an open issue in Saudi Arabia which, as a developing country, has still a long way to go towards implementing better and safer business strategies, making further focus on the business social responsibility (Duarte and Cruz-Machado, 2013), (Mandurah et al., 2012).

8.3.1.4 Testing the impact of operational performance, environmental performance and social performance towards financial performance

According to the proposed theoretical manufacturing framework depicted Figure 6.2, operational, environmental and social performances contribute towards the final financial performance of the company through hypotheses *H4a, H4a* and *H4c,* respectively. In this section, these hypothese are tested based on the analysis of the questions included in Section 5 of the questionnaire aiming to investigate how the improvements on operational, environmental and social performance obtained by the implementation of lean, green and lean-green approaches, contribute to improve the financial performance of the business.

8.3.1.4.1 H4a: Operational performance is positively related to financial performance.

To explore the hypothesis *H4a* the composite score of the set of questions *5.1 Operational performance towards Financial Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.18, are the same as in the cases of the hypotheses *H1a, H1b, H2a* and *H2b*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H4a* is true.

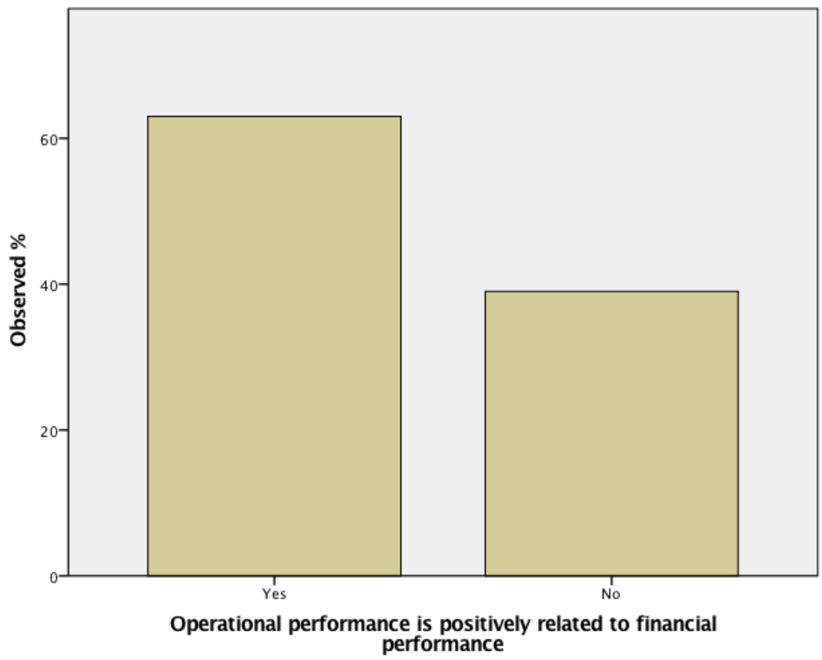

Figure 8.18: One sample binomial test results for *H4a*.

The relationship between the operational performance and the financial performance has largely been studied (Chiappetta Jabbour et al., 2013). In general, improvements in the operational performance are achieved by optimising the different production processes and the supply chain management in order to strictly fulfil business needs without surplus. Although most of the researchers in the field agree that improvements in operational performance can lead to improvements in financial performance, there are the ones, such as the ones in (Protopappa-Sieke and Seifert, 2010) that suggest that improving increasing costs due to operational needs may lead to a decrease in the financial performance. In (Protopappa-Sieke and Seifert, 2010), it is argued that optimising the production may consume more time and resources demanding, for instance to increase transportation costs. According to the results obtained here, Saudi employees agree with most of the researchers in the field, supporting the idea that improvements in operational performance can lead to improvements in financial performance. This employees' perception can be explained as follows. Improvements in processes and equipments, such as the use of "error proof" equipment, cycle time reduction, availability and reliability of machines, and use of cellular manufacturing, avoid incorrect processing and over-processing, whereas improvements in planning and control strategies, such as pull-flow control, overlapped production, visual control of the shop floor, small lot sizing, scheduling, levelled production, and inventory reduction contribute to reduce wastes in overproduction. In this way, the material, components and energy usage as well as the work in process and floor space utilisation are reduced, reducing the damaged products and the production costs without affecting the delivery time, making companies more competitive and profitable, improving the company's financial performance.

8.3.1.4.2 H4b: Environmental performance is positively related to economic performance.

To explore the hypothesis *H4b* the composite score of the set of questions *5.2 Environmental performance towards Financial Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.19, are the same as in the cases of the hypotheses *H1a, H1b, H2a, H2b,* and *H4a*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H4b* is true.

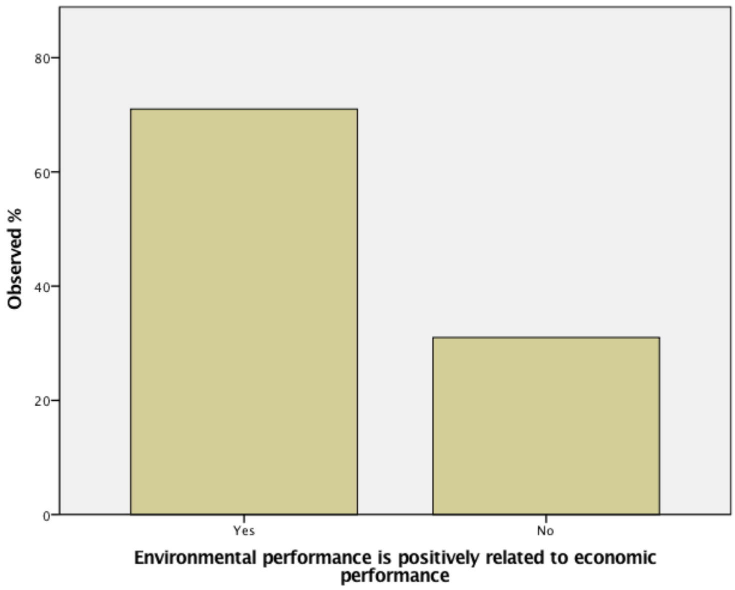

Figure 8.19: One sample binomial test results for *H4b*.

Improving environmental performance can be costly for business, usually requiring a high investment in new equipment, new working methodologies and processes, as well as specific training for employees. All these costs must be evaluated and the ROI for each one of them should be pondered before implementation. Many Saudi companies, which need raw materials for production, are reluctant to move to greener solutions, arguing either that there is not much more they can do to improve their environmental performance, or that the cost of a new investment is too high for the potential ROI they could achieve. The results obtained by the conducted survey analysed are mainly in agreement with these observations, showing that most of the Saudi employees, especially the ones in management positions, are concerned about the high cost of compliance of environmental regutaions. Nevertheless, the obtained results also show that employees working on technical positions do perceive that improvements in the environmental performance can have a positive impact on the financial performance. In particular, they highlight that some green practices like recycling excess of production, reusing material, and using waste to generate new energy, do not only improve the environmental performance of the company but also can contribute to reduce costs and optimise the productive process, improving the financial performance as well. In this regard, it can be said that Saudi employees' environmental perception is slightly changing in the sense that while Saudi top managers are still evaluating the potential ROI they could achieve if new processes aiming to achieve better environmental performance are implemented, Saudi employees are more confident regarding the financial potential of improving the environmental performance.

8.3.1.4.3 H4c: Social performance is positively related to economic performance.

To explore the hypothesis *H4c* the composite score of the set of questions *5.3 Social performance towards Financial Performance* is used. The results of the One Sample Binomial test, shown in Figure 8.20, are the same as in the cases of the hypotheses *H1c, H2c* and *H3c*. In this context, the same comments stand, arriving to the conclusion that the hypothesis *H4c* is false.

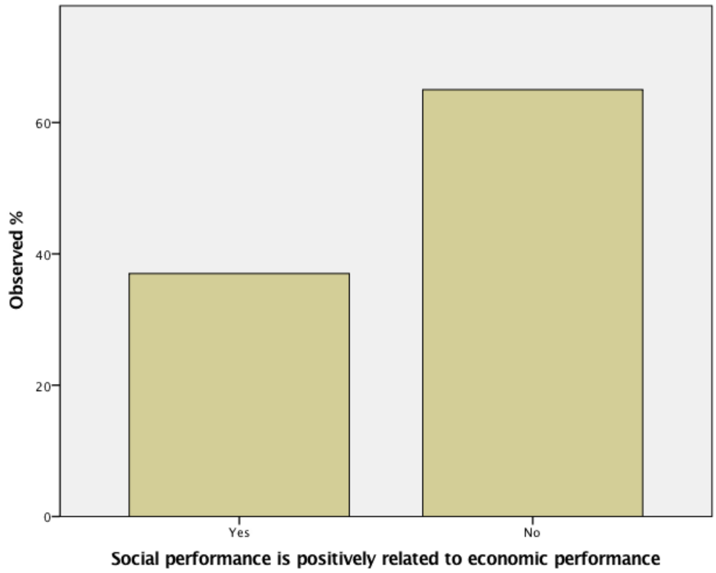

Figure 8.20: One sample binomial test results for *H4c*.

Based on the results for the cases of hypotheses *H1c*, *H2c* and *H3c*, testing the influence in social performance of lean, green and lean-green practices, respectively, social performance is not expected to have a positive impact on financial performance, as the results analysed in this section confirm. Governments, agencies and even some businesses from many developed countries, have tried to pass the message that social performance is positively related to economic performance. Nevertheless, clear, unbiased and strong positive associations have not been widely reported in the literature, suggesting that not all businesses are likely to benefit from an improved social performance. In fact, a study by (McWilliams and Siegel, 2000) has previously deconstructed this view by showing that corporate social responsibility has just a neutral impact on the financial performance. The findings of the conducted survey are in accordance with the observations in (McWilliams and Siegel, 2000), suggesting that social performance has no positive impact on the financial performance of Saudi businesses. In fact, surveyed employees have pointed out social aspects as one of the more critical issues Saudi companies should solve. In particular, they have claimed for social improvements at institutional and individual levels. On one hand, these changes can lead to benefits since they will improve workers conditions, which will benefit the company by having motivated and well-trained employees, and will improve the company's image, which will increase its sales. On the other hand, these changes require a hige investement with no ROI in the short term. This is probably the reason why employees do not perceive improvements in the social perfromace can translate in improvements in the financial performance.

8.4 Chapter Summary

In this chapter, the results of the conducted survey described in Chapter 7 are presented and discussed. This analysis is mainly based on the qualitative approach presented in Section 8.2 and complemented with the quantitative approach presented in Section 8.3.

8.4.1 Qualitative Analysis Summary

The qualitative analysis conducted in this chapter is intended to identify, evaluate and understand the perceptions, thoughts, ideas, views and feelings of Saudi practitioners regarding the introduction of lean, green and lean-green approaches in their business, as well as the expected (or already achieved) effects on crucial sustainability aspects such as, operational, environmental and social ones. As discussed in Section 5, the qualitative analysis conducted in this chapter has allowed the researcher to perform an individualistic, subjective and detailed analysis. In particular, it does not provide a direct answer of the kind of "black and white", but rather provides a different coding, allowing to identify meaningful patterns and themes towards approaching the whole research issue from the point of aggregating knowledge towards achieving a deeper understanding of the research problem. In this line, the qualitative results analysed in this chapter are intended to give a further insight into lean, green and lean-green practices and the possibility of developing an efficient theoretical framework to implement them within the real Saudi manufacturing scenario.

The qualitative results presented in this chapter show that, although Saudi employees recognise that lean practices can achieve improvements in terms of the different sustainability aspects, *viz.*, economic, environmental and social ones, they agree that, in order to achieve them, companies should develop effective systems (different from traditional ones) at institutional level capable of creating a suitable framework for implementing the required cultural and structural changes. In this regard, employees highlight the need for a strong lean leadership and a higher top management engagement, arguing that they are crucial towards ensuring the required change management providing workers the tools, knowledge and motivation to face the new challenges.

According to the qualitative results obtained in the conducted survey, Saudi employees tend to associate green practices with different benefits, making especial emphasis in the environmental ones. Nevertheless, they highlight that the implementation of green practices provides little to no ROI due to the strict regulations and the high cost of compliance. This vision is shared by top managers that argue that companies find it hard to compite when implementing green practices, being such implementation not among their main priorities. Unfortunately, since most of the Saudi companies, such as the petroleum, rubber and coal ones, highly depend on raw material, they are urged to implement green practices towards improving the community living conditions, in terms of quality of life and well-being, providing new job opportunities and empowerment to the community in order to improve their image. In this context, promoting the top management involvement becomes vital. According to the qualitative results obtained here, the role of the governamental support is crucial towards achieving so.

The obtained qualitative results show promising perspectives towards the actual combination of lean and green practices within the Saudi companies' scenario. On one hand, it has been found that, although managers have largely been reluctant to even consider the implementation of such innovation, the fact that they have identified several but specific issues that can eventually be addressed (and solved), seems to be a step forward. On the other hand, the open-ended questions included in the questionnaire have given the surveyed employees the freedom to suggest, in their own words, the strategies for addressing the identified issues, making a valuable contribution towards understanding the feasibility of the practical implementation of the combined lean-green approach. This has particularly been noticed in the case of the answers corresponding to the more experienced employees, being the ones that got more involved with the survey process, highlighting several gaps and advantages of the lean-green approach. In addition, the support of this kind of employees sharing their opinions and ideas can play a fundamental role in encouraging leaders and multiple stakeholders, including residents, to develop new strategies towards innovation. In this way, the behavioural change, which is a crucial dimension that has been detected in the themes of categories 1 and 2 discussed in Sections 8.2.1.1 and 8.2.1.2, respectively, is pursued towards filling the gap regarding the need for more interactive relations among citizens, businesses and state.

Both, the identified issues and the proposed strategies can be used as a reference for developing a set of knowledge about the lean-green approach and its actual possibility of being implemented as well as a set of new hypothesis on how to implement it. In particular, according to the qualitative results analysed in this chapter, the lean-green approach can be defined as a social innovation for sustainable development, considering it as a new combination of already existing approaches, such as lean and green ones, in a developing country like Saudi Arabia. This social interpretation of the lean-green approach is supported by explicitly accounting for institutional as well as individual levels of the company as critical actors in its whole performance, leading to sustainable results in terms of institutional aspects, such as organisational culture, and individual aspects, such as better job conditions and new job opportunities. In this line, surveyed employees agree that the implementation of the lean-green combined approach involves changes at three social levels, *viz.*, institutional, individual and community ones, being a proper change management the key aspect towards succeeding in such implementation. On one hand, institutional change involves changing rules and norms in the organisations, while individual change involves employee training and motivation. On the other hand, both employees and institutions should be the main actors influencing the broader social change, regulating the impact on the communities' sustainability and how this impact can return in terms of social investment works towards increasing the companies' profit.

Finally, the developed knowledge by the qualitative analysis conducted in this chapter can be practically implemented in the context of educational programs by experts of international aid, as well as by Human Resources in the companies, supporting the sustainable process of Saudi Arabia as a pathway to better norms and standards.

8.4.2 Complementary Quantitative Analysis Summary

The quantitative analysis presented in this chapter was intended to complement the qualitative findings discussed in Section 8.2. The conducted survey is based on an *ad-hoc* designed questionnaire applied to 102 employees from 14 different Saudi companies. Based on a PCA analysis, 13 major components have been identified from the questionnaire, from which several hypotheses have been tested. In general, the statistical analysis of the collected primary data is in agreement with the findings discussed in Section 8.2. In particular, according to the qualitative analysis held in Section 8.2, Saudi employees claim for a stronger leadership, governamental support, and the development of an effecient system at institutional and individual levels capable of creating a suitable framework for implementing the required cultural and structural changes to implement lean, green and, when possible, green-lean practices. In this context, although they are highly concerned about the costs these practices, especially, green ones, can imply, they are starting to recognise that they can lead to several business opportunities. The quantitative results analysed here not only supports these observations, but also quantifies to what extent Saudi employees think that lean and green practices can have a positive impact on the companies' operational and environmental performances. Moreover, they also show that employees are optimistic regarding the synergetic effect between lean and green practices when implemented together, which is the basis of the proposed theoretical manufacturing framework presented in Figure 6.2, since they agree that green and lean practices combined can lead to better operational and environmental results than green practices implemented individually. Moreover, according to the surveyed practitioners, not only the operational performance improvements achieved by implementing lean, green and lean-green practices, but also the environmental ones, which have long been questioned, do have a significant (positive) impact on the financial performance of the companies. In this sense, the lean-green theoretical manufacturing framework developed in Chapter 6, can be partically validated by validating 8 out of 12 of its supporting hypotheses (*H1a, H1b, H2a, H2b, H3a, H3b, H4a* and *H4b*).

Finally, the quantitative results obtained in this chapter show that employees do not consider that social aspects can be improved by implementing any of the proposed practices (lean, green or lean-green). In this same line, they do not believe that social performance can be positively correlated with financial performance. In this context, companies are urged to develop cultural change programs towards improving workers' and local community conditions in an attempt to show they actually care about social issues. In this way, they would benefit from more engaged employees and customers. On the other hand, it is also crucial to develop social indicators so that companies can measure the correlation between the different manufacturing practices and their social performance as well as the correlation between their social performance and the financial one. In this way, companies would be able to quantitatively evaluate their improvements and take better decisions regarding their social oriented practices.

In Chapter 9, the conclusions of the conducted research in this thesis are presented. In particular, the most relevant research findings are highlighted, the limitations of the study are discussed, some possible uses for the obtained results are suggested and some recommendations are made. Finally, future directions for further research are presented.

9 CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

9.1 Introduction

Nowadays, due to the rapidly changing and highly competitive marketplace, companies all over the world are facing new challenges, being urged to move towards superior sustainable manufacturing practices capable of ensuring a healthy balance among their economic, environmental and social aspects. According to most of the researchers in the field, the solution lies in considering the widely accepted lean concept with a renewed interest and combining it with green practices seeking for a synergetic effect that can fulfil the current market requirements. Nevertheless, to integrate both manufacturing approaches into a single one is a very complex and challenging task (Yauch and Steudel, 2003), (Garza Reyes, 2015b), (Kurdve et al., 2014), (Garza Reyes et al., 2014), being a lack in the literature of suitable integration and combination strategies as well as of successful empirical evidence of their practical implementation (Hayani et al., 2016). In addition, the actual scenario get worse when trying to implement such an innovation in developing countries, where, unlike the developed ones, neither companies' leaders are willing to invest in such type of tendencies nor government or stakeholders support them. Within this general context, in Saudi Arabia, where most of the businesses act as suppliers of raw materials, the implementation of lean and green practices (either individually or together) has particularly been delayed. Then, the main motivation of the conducted research in this thesis consisted in filling the research gaps regarding the feasibility of practically combining lean and green approaches as well as the best strategies to do so in order to encourage researchers, practitioners and managers, especially Saudi ones, to adopt the combined approach by providing creative tools towards achieving the currently required levels of sustainability keeping the balance among economic, environmental and social performances. In order to do so, a novel theoretical manufacturing framework combining lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and mitigating their weaknesses, has been developed in Chapter 6 based on the findings of the SLRs presented in Chapters 2, 3 and 4. Then, in order to explore the particular Saudi real manufacturing scenario and make the proposed theoretical manufacturing framework better suited for such environment by validating, testing and adjusting it, a survey was conducted in different Saudi companies from different business areas.

The remaining of the chapter is organised as follows. In Section 9.2, the main findings of the conducted research within the framework of this thesis are presented and discussed. Section 9.3 is devoted to discuss the benefits of using the qualitative approach for analysing the obtained results as well as using the quantitative approach to support it. In Section 9.4, the usability of the obtained results is discussed and some useful recommendations are provided. In Section 9.5, the limitations of the present research are discussed. Finally, in Section 9.6, some future work directions are suggested.

9.2 Main Research Findings

The research conducted in this thesis was focused in answering the research questions formulated in Section 5.2 regarding which are the actual possibilities of combining lean, green and lean-green approaches as well as which are the most efficient strategies to do so. In this line, a novel theoretical manufacturing framework was developed in Chapter 6 based on the research findings and gaps identified in the different SLRs presented in Chapters 2, 3 and 4. These research findings are further summarised in Section 9.2.1. In addition, a validating survey was conducted to explore and understand the real situation of the Saudi manufacturing scenario, as well as to test the proposed theoretical manufacturing framework within it. The survey results were mainly analysed via a qualitative approach, whereas a complementary quantitative analysis was also performed to provide a numerical evaluation and a different perspective. The survey findings are further summarised in Section 9.2.2. Finally, the general research findings of the present thesis are presented and discussed in Section 9.2.3.

9.2.1 SLRs: Research Findings

In recent years, companies have started to consider lean practices with a renewed interest (Kurdve et al., 2014) towards obtaining not only economic but also environmental and social improvements (Sundar et al., 2014), (Bhamu and Sangwan, 2014). According to the SLR presented in Chapter 2, the continuous improvement lean cultural background, which promotes all types of waste reduction, favours pollution prevention and optimise the raw material and energy consumption, which are crucial factors for achieving a better environmental performance (Dieste and Panizzolo, 2018), (Fliedner and Majeske, 2010), (Alves Pinto Junior and Veiga Mendes, 2017), (Siti Norhafizan Hibadullah, 2013). Moreover, promising results have been obtained in this direction by adapting lean tools to address green objectives (Danese et al., 2017), (Rosenbaum et al., 2012), (Folinas et al., 2013), (Fliedner, 2008), (Alves Pinto Junior and Veiga Mendes, 2017), (Dieste and Panizzolo, 2018), (Govindan et al., 2014), (Herrera et al., 2018). In particular, the well-known VSM technique is the most used lean method towards reaching green results (Bortolotti et al., 2015), (Rosenbaum et al., 2012), (Pampanelli et al., 2014), since it allows visualising and designing the production, information, and flow of material by recognising wastes (and their sources) that can be extended from the 7 lean wastes, *viz.*, transport, inventory, motion, waiting, over-processing, over-production and defects, to address the so-called green wastes, *viz.*, energy, water, material, transportation, emissions and biodiversity (Folinas et al., 2013). In addition, lean practices, such as the 5S and the standardisarion of work provide employees a better organised workplace allowing them not only to work more efficiently, but also to feel safer, which is crucial for their well-being.

Although researchers in the field recognise the benefits the implementation of the lean practices can lead, they highlight that companies do face several barriers when trying to actually implement them, limited not only to financial, technical and managerial issues, but also including the lack of government and stakeholder support (Marhani et al., 2013). In addition, researchers agree that in order to achieve an actually higher sustainability level, including significant improvements of the environmental and social performances, it is not enough to just adapt lean practices, being necessary to resort also to green ones. According to the SLR presented in Chapter 3, this leads to a further challenge since, although in recent years some researchers have begun to consider that green practices can actually lead to economic improvements (Bashkite and Karaulova, 2012), (Zhu and Sarkis, 2004), (Bohringer et al., 2008), (Miroshnychenko et al., 2017), such relation remains unclear, especially for top managers. In this regard, the main concerns are the high investment green practices imply in terms of innovation and technology, the strict regulations, and the high cost of compliance. In this context, top managers argue that green practices provide no or little ROI, claiming for government and stakeholders support in order to be actually capable of take advantage of green practices for improving not only environmental but also economic performances.

As it has been discussed lean and green practices have their strengths but also their weaknesses, making researchers to believe that neither lean nor green practices are enough to ensure the required balance among the different aspects of sustainability when implemented individually. In this context, several researchers have proposed to combine them towards being actually able to achieve a superior sustainability performance. According to the SLR presented in Chapter 4, although lean and green approaches can be similar, there exist several conflicting points between them, such as, the waste definition and the customer target. In this context, although the continuous improvement-based waste elimination lean organisational culture favour the implementation of green practices and enhance their results (Rao and Holt, 2005), (Dhingraa et al., 2014), (Dües et al., 2012), there are some lean objectives that are in conflict with green ones, making their actual combination to be a quite complex and challenging task (Venkat and Wakeland, 2006), (Franchetti et al., 2009), (Kleindorfer et al., 2005), (Dües et al., 2012), (Garza Reyes et al., 2014), (Mollenkopf et al., 2010). In particular, one of the main barriers encountered towards implementing these practices together is the fact that, from a lean perspective, environmental issues are sometimes considered as a problem for products, services, designs and production processes (Ng et al., 2015), making many industry leaders to perceive them as a burden for achieving profits. In addition, unlike lean methods that are well-defined, documented, standard and widely used, green practices (except for a couple of them, such as LCA and EOL) are usually based on customised approaches, making it more difficult to have benchmark models capable of being replicated on a large scale and providing standard (comparable) sustainability references (Garza Reyes et al., 2014). Finally, a lack of literature regarding the actual implementation of combination strategies as well as of empirical evidence of successful implementations of such strategies, has been detected, making it crucial to conduct further research to provide empirical evidence supporting the combination of lean and green approaches within the real manufacturing scenario (Bashkite and Karaulova, 2012), (Garza Reyes, 2015a), (Kurdve et al., 2014).

On the other hand, there are researchers that agree that lean and green practices can efficiently be implemented together since they have the same structure and they are synergetic (Hayani et al., 2016), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), (Galeazzo et al., 2014). According to the SLR presented in Chapter 4, the (few) currently available theoretical combination approaches in the literature are based on waste management techniques (Bergmiller and McCright, 2009), by proposing new waste definitions, customised according to the status of the firm, covering not only lean wastes, in terms of time and costs, but also wastes from the environmental perspective, in order to account for hidden sources of waste (Bashkite and Karaulova, 2012). In addition, these approaches are usually focused on the supply chain area (Nicholas, 2010), (Dües et al., 2012), (Bortolini et al., 2016), (Yasutaka and Tawara, 2006), (Campos and Vazquez-Brust, 2016), (Mollenkopf et al., 2010), (Wiengarten et al., 2013) where lean and green practices seem to better integrate to each other, making it evident the lack for approaches addressing not only the supply chain issues but also production issues where the conflicting points have long been considered irreconcilable (Folinas et al., 2013). Finally, the existing solutions are highly customised (Rosenbaum et al., 2012), making it crucial to develop standard approaches based on widely used performance metrics, in particular, regarding environmental as well as social aspects (Kumar and Sanchez Rodrigues, 2018), (Kurdve et al., 2011).

The analysis of the SLRs presented in Chapters 2, 3 and 4, allows the researcher to make the following contributions to the state-of-the-art:

- Provide a deep insight into the current situation of lean and green practices, regarding not only their adoption but also their development, the perceived benefits and encountered conflict of interest and limitations in the real manufacturing scenario.
- Show to what extent lean and green practices can be integrated into a single combined approach, evaluating their synergic effects.

According to the SLRs presented in Chapters 2, 3 and 4, further summarised above, it can be concluded that the lean-green manufacturing is still a relatively new practice, lacking of a clear and structured research definition, and of significant evidence of successful cases in the practice. In addition, due to the lack of widely used and standard sustainability metrics, the research gap becomes deeper when evaluating the lean-green approach performance in terms of sustainability improvements. Based on the analysis of the research findings and gaps identified in the SLRs presented in Chapters 2, 3 and 4, a new theoretical manufacturing framework combining lean, green and lean-green practices has been proposed in Chapter 6 based on the synergetic effect already demonstrated in previous research (Ng et al., 2015), (Kumar and Sanchez Rodrigues, 2018), (Campos and Vazquez-Brust, 2016), (Garza Reyes et al., 2014), (Garza Reyes, 2015a), (Dües et al., 2012), (Galeazzo et al., 2014). To do so, a synergetic model, where different variables contribute towards a common sustainability objective within the framework of the STS theory (Bergmiller and McCright, 2009), accounting for the crucial interaction among technical as well as social aspects, has been developed. The proposed lean-green theoretical manufacturing framework considers the interaction of the different contributions (modelled as hypotheses) of lean and green practices towards the operational, environmental and social performances as well as the lean practices moderation of the relationship between green practices and the operational, environmental and social performances. In addition, based on the findings of the SLRs presented in Chapters 2, 3 and 4, different factors, such as the firm's size and age can influence in the overall firm's sustainability performance. As such, in the proposed framework, the contributions of the different hypotheses to the final sustainability performance are regulated by the firm's size and age. The proposed lean-green manufacturing framework is developed in order to improve the sustainability performance of the companies, providing practitioners and researchers an innovative tool capable of combining different lean, green and lean-green strategies in such a way that their strenghts can be enhanced and their weaknesses can be mitigated. Finally, in order to evaluate the feasibility of practically implementing the proposed lean-green theoretical manufacturing framework within the context of the Saudi real manufactring scenario, the proposed manufacturing framework was validated based on a survey conducted in different Saudi companies focused on different business areas, including close and open-ended questions, as described in Chapter 7. The results of the survey were analysed and discussed in Chapter 8. In particular, this analysis was conducted mainly based on a qualitative approach, whereas a complementary quantitative analysis was also performed.

9.2.2 Survey: Research Findings and Gaps

In order to make the general theoretical manufacturing framework combining lean, green and lean-green approaches proposed in Chapter 6 more suitable to be implemented within the context of the real manufacturing Saudi scenario, a survey was conducted in different Saudi companies focused on different business areas. The primary data collected by this survey was analysed in Chapter 8. This analysis was conducted mainly based on a qualitative approach allowing to deeply exploring the Saudi employees perceptions, feelings, thoughts and opinions. In addition, in order to complement such qualitative analysis, providing a different perspective and allowing for numerical evaluation when necessary, a complementary quantitative analysis was also conducted. In particular, the quantitative analysis allows testing the set of hypotheses supporting the proposed lean-green theoretical manufacturing approach presented in Chapter 6 within the Saudi companies' context. In this way, resorting not only to a qualitative but also to a quantitative approach, the researcher was allowed to better understand the current Saudi manufacturing situation being able to make generalised conclusions as well as to take into account relevant details.

Based on the analysis of the primary data collected via the conducted survey, promising results have been obtained showing that, in general, Saudi practitioners are starting to change their perception about the lean and green approaches implementation, being more aware of their benefits regarding some of the main aspects of sustainability, especially the operational and environmental ones. This observation is particularly supported by the quantitative analysis where it has been found that Saudi employees think that lean and green practices do have a positive impact on the companies' operational and environmental performances. Nevertheless, Saudi practitioners agree that, in order to achieve these benefits, Saudi companies are urged to develop effective systems at institutional as well as individual levels capable of creating a suitable framework for implementing the required cultural and structural changes. In this regard, employees highlight the need for a strong leadership and a higher top management and stakeholder involvement, arguing that they are crucial towards ensuring the required management change and provide workers the tools, knowledge and motivation to face the new challenges. In addition, in the particular case of green practices implementation, Saudi employees are highly concerned about the financial impact such practices can have. In particular, they argue that a huge investement is required to implement the needed new technology, the environmental regulations are too strict and the costs of compliance are too high. This vision is especially shared among top managers, which are the ones involved in decision making, delaying the green practices adoption in Saudi companies. On the other hand, employees working in technical positions tend to perceive some business opportunities when implementing green practices capable of leading to financial benefits, like recycling excess of production, reusing material, and using waste to generate new energy.

The survey results also show promising perspectives towards the actual combination of lean and green practices within the Saudi companies' scenario. In particular, according to the results obtained by the quantitative analysis, Saudi employees do recognise that lean practices can moderate green practices, improving operational and environmental performances when respect to the operational and environmental performances obtained when implementing green practices individually. In this sense, the fact that the lean culture favours the implementation of green practices as well as helps obtainaining better results, is confirmed. In addition, these results also show that lean practices, which can optimise operational and financial aspects of the company, can mitigate the (potentially adverse) impact of green practices in the financial performance, helping to improve the environmental performance without facing additional costs.

Despite recognising the potentiality of the combined approach, Saudi employees are also well aware of the main barriers this implementation can carry. In this line, Saudi employees' answers have been useful to understand the current situation of Saudi companies, highlighting the main issues they identify and providing interesting suggestions to face them. In particular, Saudi employees highlight that Saudi companies, as it is the case of most of developing countries, have still a long way to go regarding social aspects. Moreover, according to the quantitative analysis, Saudi employees do not associate neither lean nor green practices with social benefits, showing that there has long been a lack of genuine interest in social issues, reflected not only by the lack of social indicators (measurements), but also by the lack of social politics, either internal (institutional and individual levels) or external (community level), making employees to be afraid of the change and resist it. In this regard, Saudi employees agree that there is currently a lack of well-established procedures at individual, institutional and community levels to provide an adequate framework where the change can be carried out. On one hand, institutional change involves changing rules and norms in the organisations, while individual change involves employee training and motivation. On the other hand, both employees and institutions should be the main actors influencing the broader social change, regulating the impact on the communities' sustainability and how this impact can return in terms of social investment works towards increasing the companies' profit. In this context, Saudi employees suggest that companies should reduce the number (and complexity) of the currently used manufacturing processes; simplify the productive and administrative procedures making them more efficient; promote educational programs for employees, in terms of preparing them for the change and training them towards adopting innovative manufacturing techniques; and improve employees' working conditions, in terms of safety, health and salary, so that they can be more engaged and willing to learn new strategies and implement them.

9.2.3 General Research Findings

The conducted research within the framework of this thesis makes valuable contributions to the state-of-the-art by giving not only an in-depth insight into the current trends in the lean, green and lean-green manufacturing fields, making special focus in their link with the three pillars of sustainability, *viz.*, economic, environmental and social, but also by evaluating the actual possibility of combining such practices within a real and generalised manufacturing scenario. In particular, in order to fill the gap regarding the lack of lean-green combination strategies in the literature, a novel lean-green manufacturing framework providing an innovative, flexible and useful theoretical tool capable of integrating such practices within a synergetic environment is developed based on the identified research findings in the SLRs conducted in Chapters 2, 3 and 4. In this sense, the thesis contributes to the state-of-the-art by providing a new theoretical lean-green framework that can be implemented resorting to different lean and green techniques and can be adapted to different manufacturing contexts. In addition, valuable contributions to the particular Saudi manufacturing sector have also been provided by conducting an *ad-hoc* designed survey towards deeply exploring it and testing the proposed manufacturing framework within its context. As a result, it has been found that, although Saudi top managers are highly concerned about whether it is possible to actually achieve a good ROI when implementing lean-green strategies, the rest of Saudi employees are aware of the benefits that this kind of practices can imply. Moreover, although identifying the several barriers the lean-green implementation can imply, they have suggested several ideas towards facing this challenging paradigm change. In this way, it is expected that the willingness of Saudi employees as well as their practical suggestions towards improving companies' politics at institutional, individual and community levels, can encourage top managers, stakeholders and government to get more involved, invest in innovative solutions and manage change towards sustainability.

Finally, the presented results in this thesis not only makes a valuable contribution to the literature of lean, green and lean-green manufacturing in general and to the Saudi one in particular, but also provides useful benchmark results that can be used as the starting point towards more standardise lean-green practices leading to more comparable sustainable performances' measures. This is vital towards developing further lean-green strategies as well as towards evaluating companies' performance for diagnosis, improvement and comparison for the sake of competitiveness.

9.3 Qualitative vs. Quantitative Results

As discussed in Section 5, the pros and cons of using qualitative or quantitative research methods have long been discussed in the literature (Trist, 1981), (Johnson and Christensen, 2000), (Punch, 2000), (Shaffer, 1989), (Williams, 2007), (Ochieng, 2009). In general, most of the researchers agree that both methods can be complementary. In addition, although the choice of the research method (qualitative or quantitative) should be done prior to the data collection so that a general methodology framework can be followed within the chosen pragmatic philosophy, the researcher is free to use one or another whenever he deems it necessary (Oberiri, 2017). For instance, if further research questions occur during the primary data collection or its analysis, a qualitative approach could be used to properly address them by allowing subjective content to be identified based on a direct conversation with the respondent. On the other hand, if numerical evaluation is required, the qualitative analysis could be complemented with a quantitative one. Taking into account such kind of situations, several researchers have proposed to combine both qualitative and quantitative approaches (Taylor, 2008), (Teddlie and Tashakkori, 2009), (Bryman, 2006), (Yauch and Steudel, 2003). The present research has indeed been conducted within this framework, being mainly based on a qualitative approach capable of deeply exploring the respondents' thoughts, perceptions and feelings, but also including a complementary quantitative analysis capable of providing another point of view and numerical evaluation when needed.

Generally speaking, the conducted research has been mainly based on a qualitative analysis. This analysis has allowed the researcher to approach the whole research issue by accumulating new knowledge and developing an analysis framework setting initial research questions rather than hypotheses, being crucial towards researching subjectivity, sensitive or marginal groups of the population, discovering hidden issues and avoiding the analysis of excessively obvious findings. In addition, a complementary quantitative analysis has also been performed to support the qualitative findings by providing a different analysis perspective and numerical evaluation.

Practically speaking, the conducted survey has been based on a questionnaire including both, Likert scale and open-ended questions, taking special care of reflecting the ethical dimensions of the research based on the particularities of the respondents, as suggested in several peer-review journals (Bryman, 2007). In addition, the validity of the survey has been evaluated in terms of its statistical significance towards ensuring the reliability of the obtained results. The qualitative analysis allowed the researcher to better understand the real situation, being able to identify not only general perceptions about lean, green and lean-green practices collected through the Likert scale answers where respondents were tied to a limited range of answers; but also to understand how each employee, working in each kind of industry and job position, felt about them by letting respondents to openly and freely answer the textual questions. In this way, valuable information has been obtained, allowing the researcher to develop new knowledge towards better answering the research questions as well as formulating new and more specific hypotheses. In addition, in order to test the hypotheses supporting the proposed lean-green theoretical manufacturing framework presented in Chapter 6, a complementary quantitative analysis has also been conducted. In this way, the qualitative findings can be supported and complemented by a numerical evaluation of the primary collected data.

9.4 Usability of Results

Based on the SLRs presented in Chapters 2, 3 and 4 it has been observed that there is still a lack of a deep understanding regarding the link between lean and green practices with the different sustainability aspects of the companies. In this same line, the idea of combining these practices into a single approach is relatively new and has not been fully explored yet. In particular, the actual possibility of practically implementing this combination in the real manufacturing scenario needs to be studied and the development of further strategies to do so urges. The main contribution of this thesis is to provide academic as well as practitioners a deep insight into the current trends in lean, green and lean-green manufacturing, evaluating their capability to improve the companies' sustainability performance, in terms of economic, environmental and social ones. In particular, as a result of the research conducted in this thesis, valuable contributions have been made towards helping the (Saudi) research and manufacturing communities as well as the organisational bodies, such as governments, to better understand, adopt and manage the current manufacturing tendency of using not only lean and green approaches but also of combining them.

In particular, the novel theoretical manufacturing framework developed in this thesis integrates lean, green and lean-green practices within a synergetic environment taking explicitly into account their contributions and their intereaction towards these three pillars of sustainability. In this way, this thesis contributes to the state-of-the-art by providing practitioners and researchers a general and flexible theoretical manufacturing framework which has the advantage of being adaptable to any manufacturing context and can be customised for any application by chosing the lean and green techniques that better suite it. In addition, this thesis makes especial contributions to the Saudi manufacturing sector by testing the proposed theoretical manufacturing framework within the context of different Saudi manufacturing companies. In particular, a deep qualitative analysis is conducted in order to explore Saudi employees' thoughts, perceptions and feelings regarding the practical implementation of lean and green practices as well as the feasibility of combining them. In addition, a complementary quantitative analysis is also conducted to numerically support this qualitative analysis. In this way, the results of this thesis are intended to allow practitioners to have a clearer picture of what employees think about the business opportunities as well as the main challenges and barriers the implementation of lean, green, and especially lean-green practices can imply.

9.4.1 Contributions to the Research Community

The SLRs in Chapters 2 and 3 have identified the main challenges, barriers, issues and opportunities of the current trends in lean and green practices, making especial focus on their link with the companies' sustainability performance in terms of economic, environmental and social ones; whereas the SLR in Chapter 4 has explored the actual possibility of integrating these practices into a combined approach. In this way, the following contributions to the state-of-the-art have been done:

- Provide a deep insight into the current situation of lean and green practices, regarding not only their adoption but also their development, the perceived benefits and encountered conflict of interest and limitations.
- Provide a deep understanding about the potential of lean and green practices to improve the different sustainability aspects of the company.
- Show to what extent lean and green practices can be integrated into a single combined approach taking advantage of their synergic effects.
- Study the potential of the lean-green combination to improve sustainability performance.

Based on these analyses, it is possible to draw several conclusions. In the first place, it is important to highlight that, although companies are urged to move towards greener practices, the high investment, the strict regulations and the high cost of compliance, have been preventing companies for adopting them. In this line, lean practices, which promote all types of waste reduction, have become to be seen with a renewed interest since they can be used as a catalyser for green practices implementation, favouring their adoption and mitigating their (negative) impact on the financial aspect of the company. For instance, lean practices favour pollution prevention and optimise the raw material and energy consumption, which are crucial factors for achieving a better environmental performance. In addition, lean practices, such as the 5S and the standardisarion of work provide employees a better organised workplace allowing them not only to work more efficiently, but also to feel safer, which are crucial factors for achieving a better social performance.

As discussed throughout the thesis, although being promising, the combination of lean and green practices is a challenging task. In this context, there is a lack of theoretical and practical strategies for implementing this combination as well as of practical evidence of successful cases. The novel lean-green manufacturing framework developed in this thesis constitutes a valuable contribution to the state-of-the art by providing researchers a standard, general and flexible theoretical manufacturing framework giving them the possibility of taking advantage of the synergy of lean and green practices to achieve better sustainability results. In particular, the following comtributions to the state-of-the-art are done:

- Provide a novel framework to combine lean, green and lean-green practices taking into account their contributions to each sustainability aspect, as well as their interaction.
- Give researchers the possibility of evaluate different lean and green practices in order to study their performance and chose the one that works better for their particular application.
- Give researchers a standard theoretical manufacturing framework capable of providing benchmark results in order to be comparable with other results in the state-of-the-art as well as to be useful to develop further manufacturing approaches using the one proposed in this thesis as a reference model.

9.4.2 Contributions to the Manufacturing Community

In order to test the developed lean-green theoretical manufacturing framework presented in Chapter 6, the survey described in Chapter 7 was conducted within the context of different Saudi manufacturing companies focused on different business areas. The results of this survey were analysed and discussed in Chapter 8. In particular, this analysis was mainly conducted resorting to a qualitative approach allowing to deeply exploring the Saudi employees perceptions, feelings, thoughts and opinions. In addition, the qualitative findings were supported by a complementary quantitative analysis providing a different perspective and allowing for numerical evaluation when necessary. In addition, the quantitative analysis allows testing the set of hypotheses supporting the proposed lean-green theoretical manufacturing framework presented in Chapter 6 within the Saudi companies' context. In this way, resorting not only to a qualitative but also to a quantitative approach, the researcher was allowed to better understand the current Saudi manufacturing situation being able to make generalised conclusions as well as to take into account relevant details.

In the first place, it is important to highlight that, in general, Saudi practitioners are starting to change their perception about the lean and green approaches implementation, being more aware of the positive impact they can have on operational and environmental performances. Moreover, according to the results obtained by the quantitative analysis, Saudi employees do recognise that lean practices can moderate green practices, improving operational and environmental performances when respect to the operational and environmental performances obtained when implementing green practices individually. These results show that lean practices, which can optimise operational and financial aspects of the company, can mitigate the (potentially adverse) impact of green practices in the financial performance, helping to improve the environmental performance without facing additional costs. Unfortunately, this vision is mostly shared by employees working on technical jobs, being top managers still reluctant to implement such practices, especially green ones which capability of providing ROI have largely been called into question, delaying their adoption in Saudi companies. In this line, one of the main conclusions that this thesis allows to draw is that Saudi employees agree that, in order to actually achieve the promising results that lean, green and lean-green practices can lead, a stronger leadership, a higher top management and stakeholder involvement, and further government support are needed towards enabling Saudi companies to develop effective systems at institutional, individual and community levels capable of creating a suitable framework for implementing the required cultural and structural changes. The conducted survey, provides a truthful and clear picture of the current global market situation, and the Saudi one in particular, in which Saudi leaders can rely to plan and design their way towards innovation, whereas the proposed novel manufacturing framework, supported by the qualitative and quantitative analyses, provides a reliable framework supporting their steps towards actually implementing it. In particular, based on the suggestions of Saudi employees companies should:

- Design and implement change management programs at the institutional level, including changing rules and norms.
- Establish clear procedures at the individual level to motivate employees, making them willing to learn new techniques towards implementing the lean-green combined approach.
- Improve their communication policy. In this way, employees can be well-informed regarding the changes the company is going through and the role they play. In this way, employees can be more confident about the new tasks they should develop and their new position in the company, avoiding the fear of losing their jobs.
- Train their employees so that they can be more confident and develop their new job in a more efficient way.

In addition, according to Saudi employees, both employees and institutions should be the main actors influencing the broader social change, regulating the impact on the communities' sustainability and how this impact can return in terms of social investment works towards increasing the companies' profit. In this context, Saudi employees make a valuable contribution of the manufacturing community by providing useful suggestions that companies can take into account to improve their sustainability performance:

- Reduce the number (and complexity) of the currently used manufacturing processes.
- Simplify the productive and administrative procedures making them more efficient.
- Develop social indicators (measurements).
- Promote educational programs for employees, in terms of preparing them for the change and training them towards adopting innovative manufacturing techniques.
- Improve employees' working conditions, in terms of safety, health and salary, so that they can be more engaged and willing to learn new strategies and implement them.

Finally, provided the cultural change discussed above can be properly carried out, the lean-green theoretical manufacturing framework developed in this thesis could provide useful tools to Saudi practitioners towards integrating lean and green practices. In particular, the following contributions to the manufacturing community can be mentioned:

- Operational aspects:
    - Unlike most of the available lean-green approaches in the literature, the proposed approach is not limited to supply

chain applications, making it possible to implement it throughout the entire manufacturing process.

- Including the firm's size and age as control variables, allows implementing the proposed manufacturing framework not only in big and long-established companies but also in emerging SMEs, making it useful for developing countries, such as Saudi Arabia, where SMEs and young companies abound.
- The flexibility of the proposed generic theoretical framework allows customising it selecting the lean and green practices that better fulfil the requirements of the particular application being addressed.

- Environmental aspects:
    - The proposed manufacturing framework can help companies, in particular the ones in Saudi Arabia that mainly act as suppliers of raw materials, such as, petroleum and chemical products, which are the principal cause of the environmental impact of business processes, to manage them in a more efficient way by taking into account not only lean but also green wastes definitions. In this way, it is expected to give Saudi companies waste management resources capable of achieving a more convenient ROI making top managers more willing to move towards greener solutions.
- Social aspects
    - The proposed manufacturing framework allows the inclusion of social performance indicators into the manufacturing process, which is crucial towards improving the social performance of the whole company. In this way, top managers would be able to have access to quantitative measurements (quantifiable data), being capable of evaluating to what extent investing in employee training, satisfaction and engagement as well as in community well-being can make the company more profitable.

9.5 Research Limitations

In this thesis a novel theoretical manufacturing framework combining lean, green and lean-green approaches within a synergetic environment capable of enhancing their strengths and mitigating their weaknesses, has been developed in Chapter 6, based on the analysis of secondary data (SLRs presented in Chapters 2, 3 and 4). In addition, in order to explore the particular Saudi real manufacturing scenario and make the proposed lean-green theoretical manufacturing framework better suited for such environment a survey (primary data collection) towards validating, testing and adjusting it was conducted in different Saudi companies from different business areas. Some limitations of this research are inherent to the chosen methodological strategy. In this regard, although survey studies are useful tools for collecting data, they have some limitations. In general, surveys tend to oversimplify the reality by relying in questionnaires with a limited number of questions. Moreover, the cross-sectional nature of the conducted survey in this thesis also contributes to the oversimplification tendency. In addition, Likert scale questions based on pre-conceived categories represents a bias. In this thesis, the data obtained using Likert scale questions has been complemented with the data obtained by textual questions which allows participants to freely answer them providing more detailed information. Nevertheless, it is important to highlight that, although giving survey participants the freedom to answer the questions is intended to obtain more detailed, descriptive and unbiased answers, the quality of the obtained answers highly depends on the participants' engagement with the survey process. In fact, even when questions are well-formulated and relevant to the research, and the validity of the survey has been tested in terms of its statistical significance, as described in Section 7.5, the validity of the collected data, the reliability of the obtained results and their relevance to the field are highly dependent on the capability (and willingness) of the participants to properly and honestly answer the questions. For instance, in this thesis it has been found that employees with more experience tend to be more willing to answer the questions, giving more detailed and interesting answers than less experienced ones. Finally, despite providing a deep insight into the subject, the qualitative analysis is a highly intuitive approach, where the researcher has to deal with certain ambiguity and different contradictions, which can introduce some bias.

In the practice, the research conducted in this thesis is mainly qualitative. Due to time constraints, only a complementary quantitative analysis has also been carried out. In this sense, the results of the conducted research lacks for a strong statistical significance evaluation. Finally, the sample population including 102 employees from 14 different companies in Saudi Arabia, is also a critical point in this research.

Finally, the developed theoretical manufacturing framework has the advantage of being flexible, allowing its adaptation and practical implementation within any manufacturing context. In order to do so, it is crucial to select a suitable set of lean, green and lean.green techniques. Due to time constraints, neither simulation nor practical experiments have been conducted towards evaluating the performance of the proposed approach when using different manufacturing tools.

9.6 Future Work

The promising results obtained in the conducted research, have set the basis for further research. In the first place, although the proposed novel manufacturing framework constitutes a step forward to filling the gap regarding the lack of theoretical strategies for combining lean and green approaches, there is still a long way to go in this direction. In particular, the proposed manufacturing approach has been tested within the context of Saudi companies, giving an insight into their current situation regarding lean, green and lean-green practices, showing that their current adoption is just in its early stages. In this line, it has been highlighted that there is still too much work to do in order to improve the current Saudi manufacturing scenario towards positioning Saudi companies among the ones corresponding to the main developing countries, such as, China or Turkey. In order to do so, it is crucial to promote a strong leadership, a higher stakeholder involvement and a higher government support. This can be done by further divulging the results obtained in this research, providing Saudi leaders useful tools to plan their way towards innovation. In addition, taking advantage of the reliability and generalisation capability of the conducted survey, as well as the universal and flexible nature of the proposed theoretical lean-green manufacturing framework, it would be interesting to conduct it within the context of other developing countries, either the leading ones, such as China and Turkey, or the ones in the region, in order to collect further comparable data allowing to better understanding local vs. leading and local vs. regional situations, respectively. In this way, it would be possible to analyse successful strategies and adapt them to Saudi local needs, as well as to develop joint strategies that can further help Saudi companies to face the new challenges.

In addition, taking into account the practical potential of the proposed generic theoretical manufacturing framework, a natural direction for future research would consist in designing a practical implementation of the proposed framework. As discussed throughout this chapter, in order to make such implementation possible, there are several changes at institutional, individual, community and governmental levels that should take place. Although these changes should take place gradually, practical evidence showing good results can help to accelerate them. In this sense, the theoretical manufacturing framework could be simulated and evaluated in terms of economic, environmental and social indicators, being able to predict future benefits towards encouraging top managers, stakeholders and government to support and invest in the innovation. In this regard, a preliminary simulation study could be first conducted in order to evaluate the feasibility of its implementation in terms of technology, human resources, infrastructure and costs. In addition, different lean and green techniques can be tested in order to select the ones that obtain a better synergetic effect and provide higher performance improvements. Then, a pilot implementation could be carried out within the real scenario of Saudi companies, for instance, within the ones that are more responsible for environmental aspects, that is, the ones that highly depend on raw material usage, such as the coal and petroleum ones. In fact, according to the conducted survey, employees working in such kind of industries have suggested several strategies towards implementing the lean-green approach. In such a context, it would be necessary to carefully analyse and evaluate the practical feasibility of each one of their suggestions, as well as their potential benefits, in order to develop a suitable combination strategy.

Finally, based on the conducted research, developing change management programs have shown to be a key aspect towards the successful implementation of lean-green strategies. In this line, a future research direction would be to further investigate change management in order to better understand it and to find out how it can be properly designed and efficiently implemented. In this regard, further studies, such as, surveys or case studies, can be conducted in companies (either Saudi or not) that have already implemented such kind of programs in order to analyse them, evaluate their pros and cons, and be able to adapt it to the particular Saudi needs.

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APPENDICES

Appendix A Lean-Green Approach towards Sustainability: Questionnaire

This questionnaire intends to examine to what extent lean and green practices have been adopted in the context of real world industries, making especial focus on the pros and cons of such adoption. In particular, the actual impact of the currently implemented lean and green practices in the firm's sustainability performance, in terms of economic, environmental and social performances, is evaluated. Finally, the level of awareness regarding the integration of lean and green practices towards improving the firms' sustainability is measured.

In this way, it is expected to identify the main issues and current gaps towards the implementation of lean and green practices, as well as the possibility of integrating them together in a single approach within the industrial context. In the same line, it is also expected to identify the level of sustainability currently reached (maturity), as well as the expected one to be reached in a future.

Finally, based on the gathered information, it is intended to propose a theoretical framework capable of addressing the founded gaps and suggesting improvements by integrating lean and green practices being sustainability its main aim.

Date: ………………………………………………………………

Please tick appropriate answers based on your experience.

A.1 **General Information**

1. Name of organisation (optional)
   …………………………………….……………………………….
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2. Number of employees
   □□Up to 50 □□Up to 250 □□Above 250

3. Job Position
   ……………………………………………………………………………………….
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4. Professional discipline. Please explain
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5. Number of years of professional experience
   □□1-5yrs □ 6-10yrs □11-15yrs

   □□16-20 yrs □ 21yrs and above

6. What is the main activity of your business?...
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7. How would you classify the volume level of the products you make? (Please tick)

   □□Low □□Medium □□High □□Other. Please, specify:
   ……………………………….

8. Who are your customers?
   □□Retailers □□End users □□Other. Please, specify:
   ……………………………….

A.2 Lean (technical and social) Practices towards Sustainability

This section attempts to identify the maturity of lean implementation within the company environment, the barriers, the success factors, and the benefits perceived when implementing them, making particular emphasis in the lean contribution towards sustainability.

Please indicate your level of agreement with the following statements based on your experience in your organisation (questions 2.1.1, 2.1.2, 2.2.1, 2.2.2, 2.3.1, 2.3.2) and provide a complete answer for questions 2.1.3, 2.2.3, 2.3.3, 2.4.

A.2.1 Lean Practices towards Operational Performance

A.2.1.1 Which do you think are the main reasons why lean practices lead to improvements on the operational performance?

	Strongly Agree	Agree	Disagree	Strongly Disagree
They improve technological efficiency	☐	☐	☐	☐
They solve potential operational and process issues	☐	☐	☐	☐
They reduce product development time and cost	☐	☐	☐	☐
They reduce product production time and cost	☐	☐	☐	☐
They reduce product delivery time and cost	☐	☐	☐	☐
They are focused on continuous improvements	☐	☐	☐	☐
They empower employees	☐	☐	☐	☐
They eliminate waste and non-value adding activities	☐	☐	☐	☐
They improve product quality based on costumers' needs	☐	☐	☐	☐
They promote supply chain integration	☐	☐	☐	☐

A2.1.2 In your opinion, the main lean practices yielding operational benefits are…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Value stream mapping	☐	☐	☐	☐
5S	☐	☐	☐	☐
Automation	☐	☐	☐	☐
Kaizen	☐	☐	☐	☐
Pull approach	☐	☐	☐	☐
Continuous Improvements	☐	☐	☐	☐
Cell Manufacturing	☐	☐	☐	☐
Visualisation tool	☐	☐	☐	☐
Total preventive maintenance	☐	☐	☐	☐
Kanban	☐	☐	☐	☐
Changing the facility layout	☐	☐	☐	☐
Mistakes proofing/Poka-Yoke	☐	☐	☐	☐
Just-In-Time	☐	☐	☐	☐
Policy deployment/Hoshin Karni	☐	☐	☐	☐
Process redesign	☐	☐	☐	☐
Total Quality Management	☐	☐	☐	☐
Quick set up time	☐	☐	☐	☐
Root cause analysis	☐	☐	☐	☐
Small lots	☐	☐	☐	☐
Standardisation	☐	☐	☐	☐
Takt time	☐	☐	☐	☐
Work load balancing	☐	☐	☐	☐
Small group problem solving	☐	☐	☐	☐
Training employees	☐	☐	☐	☐
Top management leadership for quality	☐	☐	☐	☐
Supplier partnership	☐	☐	☐	☐
Customer involvement	☐	☐	☐	☐

A2.1.3 Which are the main barriers your company has encountered when implementing lean practices for improving operational performance?

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A.2.2 Lean Practices towards Environmental Performance

A2.2.1 In your opinion, lean practices can positively impact on the environmental performance in terms of…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Reduction/Elimination of wastes	☐	☐	☐	☐
Reduction of CO_2 emissions	☐	☐	☐	☐
Pollution prevention	☐	☐	☐	☐
Reducing resource consumption by:				
• **Reducing the defect occurrence across the whole system**	☐	☐	☐	☐
• **Keeping the equipment, components and materials organised**	☐	☐	☐	☐
• **Decreasing the set-up times and the product changeovers**	☐	☐	☐	☐
• **Reducing the inventory**	☐	☐	☐	☐
• **Increasing the equipment and product lifespan**	☐	☐	☐	☐
Reducing energy consumption by:				
• **Reducing the defect occurrence across the whole system**	☐	☐	☐	☐
• **Keeping the equipment, components and materials organised**	☐	☐	☐	☐
• **Decreasing the set-up times and the product changeovers**	☐	☐	☐	☐
• **Reducing the inventory**	☐	☐	☐	☐
• **Increasing the equipment and product lifespan**	☐	☐	☐	☐

A2.2.2 Although lean practices can lead to environmental benefits (2.2.1), they have not been aimed at doing so, leaving environmental improvement opportunities (gaps) on the table. If these gaps are filled, further environmental improvements could result from the implementation of lean practices.

	Strongly Agree	Agree	Disagree	Strongly Disagree
The continual improvement-based waste elimination lean culture creates an effective platform to address environmental risk and lifecycle considerations.	□	□	□	□
Efforts to expand the type of wastes targeted by lean methods to explicitly include pollution and risk are likely to have environmental improvement returns.	□	□	□	□
The involvement of environmental specialist within the context of lean implementation efforts can reduce the risk of non-compliance with environmental regulations and increase opportunities for realising more environmental benefits through the more explicit consideration of environmental aspects.	□	□	□	□
To include some actions suggested by public environmental agencies promoting P2 and waste minimisation into the lean practices can lead improvements in resource productivity and environmental performance of environmentally sensitive processes.	□	□	□	□

A2.2.3 Finally, which are the main conflicts of interest (if any) your company has encountered during lean practices implementation between lean objectives and environmental performance? In such a conflicting context, what further strategies do you (or your company) consider should be applied to actually achieve greener results?

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A.2.3 Lean Practices towards Social Performance

A2.3.1 According to your experience, the main contributions of lean practices towards improving the company's social performance are…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Employee self-development:				
• **Employee training**	☐	☐	☐	☐
• **Employee evaluation**	☐	☐	☐	☐
• **Employee reward**	☐	☐	☐	☐
• **Employee empowerment**	☐	☐	☐	☐
• **Employee engagement**	☐	☐	☐	☐
Employee well-being by:				
• **Ensuring employee safety**	☐	☐	☐	☐
• **Taking care of employees' health**	☐	☐	☐	☐
Supplier involvement	☐	☐	☐	☐
Lean leadership	☐	☐	☐	☐
Stakeholder commitment	☐	☐	☐	☐
Organisational culture	☐	☐	☐	☐
Society's safety and health	☐	☐	☐	☐
Interaction with the community	☐	☐	☐	☐
Public image	☐	☐	☐	☐
Improved costumer experience	☐	☐	☐	☐
Improved social responsibility	☐	☐	☐	☐

A2.3.2 Not only lean social practices, but also technical ones can have a positive impact on social aspects of the company.

	Strongly Agree	Agree	Disagree	Strongly Disagree
5S can maintain the workplace ordered and clean, so that accidents can be avoided.	□	□	□	□
Automation, standardisation and cell manufacturing can simplify the tasks developed by employees.	□	□	□	□
Continuous Improvement culture requires a full commitment of employees.	□	□	□	□
Visualisation provides an easy and fast way of communication.	□	□	□	□
Total preventive maintenance keeps equipment in a good and ready-to-use condition, so that employees can be safer.	□	□	□	□
Work load balancing helps employees by distributing the assigned amount of work load in an equitable way among them.	□	□	□	□
Small group problem solving allows encouraging employees to involve themselves and propose improvements not only to their own tasks but also to the whole system.	□	□	□	□
Training employees facilitates their self-development.	□	□	□	□
Top management lean leadership leads to improvements in work quality.	□	□	□	□
Supplier partnership promotes suppliers commitment over an extended time period, sharing the risks and rewards of the relationship.	□	□	□	□
Customer involvement allows identifying and taking into account the costumer needs throughout the whole production process.	□	□	□	□

A2.3.3 Moving a whole organisation towards lean culture is not an easy task. Did your company experience resistance to changes when implementing lean practices? How did employees deal with these changes? To what extent did the national and local culture influence this changing process?

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A.2.4 Lean Practices: Summary

Overall, which lean improvements do you think your company should implement in order to achieve further improvements in its sustainability performance, in terms of operational, environmental and social aspects?

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A.3 Green Practices towards Sustainability

This section attempts to identify the maturity of green practices implementation within the company environment, the barriers, the success factors, and the benefits perceived when implementing them, making particular emphasis in the lean contribution towards sustainability.

Please indicate your level of agreement with the following statements based on your experience in your organisation (questions 3.1.1, 3.1.2, 3.2.1, 3.2.2, 3.3.1, 3.3.2) and provide a complete answer for questions 3.1.3, 3.2.3, 3.3.3, 3.4.

A.3.1 Green Practices towards Operational Performance

A3.1.1 Although green practices are aimed at optimising the manufacturing process from an environmental rather than an operational perspective, they can lead to operational improvements.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Design for Environment helps to simplify the product design and, as a consequence, the production process.	☐	☐	☐	☐
Process planning can potentially optimise production time.	☐	☐	☐	☐
LCA can identify operational gaps so that they can be further improved.	☐	☐	☐	☐
Green practices can reduce production cost by:	☐	☐	☐	☐
• **Reducing energy consumption**	☐	☐	☐	☐
• **Reducing raw material consumption**	☐	☐	☐	☐
• **Reducing resource consumption**	☐	☐	☐	☐
EOL strategies can reduce time and cost production by:				
• **Remanufacturing**	☐	☐	☐	☐
• **Reconditioning**	☐	☐	☐	☐
• **Reusing**	☐	☐	☐	☐
• **Repurposing**	☐	☐	☐	☐
• **Repairing**	☐	☐	☐	☐
• **Recycling**	☐	☐	☐	☐

A3.1.2 Which are the main operational challenges that can be encountered when implementing green initiatives?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Green practices can lead to an undesired increment in production costs, in terms of:	☐	☐	☐	☐
• **Resource cost**	☐	☐	☐	☐
• **Process cost**	☐	☐	☐	☐
• **Transportation cost**	☐	☐	☐	☐
• **EOL strategies cost**	☐	☐	☐	☐
Being responsible for the product until its EOL requires technological improvements, more human resources and higher inversion.	☐	☐	☐	☐
Eco-friendly raw materials are not always available, and they are often expensive.	☐	☐	☐	☐
Replacing hazardous/toxic materials is neither always possible nor usually profitable.	☐	☐	☐	☐
Technology innovation	☐	☐	☐	☐
Strict regulations compliance	☐	☐	☐	☐
Specific equipment required	☐	☐	☐	☐
Green technology is still in development.	☐	☐	☐	☐
Green products can be more expensive than non-green ones.	☐	☐	☐	☐

A3.1.3 Environmental regulations have largely been considered a burden for production and operational processes. Is this the case of your company? How do your company manage to comply with international environmental standards, policies and regulations?

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A.3.2 Green Practices towards Environmental Performance

A3.2.1 Green practices are specifically aimed at reducing the environmental footprint throughout the whole product life cycle. In your opinion, the main contributions of green practices towards the environmental performance are…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Reduction/Elimination of solid wastes	□	□	□	□
Reduction/Elimination of hazardous substances	□	□	□	□
Reduction of CO2 emissions	□	□	□	□
Pollution prevention	□	□	□	□
Minimising water consumption	□	□	□	□
Minimising energy consumption	□	□	□	□
Minimising resource consumption	□	□	□	□
Using eco-friendly raw materials	□	□	□	□
Producing eco-friendly products	□	□	□	□
Applying an environmentally-friendly EOL strategy	□	□	□	□
Ensuring a safe, clean and healthy workplace	□	□	□	□
Improving company's public image	□	□	□	□
Compliance of environmental standards and regulations, such as, RoHS and WEEE	□	□	□	□

A3.2.2 According to your experience, the most efficient green practices towards reducing the environmental footprint throughout the whole product life cycle are…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Design for Environment	☐	☐	☐	☐
Green Process Planning	☐	☐	☐	☐
Life Cycle Assessment	☐	☐	☐	☐
Reverse Logistic	☐	☐	☐	☐
Green Supply Chain Management	☐	☐	☐	☐
EOL strategies:				
• **Remanufacturing**	☐	☐	☐	☐
• **Reconditioning**	☐	☐	☐	☐
• **Reusing**	☐	☐	☐	☐
• **Repurposing**	☐	☐	☐	☐
• **Repairing**	☐	☐	☐	☐
• **Recycling**	☐	☐	☐	☐
• **Incinerating**	☐	☐	☐	☐
• **Landfilling**	☐	☐	☐	☐
Green purchasing	☐	☐	☐	☐
Green marketing	☐	☐	☐	☐
Green Human Resources Management	☐	☐	☐	☐

A3.2.3 In order to be able to comply with local environmental regulations, companies often have to resort to customised green approaches. Is this the case of your company? If so, which customised green strategies have been implemented?

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A.3.3 Green Practices towards Social Performance

A3.3.1 In your opinion, which are the main contributions of green practices towards improving the company's social performance?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Employee well-being:				
• **Employee safety**	☐	☐	☐	☐
• **Employee health**	☐	☐	☐	☐
• **Cleaner workplace**	☐	☐	☐	☐
Supplier commitment	☐	☐	☐	☐
Green organisational culture				
Community's safety and health	☐	☐	☐	☐
Stakeholder commitment	☐	☐	☐	☐
Taking care of customer's well-being by providing them an eco-friendly product, free of toxic components and minimising domestic energy consumption.	☐	☐	☐	☐
Improved company's public image	☐	☐	☐	☐
Improved social responsibility	☐	☐	☐	☐

A3.3.2 There are several factors (internal and external) that can regulate (either for the better or the worse) the influence of green practices in social performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Employee environmental conscious: In order to actually enjoy a safer, cleaner and healthier working environment, employees should be aware of the importance of green practices and be willing to adopt them.	☐	☐	☐	☐
Employee training				
Supplier commitment throughout the whole green supply chain, including product EOL, is essential since sharing and integrating ideas for environmental improvements across organisational boundaries can support the achievement of high environmental performance.	☐	☐	☐	☐
Green Human Resource Management is crucial to maintain green objectives throughout the whole HRM process of recruiting, hiring, training, compensating and developing human capital.	☐	☐	☐	☐
Local community environmental conscious.	☐	☐	☐	☐
Environmental policies and regulations oriented to human aspects.	☐	☐	☐	☐
Customers' ecological knowledge	☐	☐	☐	☐
Customers' environmental conscious	☐	☐	☐	☐

A3.3.3 Green initiatives are tightly related to local communities since they affect their quality of life, in terms of safety and health, in a direct way. In this line, becoming greener tend to improve the companies' public image, increasing local people engagement. Have your company experienced this positive feedback from the local people? Which changes have you noticed since your company has become greener?

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A.3.4 Green Practices: Summary

Overall, which green initiatives do you think your company should implement in order to achieve further improvements in its sustainability performance, in terms of operational, environmental and social aspects?

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A.4 Lean-Green Aproach towards Sustainability

This section attempts to explore the current practitioners' awareness of the benefits of combining lean and green initiatives into an integrated framework in order to achieve further improvements in the companies' sustainability performance. Based on the following questions, the idea is to identify to which extent companies understand the need and importance of combining both approaches as well as their willingness to adopt such a combined approach.

Please indicate your level of agreement with the following statements based on your experience in your organisation (questions 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.2.1, 4.2.2, 4.3.1, 4.3.2, 4.4.1, 4.4.2) and provide a complete answer for questions 4.2.3, 4.3.3, 4.4.3, 4.5.

A.4.1 Lean-Green Approach: Understanding

This section is intended to evaluate the actual practitioners' understanding of the necessity of integrating both approaches (lean and green) within the organisational context in order to reach a higher level of sustainability.

A4.1.1 Do you think is it necessary to integrate lean and green approaches to move towards the next level of sustainability?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Lean is green enough to achieve the required green level.	☐	☐	☐	☐
Lean is already sustainable.	☐	☐	☐	☐
Lean and green objectives differ, so that they cannot be implemented together.	☐	☐	☐	☐
To modify the current equipment to incorporate green technology is not profitable.	☐	☐	☐	☐
Lean efficiency can be diminished when addressing green issues.				
Lean and green practices can complement each other by:				
• **Enhancing each other strengths**	☐	☐	☐	☐
• **Disguising each other weaknesses**	☐	☐	☐	☐

A4.1.2 In general, which do you think will be the main benefits of implementing a lean-green approach?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Improved corporate image	☐	☐	☐	☐
Improvement in sustainable innovation	☐	☐	☐	☐
Increased sustainable competitive advantage	☐	☐	☐	☐
Improved process flow	☐	☐	☐	☐
Reduced cost and lead time	☐	☐	☐	☐
Increased compliance with customers' expectations	☐	☐	☐	☐
Improvement of environmental quality	☐	☐	☐	☐
Increased employee morale and commitment	☐	☐	☐	☐
Reduction in:				
Material usage	☐	☐	☐	☐
Energy consumption	☐	☐	☐	☐
Wastes	☐	☐	☐	☐
Water usage	☐	☐	☐	☐
Increased productivity	☐	☐	☐	☐
Improvements in health and safety	☐	☐	☐	☐

A4.1.3 In general, which are the main barriers do you think your organisation will have to face when implementing the integrated lean-green approach?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Lack of management commitment	□	□	□	□
Long implementation period	□	□	□	□
Employees are not properly trained in terms of:				
• **Lean practices**	□	□	□	□
• **Green practices**	□	□	□	□
• **How to address the combined approach of lean and green practices**	□	□	□	□
Lack of required resources in terms of:				
• **Know-how**	□	□	□	□
• **Equipment**	□	□	□	□
• **Technology**	□	□	□	□
• **Human Resources**	□	□	□	□
Gaps in standards and approaches	□	□	□	□
Fragmented nature of industry	□	□	□	□
Cultural barriers	□	□	□	□
Resistance to change	□	□	□	□
Government bureaucracy and instability	□	□	□	□
Long lists of supply chain and lack of trust	□	□	□	□

A4.1.4 In general, which are the fundamental success factors towards being actually able to reach improvements in sustainability when implementing the lean-green approach?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Management commitment	□	□	□	□
Good working environment	□	□	□	□
Customer focus and integration	□	□	□	□
System and process change management	□	□	□	□
Regular training of employees	□	□	□	□
Employee commitment	□	□	□	□
Effective planning	□	□	□	□
Integration of team and end to end supply chain	□	□	□	□
Adoption of a continuous improvement culture	□	□	□	□
Benchmarking of suppliers against each other	□	□	□	□
Strong communication and coordination between different sectors	□	□	□	□
Evaluation and review of performance/progress towards targets	□	□	□	□
Wide understanding, acceptance and adoption of lean and green concepts	□	□	□	□
Understanding of lean contributions towards implementation of green initiatives	□	□	□	□

A.4.2 Lean-Green Approach towards Operational Performance

This section is intended to evaluate the actual synergetic effect that lean and green approaches can have on the organisations' operational performance in particular, and to what extent practitioners are aware of such synergetic effect.

A4.2.1 A lean organisational culture can favour the adoption of green initiatives towards operational performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Lean working places and processes are more flexible, providing a suitable framework for implementing the required modifications and innovations for implementing green practices.	☐	☐	☐	☐
Lean manufacturing techniques, such as VSM, can be adapted to manage environmental issues based on green approaches. In this way, production and environmental goals can be simultaneously accomplished.	☐	☐	☐	☐
Employee self-development, in terms of employee training, empowerment and engagement, provides a fruitful environment for employees to be willing and capable to adopt new strategies, practices and technologies.	☐	☐	☐	☐
Lean production can reduce the marginal cost of green practices.	☐	☐	☐	☐
Lean 7 waste definition (transport, Inventory, motion, waiting, over-processing, over-production, defects) can be extended to address wastes from the green perspective (solid waste, hazardous wastes, air emissions, wastewater discharges).	☐	☐	☐	☐
Implementing green practices within a lean-oriented production process can lead green practices to be more efficient regarding lead times and cost.	☐	☐	☐	☐

A4.2.2 The lean-green approach can achieve several operational improvements.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Produced products will be not only high quality and low priced (lean), but also environmentally-friendly, taking the customer oriented nature of lean practices to a next level.	☐	☐	☐	☐
Green can improve lean profitability avoiding paying high taxes and financial punishments imposed by environmental regulations.	☐	☐	☐	☐
The lean-green approach improves competitive advantages since ensures better sustainable standards compliance.	☐	☐	☐	☐
The lean-green approach takes the reduction of resource consumption a step further than lean and green does individually. In particular, it further reduces the consumption of:				
• **Material usage by not only avoiding unnecessary wastes, but also reusing, repurposing and recycling**	☐	☐	☐	☐
• **Energy by being conscious of the energy usage not only for reducing cost but also for environmental reasons**	☐	☐	☐	☐
• **Water**	☐	☐	☐	☐

A4.2.3 Finally, in order to achieve the synergic effects mentioned in Question (4.2.2), lean and green practical implementation have to be well-coordinated. Which are the main operational issues you think your organisation will have to face when trying to implement both practices within an integrated framework? What do you consider could be the best strategy to implement such lean-green approach?

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A.4.3 Lean-Green Approach towards Environmental Performance

This section is intended to evaluate the actual synergetic effect that lean and green approaches can have on the organisations' environmental performance in particular, and to what extent practitioners are aware of such synergetic effect.

A4.3.1 A lean organisational culture can favour the adoption of green initiatives towards environmental performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Green practices are likely to achieve further greener results when being implemented in a lean-oriented production process which already works efficiently.	☐	☐	☐	☐
Employee empowering lean culture allows employees to be more aware of environmental issues, making it easier to spread the green thinking all across the organisation.	☐	☐	☐	☐
Lean strong interaction with local community can make it easier to customise green practices towards compliance of local regulations.	☐	☐	☐	☐

A4.3.2 Which further environmental benefits do you think the integrated lean-green approach can achieve?

	Strongly Agree	Agree	Disagree	Strongly Disagree
Produced products will be not only high quality and low priced, but also environmentally-friendly.	☐	☐	☐	☐
Lean waste reduction culture provides a proper environment for green practices to achieve better results in terms of reducing the environmental footprint.	☐	☐	☐	☐
EOL strategies aimed at reducing environmental damage can be more efficient when implemented using lean approaches.	☐	☐	☐	☐

A4.3.3 Although lean organisational culture can help to enhance the green results obtained by implementing green practices, there are some lean objectives that are in conflict with green objectives. Such is the case of the replenishment frequency (associated with the inventory level) that, from a lean perspective, has to be high in order to fulfil customers' requirements, while for a green perspective, a high replenishment frequency imply higher emissions, so they have to be reduced. Which are the main conflicting points towards reaching the environmental performance you think your organisation will have to face when trying to

implement an integrated lean-green approach? What do you suggest to address such conflicts?

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A.4.4 Lean-Green Approach towards Social Performance

This section is intended to evaluate the actual synergetic effect that lean and green approaches can have on the organisations' social performance in particular, and to what extent practitioners are aware of such synergetic effect.

A4.4.1 A lean organisational culture can favour the adoption of green initiatives towards social performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Lean practices favours social performance sought by green initiatives, for instance:	☐	☐	☐	☐
• **5S provides a well-organised and clean workplace, making it easier to ensure employees' safety and health.**	☐	☐	☐	☐
• **Total preventive maintenance keeps equipment in a good and ready-to-use condition, favouring a safer working environment.**	☐	☐	☐	☐
• **Work load balancing takes care of employees' health by distributing the assigned amount of work load in an equitable way among them.**	☐	☐	☐	☐
Lean strong interaction with local community can make it easier to customise green practices towards compliance of local regulations.	☐	☐	☐	☐
Lean strong interaction with local community can make it easier to customise eco-friendly products in order to fulfil local people needs.	☐	☐	☐	☐

A4.4.2 Lean and green practices can achieve synergetic effects towards social performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Produced products will be not only high quality and low priced, but also environmentally-friendly, improving customers' experience making customers to be more engaged.	☐	☐	☐	☐
To be green improves the corporate image, being further improved by the fluent communication channel with local community provided by the lean environment.	☐	☐	☐	☐
The employee satisfaction is guaranteed by not only training, empowerment and engagement, but also ensuring safety and health.	☐	☐	☐	☐
Being responsible for product until its EOL, makes organisations to recruit new human resources, opening new job opportunities to local community.	☐	☐	☐	☐

A4.4.3 How do you think your organisation can handle change resistance and cultural barriers when implementing the integrated lean-green approach?

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A.4.5 Lean-Green Practices: Summary

Finally, in your opinion, which are the actual possibilities of your organisation to implement a green-lean approach towards improving the overall sustainability performance?

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A.5 Triple-Bottom-Line Sustainability Model: Operational, Environmental and Social Performances towards Financial Performance

This section attempts to evaluate in which way operational, environmental and social performances obtained by lean, green and lean-green approaches do contribute towards the financial performance of the organisation.

Please indicate your level of agreement with the following statements based on your experience in your organisation (questions 5.1.1, 5.2.1, 5.3.1) and provide a complete answer for question 5.4.

A.5.1 Operational Performance towards Financial Performance

A5.1.1 The operational performance captures the degree to which firms can achieve cost reduction, improved quality, delivery and flexibility as a result of implementing manufacturing practices. Improvements in operational performance are reflected in the financial performance by…

	Strongly Agree	Agree	Disagree	Strongly Disagree
Increasing profitability by reducing production costs by:				
• **Reducing energy consumption**	☐	☐	☐	☐
• **Reducing raw material consumption**	☐	☐	☐	☐
• **Reducing resource consumption**	☐	☐	☐	☐
• **Reducing lead times**	☐	☐	☐	☐
• **Optimising delivery times and costs**	☐	☐	☐	☐
• **Optimising product design**	☐	☐	☐	☐
• **Elimination of unnecessary processes**	☐	☐	☐	☐
• **Elimination of wastes**	☐	☐	☐	☐
Increasing profitability by producing a high quality product	☐	☐	☐	☐

A.5.2 Environmental Performance towards Financial Performance

A5.2.1 In the current global situation, where the whole community is becoming more aware of the environmental impact of manufacturing activities, taking care of the environmental performance is crucial to reach improvements in the financial performance.

	Strongly Agree	Agree	Disagree	Strongly Disagree
To take care about the environment is a must for organisations seeking to lead in future markets.	☐	☐	☐	☐
People is more willing to buy greener products than non-greener ones.	☐	☐	☐	☐
International standard and local regulations are becoming stricter, yielding to high taxes and financial punishments in case they are not complied. Ensuring a good environmental performance will avoid paying them.	☐	☐	☐	☐
Companies risk is reduced by adopting practices towards environmental responsibility.	☐	☐	☐	☐

A.5.3 Social Performance towards Financial Performance

A5.3.1 Developing corporate strategies to do "well" by doing "good" and turning companies into responsible organisations that care about the social aspects is becoming increasingly a must for reaching financial performance improvements.

	Strongly Agree	Agree	Disagree	Strongly Disagree
Implementing practices towards employees' well-being, such as, ensuring their safety, health and training, as well as encouraging their involvement and engagement, makes them to be more committed with organisations' goals, and so, to work more efficiently, increasing the company's profitability.	☐	☐	☐	☐
An improved corporate image helps to improve profitability.	☐	☐	☐	☐
Companies risk is reduced by adopting practices towards social responsibility.	☐	☐	☐	☐
To maintain a healthy relationship with stakeholders impact positively on financial performance.	☐	☐	☐	☐
Increasing revenue through sale of social friendly products.	☐	☐	☐	☐
The fulfilment of the needs of the society helps organisation to enhance the firm value by:				
• **Reducing cost through efficient utilisation of scarce resources**	☐	☐	☐	☐
• **Improving transparency**	☐	☐	☐	☐
• **Reducing conflict of interest**	☐	☐	☐	☐

A.5.4 Sustainability Model: Summary

Overall, which do you think are the main success factors towards reaching financial performance improvements?

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Kindly supply any additional input/information you consider relevant to this questionnaire ………………………………………………………………………………………………………
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Thank you for completing the questionnaire

Please supply your email address if you would like to receive a summary of the survey results ………………………………………………………………………………………

A.6 Rationale for the Questions

Tabla A-1: Rationale for the questions.

Section	Question Theme	Question	Rationale for the Question
2. Lean Practices towards Sustainability **This section attempts to identify the maturity of lean implementation within the company environment, the barriers, the success factors, and the benefits perceived when implementing them, making particular emphasis in the lean contribution towards sustainability.**	**2.1 Lean Practices towards Operational Performance**	2.1.1 Which do you think are the main reasons why lean practices lead to improvements on the operational performance?	To understand the main reasons behind implementing lean practices for improving operational performance.
		2.1.2 In your opinion, the main lean practices yielding operational benefits are…	To evaluate which are the most accepted, adopted and understood lean practices within the operational sector.
		2.1.3 Which are the main barriers your company has encountered when implementing lean practices for improving operational performance?	To find out which are the barriers organisations have to face, in terms of operational issues, when implementing lean practices.
	2.2 Lean Practices towards Environmental Performance	2.2.1 In your opinion, lean practices can positively impact on the environmental performance in terms of…	To understand which are the currently perceived green benefits of implementing lean practices.
		2.2.2 Although lean practices can lead to environmental benefits (2.2.1), they have not been aimed at doing so, leaving environmental improvement opportunities (gaps) on the table. If these gaps are filled, further environmental improvements could result from the implementation of lean practices.	To understand if companies are actually interested in further improving their green results.
		2.2.3 Finally, which are the main conflicts of interest (if any) your company has encountered during lean practices implementation between lean objectives and environmental performance? In such a conflicting context, what further strategies do you (or your company) consider should be applied to actually achieve greener results?	To find out which are the perceived and, when possible, addressed conflicts between lean and green objectives within the real manufacturing world.
	2.3 Lean Practices towards Social Performance	2.3.1 According to your experience, the main contributions of lean practices towards improving the company's social performance are…	To evaluate the companies' awareness of lean social benefits.
		2.3.2 Not only lean social practices, but also technical ones can have a positive impact on social aspects of the company.	To evaluate to which extent companies are aware of the social impact of the lean practices they are currently implementing as well as to find out whether they are taking advantage of them or not.

		2.3.3 Moving a whole organisation towards lean culture is not an easy task. Did your company experiment resistance to changes when implementing lean practices? How did employees deal with these changes? To what extent did the national and local culture influenced this changing process?	To find out how the company managed to deal with change resistance and cultural issues.
		2.4 Overall, which lean improvements do you think your company should implement in order to achieve further improvements in its sustainability performance, in terms of operational, environmental and social aspects?	To find out which are the practitioners' particular vision and ideas towards reaching further improvements towards operational, environmental and social aspects.
3. Green Practices towards Sustainability **This section attempts to identify the maturity of green practices implementation within the company environment, the barriers, the success factors, and the benefits perceived when implementing them, making particular emphasis in the lean contribution towards sustainability..**	**3.1 Green Practices towards Operational Performance**	3.1.1 Although green practices are aimed at optimising the manufacturing process from an environmental rather than an operational perspective, they can lead to operational improvements.	To understand whether operational benefits of green practices can actually be perceived within the manufacturing sector.
		3.1.2 Which are the main operational challenges that can be encountered when implementing green initiatives?	To evaluate which are the main practical issues encountered when implementing green practices.
		3.1.3 Environmental regulations have largely been considered a burden for production and operational processes. Is this the case of your company? How do your company manage to comply with international environmental standards, policies and regulations?	To find out to what extent green practices are still considered as a burden towards production, and whether companies are willing (and how) to deal with them.
	3.2 Green Practices towards Environmental Performance	3.2.1 Green practices are specifically aimed at reducing the environmental footprint throughout the whole product life cycle. In your opinion, the main contributions of green practices towards the environmental performance are…	To evaluate which are the main environmental benefits pursue and perceived when implementing green practices within the manufacturing sector.
		3.2.2 According to your experience, the most efficient green practices towards reducing the environmental footprint throughout the whole product life cycle are…	To evaluate which are the most effective green practices being currently implemented within the manufacturing context.
		3.2.3 In order to be able to comply with local environmental regulations, companies are often compelled to resort to customised green approaches. Is this the case of your company? If so, which customised green strategies have been implemented?	To evaluate whether companies have to resort to customised solutions and which are the ones currently implemented (if any).
	3.3 Green Practices towards Social Performance	3.3.1 Which do you consider are the main contributions of green practices towards improving the company's social performance?	To find out the main changes perceived regarding social aspects when becoming greener.
		3.3.2 There are several factors (internal and external) that can regulate (either for the better or the worse) the influence of green practices in social performance.	To understand which are the main green factors influencing social aspects.
		3.3.3 Green initiatives are tightly related to local communities since they affect their quality of life, in terms of safety and health, in a direct way. In this line, becoming greener tend to improve the companies' public image, increasing local people engagement.	To evaluate whether the company has perceived good feedback from the local community when implementing green initiatives.

		Have your company experienced this positive feedback from the local people? Which changes have you noticed since your company become greener?	
		3.4 Overall, which green initiatives do you think your company should implement in order to achieve further improvements in its sustainability performance, in terms of operational, environmental and social aspects?	To find out which are the practitioners' particular vision and ideas for incorporating new methods in order to reach further improvements in terms of operational, environmental and social performances.
4. Lean-Green Approach towards Sustainability **This section attempts to explore the current practitioners' awareness of the benefits of combining lean and green initiatives into an integrated framework in order to achieve further improvements in the companies' sustainability performance. Based on the following questions the idea is to identify to which extent companies understand the need and importance of combining both approaches as well as their willingness to adopt a combined approach.**	**4.1 Lean-Green Approach: Understanding** This section is intended to evaluate to the actual practitioners understanding of the necessity of integrating both approaches within the organisational context in order to reach a higher level of sustainability.	4.1.1 Do you think is it necessary to integrate lean and green approaches to move towards the next level of sustainability?	To find out to what extent practitioners are aware of the need for incorporating an integrated lean-green approach.
		4.1.2 In general, which do you think will be the main benefits of implementing a lean-green approach?	To find out if practitioners do understand the benefits a combined approach could provide to the company sustainability performance.
		4.1.3 In general, which are the main barriers do you think your organisation will have to face when implementing the integrated lean-green approach?	To find out which are the main arguments against implementing a combined approach.
		4.1.4 In general, which are the fundamental success factors towards being actually able to reach improvements in sustainability when implementing the lean-green approach?	To evaluate the current practitioners' understanding of which should be the given conditions in order to favour the lean-green approach implementation.
	4.2 Lean-Green Approach towards Operational Performance This section is intended to evaluate to the actual synergetic effect that lean and green approaches can have on the organisations' operational performance in particular, and to what extent	4.2.1 A lean organisational culture can favour the adoption of green initiatives towards operational performance.	To find out practitioners' awareness regarding how a lean culture can enhance green practices performance towards reaching operational improvements.
		4.2.2 The lean-green approach can achieve several operational improvements.	To find out whether practitioners understand the operational benefits the lean-green approach can obtain.
		4.2.3 Finally, in order to achieve the synergic effects mentioned in Question (4.2.2), lean and green practical implementation have to be well-coordinated. Which are the main operational issues you think your organisation will have to face when trying to implement both practices within an integrated framework? What do you suggest could be the best strategy to implement such lean-green approach?	To understand which are the main issues practitioners understand they will have to face when implementing the combined approach, as well as to find out whether they have innovative ideas to address such issues.

practitioners are aware of such synergetic effect.		
4.3 Lean-Green Approach towards Environmental Performance This section is intended to evaluate to the actual synergetic effect that lean and green approaches can have on the organisations' environmental performance in particular, and to what extent practitioners are aware of such synergetic effect.	4.3.1 A lean organisational culture can favour the adoption of green initiatives towards environmental performance.	To find out practitioners' awareness regarding how a lean culture can enhance green practices performance towards reaching environmental improvements.
	4.3.2 Which further environmental benefits do you think the integrated lean-green approach can achieve?	To evaluate if practitioners can perceive further environmental improvements from implementing the combined approach.
	4.3.3 Although lean organisational culture can help to enhance the green results obtained by implementing green practices, there are some lean objectives that are in conflict with green objectives. Such is the case of the replenishment frequency (associated with the inventory level) that, from a lean perspective has to be high in order to fulfil customers' requirements, while for a green perspective a high replenishment frequency imply higher emissions, so they have to be reduced. Which are the main conflicting points towards reaching the environmental performance you think your organisation will have to face when trying to implement an integrated lean-green approach? What do you suggest to address such conflicts?	To find out whether practitioners believe green objectives are not compatible with lean ones, and to evaluate how they suggest addressing potential conflicts between both approaches.
4.4 Lean-Green Approach towards Social Performance This section is intended to evaluate the actual synergetic effect that lean and green approaches can have on the organisations' social performance.	4.4.1 A lean organisational culture can favour the adoption of green initiatives towards social performance.	To find out practitioners' awareness regarding how a lean culture can enhance green practices performance towards reaching social improvements.
	4.4.2 Lean and green practices can achieve synergetic effects towards social performance.	To find out whether practitioners understand the social benefits the lean-green approach can obtain.
	4.4.3 How do you think your organisation can handle change resistance and cultural barriers when implementing the integrated lean-green approach?	To understand to what extent practitioners are capable of handling human resources and dealing with cultural organisation.
	4.5 Finally, in your opinion, which are the actual possibilities of your organisation to implement a green-lean approach towards improving the overall sustainability performance?	To find out which are the actual possibility practitioners believe they have to implement a combined lean-green approach towards increasing their sustainability performance, and to

		measure to what extent they are willing to do so.
5. Triple-Bottom-Line Sustainability model: Operational, Environmental and Social Performances towards Financial Performance **This section attempts to evaluate in which way operational, environmental and social performances obtained by lean, green and lean-green approaches do contribute towards the financial performance of the organisation.**	5.1.1 The operational performance captures the degree to which firms can achieve cost reduction, improved quality, delivery and flexibility as a result of implementing manufacturing practices. Improvements in operational performance are reflected in the financial performance by…	To evaluate the practitioners' awareness regarding how improvements in operational performance can be reflected in financial performance.
	5.2.1 The current global situation, where the whole community is becoming more aware of the environmental impact of manufacturing activities, taking care of the environmental performance is crucial to reach improvements in financial performance.	To find out whether practitioners are aware of the crucial importance that the environmental responsibility currently has towards improving financial performance.
	5.3.1Developing corporate strategies to do "well" by doing "good" and turning companies into responsible organisations that care about the social aspects is becoming increasingly a must for reaching financial performance improvements.	To find out whether practitioners are aware of the crucial importance that the social responsibility currently has towards improving financial performance.
	5.4 Overall, which do you think are the main success factors towards reaching financial performance improvements?	To find out which are the factors that practitioners consider as crucial for reaching financial performance improvements.