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THE IMPACT OF LEAN PRACTICES ON THE ENVIRONMENTAL PERFORMANCE OF MANUFACTURING COMPANIES

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"All that we see or seem is but a dream within a dream"

– Edgar Allan Poe

Summary

Lean production has emerged in the past decades as one of the most popular subjects in business and manufacturing literature and it is the most widespread production paradigm currently applied in industry. The lean paradigm is characterized by five principles (value, mapping the value stream, flow, pull and continuous improvement) and by the relevance of reducing waste (muda). In parallel, the environmental performance of a company in terms of pollution prevention and reduction of the use and waste of resources is an issue increasingly concerning both firms and customers in recent years. This focus on these topics has fostered an area of research that it is frequently acknowledged as green production. Lean and green production paradigms are both focused on waste reduction and various scholars have studied their relationships (common points and divergences) and the synergic effects of joining these two management approaches. However, the impact of lean practices on environmental performance is still unclear, as limited empirical research has been conducted in this field. From this idea arises the aim of this research, which is to analyse the relationship between lean and environmental performance in manufacturing with a strong empirical focus. This research was carried out in two main stages: a review of the relevant literature as an exploration stage and a multiple case study analysis in five manufacturing companies to empirically analyse the aforementioned impacts. Onsite data were collected from firms during a time span of research of five years, involving archival data and developing semi-structured interviews. Besides, a cross-case analysis was carried out to map the possible relationships between lean practices and environmental measures. The findings of this thesis indicate that the environmental performance of the companies analysed is generally enhanced in the long-term after the implementation of lean practices. Moreover, the results from the multiple case study suggest that the environmental performance of the firms under study is mainly improved using JIT and TQM practices in a lean transformation context. These results are perfectly aligned with the preliminary evidences obtained in the literature review analysis developed in this thesis and provides robustness to the conclusions obtained. The research findings provide a better understanding of the phenomena, unveil new evidences and can be particularly useful for both researchers and practitioners who are facing the challenge of studying and implementing lean without omitting environmental performance goals, sharing efforts as much as possible.

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Abbreviations and acronyms

3BL – Triple Bottom Line

5S – Sort (Seiri), Set in order (Seiton), Shine (Seiso), Standardize (Seiketsu) and Sustain (Shitsuke)

CSR – Corporate Social Responsibility

EPA – Environmental Protection Agency

HRM – Human Resource Management

IMVP – International Motor Vehicle Program

ISO – International Organization for Standardization

JIT – Just In Time

KPI – Key Performance Indicator

PDCA – Plan Do Check Act

SCM – Supply Chain Management

SLR – Systematic Literature Review

SMED – Single-Minute Exchange of Die

TPM – Total Productive Maintenance

TPS – Toyota Production System

TPV – Total Performance Variation

TQM – Total Quality Management

VOC – Volatile Organic Compound

VSM – Value Stream Mapping

WIP – Work In Process

Chapter 1. Introduction

This introduction chapter provides briefly some background to the research, then explains the problem statement and research gaps, subsequently sets the objectives of the thesis and formulates the research questions, and finally concludes giving an overview of the research with a description of the thesis structure.

1.1 Background

The Lean production system (Womack and Jones, 1996) is the most extended production paradigm nowadays with its practices and methods initiated by Toyota (Toyota Production System) between 1950 and 1960 which have been replacing conventional methods in manufacturing industries. This philosophy is based on the pillars of "doing more with less", becoming closer and with focus on delivering customer value, and it is settled in the five lean principles: value, mapping the value stream, flow, pull and seek perfection. Additionally, due to the currently intense pressure to utilize the resources optimally, lean management pursues the reduction of non-value-added activities in the whole processes of the company and sets up seven types of waste, also known as muda in lean atmospheres (Womack and Jones, 1996; Ohno, 1988).

In parallel, the notion of Sustainability appeared as the "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The aim of sustainable strategies is to facilitate the creation of favourable situations by aligning three dimensions of the company also known as triple bottom line or 3BL, these are: social, economic and environmental. These dimensions are really present in corporate decisions and in social responsibility strategies of firms and are in continuous emergence and on demand by stakeholders and institutions.

Limiting the sustainability concept with an environmental performance view, arises the notion of Green manufacturing (Van Berkel et al., 1997) which "aims a continuous integration of environmental improvements of industrial processes and products to reduce or prevent pollution to air, water and land; to reduce waste at the source; and to minimize risks to humans and other species". It is possible to relate the waste reduction orientation of lean production with the sustainable manufacturing concept which is "the creation of manufactured products which use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" (U.S. Department of Commerce, 2010).

In brief, to be competitive in industry, organizations must combine more than ever products or services with higher quality levels, with significant cost reductions and in less production and delivery times. Simultaneously, firms have to be socially responsible and be aware of their implications for the environment. Lean manufacturing may help firms in the achievement of both objectives if they demonstrate real commitment and awareness about their effects on the environment, however companies should be cautious on this since lean implementation could also lead to unexpected negative impacts.

1.2 Problem statement and research gaps

Among the most important factors of the increasing importance of environmental performance is the fast depletion of natural resources that has forced companies to continuously improve their processes pursuing environmental efficiency strategies. Consequently, central to the definition of green production is the theme of waste reduction management which is present in many approaches for reducing environmental impacts. From this point of view, it seems that lean production and sustainable/green production have many elements in common since both are focused on reducing waste and increasing efficiency of production processes. This shared objective of waste reduction between both economic (lean) and ecologic (green-sustainable) approaches was the issue that originated this research.

Recently several academics have analysed the possible relationships between the adoption and the effects of both lean and green production paradigms. The results achieved to date are not always consistent with themselves, some studies strongly highlight the existence of a positive relationship while others are more cautious by suggesting that lean practices' implementation does not always enable environmental performances in companies.

Regardless of the results obtained by these authors, the study of the relationships between lean and environmental performance has also encouraged various scholars to explore new areas of research within this field. Some of these academics have developed joint models for the implementation of both paradigms (Ng et al., 2015; Pampanelli et al., 2014; Kurdve et al., 2014; Verrier et al., 2016), have designed assessment frameworks (Gupta et al., 2017; Helleno et al., 2017; Thanki and Thakkar, 2016) and studied the barriers that may counter the implementation and assessment of lean and green paradigms (Cherrafi et al., 2017a; Mittal et al., 2016); other authors have investigated the relationship between both concepts in different sectors besides manufacturing and with special characteristics such as construction, consumer goods industry, logistics and foundry industry (Bae and Kim, 2018; Colicchia et al., 2017; Ugarte et al., 2016; Garza-Reyes et al., 2016; Prasad et al., 2016); in addition, the analysis of these relationships within diverse national contexts such as India, China, Sweden and Brazil, has been also under study by several academics (Thanki et al., 2016; Zhan et al., 2016; Kurdve et al., 2014; Jabbour et al., 2013).

Moreover, the great majority of the empirical studies already done are anecdotal or framed in application examples and not focused on a long-term analysis. Hence, during the study of this relationships in literature, two clear gaps were identified. These open research opportunities guided the research carried out in this thesis. The first one is the necessity for a clear identification of the effects of lean practices on environmental measures which is an issue that requires further investigation. The second research gap regards to the study of the relationships between lean and environmental performance observed during an extended period. A major part of studies in literature are often punctual analyses in time while a medium-long term vision is lacking considering the evolution of the process of lean transformation in the company.

Finally, beyond the research gaps, the originality of this study lies in the examination of the links between lean practices and environmental measures found in literature and in practice during an extended time span. The study of these relationships is of great interest to scholars in the operations and waste management and sustainability areas; as well as to practitioners and managers designing lean and sustainable strategies and to policy advisors. Moreover, provides valuable information for companies to pull demand, since firm's environmental impact is a problem concerning more and more customers, which are requesting cleaner products and raw materials, less waste and reduced environmental damage in general.

1.3 Objectives, research questions and methodology applied

The first aim of this study is to conduct a literature review to understand the phenomenon and identify relevant preliminary evidences regarding the relationships between lean and environmental performance.

Based on this primary investigation, the second and main research objective is to empirically analyse the relationship between lean and sustainable/green manufacturing with a strong emphasis on environmental performance. More precisely, this study mainly intends to discuss whether firms which have applied lean principles and methods have improved or not their environmental measures and deepen on which environmental measures are impacted directly.

Based on the preliminary exploration of the research area noted above, and regarding the objectives and gaps of knowledge, the final research questions are:

- RQ1: Do lean practices impact on environmental measures?
  To classify the type of relationships as a preliminary approach.
- RQ2: How do lean practices impact on environmental measures?
  To deepen on in which way lean practices impact the environmental measures.

After establishing the research questions, the first of them (RQ1) was addressed with the systematic literature review itself, investigating the current state of the art of the corresponding research field and providing the first insights of this thesis. For the second research question (RQ2), it was decided that the most appropriate methodology was a multiple case study approach, in order to focus the research in both qualitative and empirical ways. The case studies were developed in five manufacturing companies to deepen in the preliminary evidences already found in literature in several different contexts and using data of a long-term period of time. Then were applied both within-case and cross-case analysis in order to investigate the empirical evidences obtained from the companies and to elucidate the links between the cases.

1.4 Structure of the thesis

As a starting point, Chapter 2 collects various theoretical insights on the lean and green production paradigms, which are the main themes that will be repeated during the course of this thesis. This chapter contains information about the origins of both paradigms, their main principles, concepts, wastes and various relevant practices which must be explained just before the start of their joint examination, first with the analysis of the literature and then with the empirical study.

Chapter 3 sets out a comprehensive review of previous published research on the relationship between lean manufacturing and environmental performance, including the study of various lean practices and environmental measures. In it, are detailed the systematic literature review method utilized, the selection criteria of the sample of papers, also the articles found are assorted according to their main characteristics, some classifications are outlined according to the evidences obtained in the studies featuring practices and measures and finally, it is provided a final summary-table. Apart from the systematic literature review in this section are presented the research gaps emerged, research objectives and questions are then stated to end up the chapter with the theoretical framework that guided the research.

Chapter 4 describes the research methodology. After a brief description of the research approach in the first section, the subsequent section explains the research protocol followed: presenting the questionnaire used, the process for assuring reliability of the instruments used to collect the data from the cases and the criteria of selection of the case studies. Moreover, it is outlined for the first time in this thesis the companies considered for the study, showing in a table some descriptive data of the firms. Finally, the data collection and analysis processes are explained.

The empirical part of this thesis starts with Chapter 5. It first provides a general description of the companies involved in the study, then the within-case analysis is developed for each company showing the empirical results emerged from the in-depth analysis of every firm. Finally, the cross-case analysis is developed collecting the main evidences emerged and performing a comparison between the cases.

In Chapter 6, the discussion of the results is described and the answers to the research questions are provided, the implications of the research findings are also outlined, as well as the limitations of this thesis and the new directions for future research. Finally, the summary of conclusions that have been drawn from the results of the various analysis is presented.

Chapter 2. Theoretical background

This chapter collects the theoretical background on the main concepts comprised in this thesis which were used as a basis to carry out this research as well: these main concepts revolve around the lean and green production paradigms. Consequently, the following sections about these two notions contain information about their origins, their main principles, concepts, wastes and main practices which must be explained before the start of their joint analysis, first with the review of the literature and then with the empirical study.

2.1 Lean production: history, principles and techniques

This first section describes the main theoretical knowledge about the lean paradigm, starting from its origins, to then explain the main principles of this concept and to end up with a brief depiction of various relevant practices.

2.1.1 The origins of the lean paradigm

Based on the production system formulated by Henry Ford, it was then developed by Taiichi Ohno and his team, who worked for Toyota, the production system that is nowadays one of the most famous and relevant worldwide: the "Toyota Production System" or TPS.

In 1930, Toyota was a car manufacturer experiencing difficulties, that mainly manufactured poor quality vehicles. More in detail, the company mostly produced trucks for the Japanese imperial army using economical processes, and therefore, the technologies used were not very developed.

In consequence, the Toyota Motor Company developed a new production system to survive the competition in the automotive industry after Japan lost the second world war in 1945. At that time Toyota decided to enter the commercial vehicle market in 1947. Simultaneously, Ford in the United States had already accumulated around 40 years of experience in mass production of cars through their own production system: the assembly line.

Consequently, immediately after the post-war period, Taiichi Ohno was put in charge of improving Toyota's operational productivity. He was also appointed director of the mechanical workshops of an engine factory and, between 1945 and 1955, he and his team had the opportunity to experiment with many concepts in production. It is in those years, when the Toyota Production System was created by Taiichi Ohno and his team, based on years of practical experience and ideas obtained from the United States and in addition to the adoption of Jidoka principles.

In this sense, the ancient idea of Jidoka was created in 1902 by the founder of the weaving company Toyoda, Sakichi Toyoda. Translated literally Jidoka means "autonomation", which is the contraction of two words: autonomy and automation. This concept refers to the notion of quality generation during the production process and the separation between man and machine. In fact, whenever a defect or a malfunction is discovered, the machinery has to stop automatically and the workers have to respond immediately for correcting this problem, interrupting the production flow. This technique usually entails alert systems which detect failures immediately when they occur.

This technique prevented the creation defective products within the manufacturing process. Later, in 1924, Toyoda by himself created an automatic chassis that allowed workers to operate multiple machines. The rights to produce the chassis outside Japan were then sold to Platt Brothers Ltd. in England and the benefits obtained with this operation were then partially reinvested to start, in 1937, a motor division under the direction of Kiichirō Toyoda, son of the owner of Toyoda, Sakichi Toyoda. The name of the company was later changed to Toyota for superstitious reasons, to distinguish the private life and career of the founders, and to simplify the pronunciation.

After this, Toyota managed to overcome faster than other companies the 1973 recession, which was very tough due to the oil crisis. In the 1980s, Toyota began to focus exclusively on mass production and cost reduction.

In 1985 the International Motor Vehicle Program (IMVP) was launched to undertake a detailed study of the new Japanese techniques to produce engines. An American engineer, named John Krafcik, who was part of the IMVP program, asked the following question to all the other members of the commission: "How do we call the production system used by Toyota?".

The TPS was neither craft production nor mass production, but it combined the advantages of these two systems, avoiding the high costs of the first and the rigidity of the second, and succeeding in using less input to produce quality products in huge volumes and varieties. Therefore, it was decided to call this production system "lean". So, the term "Lean Manufacturing" is nothing but a different name to indicate the "Toyota Production System".

2.1.2 Lean principles and types of waste

In the book "The machine that changed the world", which is considered one of the first important works in this field, Womack et al. (1990) define the five fundamental principles of lean manufacturing. These principles are mainly focused on the identification of waste and its subsequent elimination in order to produce more product with a lower consumption of resources. The five principles of the "lean thinking" are summarized in the following lines:

- Value: it means to identify what customers are willing to pay for. Companies must start designing and manufacturing products targeting what customers need. In other words, companies must give customers what they want and not always what is more convenient for the manufacturers. Taiichi Ohno said that, all industrial thinking must begin by differentiating the value for the customer from the waste or "muda".
- Value stream: once the value (which constitutes the final objective) has been determined, all activities that add value to the product must be aligned in the right sequence and must be disposed all along the supply chain. Therefore, the value flow is composed by the specific operations that, if performed correctly and in the right order, produce the product or service that the customer appreciates. The value is added to a product while someone is working on it, while no value is added when it is waiting to be processed (WIP), this translates into a source of waste. In summary, the goal is to identify every step that does not create value to then eliminate it.

- Flow: in lean companies, products have to flow constantly and without interruptions through a series of value-adding activities. This means that companies must work on each product continuously throughout the process so that there are no waiting times or waste, within or between activities. Companies should avoid lots and queues, or at least reduce them continuously to never delay the passage of a product among value adding activities.
- Pull: means that the system should respond to customer demand, customers are those who pull work through the system. After optimizing the flow, the time to reach customers can be significantly reduced. This makes it much easier to deliver products according to customer needs, such as in "just in time" production or delivery. Therefore, the products do not have to be built in advance or the materials do not have to be stored, generating money savings for both producers/suppliers and customers.
- Perfection: this principle is perhaps the most important of the lean philosophy. In fact, lean thinking and process improvement efforts must be made part of the corporate culture. Once the first four principles have been accomplished, lean companies have to better understand how to improve the whole system, trying to generate ideas for further improvements. Perfection does not only mean quality of the product/service, it also means producing exactly what the customer wants, exactly when it is needed, at a fair price and minimizing waste.

After having introduced the five lean principles and as was noted, another key point of the lean philosophy is the determination to eliminate all forms of waste, the so-called muda, within the company's processes. To achieve high levels of efficiency in a process it is necessary that this is designed in such a way that waste can be easily identified and then eliminated. A wasteful activity is defined as a process that absorbs resources but does not add value to the customers or to the organization (Womack and Jones, 1996).

Consequently, every type of waste represents a cost for the company that, consequently, it is not willing to pay. It is crucial to increase employee awareness in the concept of waste, as well as provide ways to identify and reduce it. In summary, it is possible to categorise seven types of waste that will be described below:

- Defects: these occur when a product or component no longer complies with the customer's needs. This customer can be internal or external to the production operations. Whenever defects happen, additional costs are incurred for the reprocessing of the part, the reprogramming of the production, etc.; this means additional labour costs. A defective product must not reach the customer and it must be considered as a loss. As usual, it is better to prevent defects than to detect them. Thus, the implementation of poka-yoke systems and giving autonomy to employees can help to prevent this lean waste.
- Overproduction: it occurs when more outputs are produced than required by customers at any time. This waste leads to high stock levels that hide several problems within the company, and in many cases, a part of these stocks is wasted because customer demands change over time. Overproduction is considered the greatest form of waste in the lean thinking philosophy as it can lead to the generation of all other forms of waste.
- Waiting: time is always crucial in production. Therefore, whenever the goods are not being transported or processed, they are in a waiting position.
- Transport: when a product is moved, risks being damaged, lost or delayed, and additionally, transport turns out to be a cost without any added value. Transportation does not make any transformation to the product that the customer is willing to pay. In the ideal lean production process, the whole of operations should be next to each other. In summary, the distance between the processes usually leads to the accumulation of stocks, due to the impractical nature of moving small quantities of materials or products over long distances.
- Over processing: this waste occurs when further work is done on a piece over the work levels actually requested by customers. Examples can be processes where inappropriate techniques are used, oversized machinery, operations not demanded by the customer and so on. This also includes the use of more precise, complex, superior quality or expensive components than those that may be necessary.
- Inventory: it may be composed by raw materials, work in process (WIP) or finished products. The stocks of these products will need to be stored and therefore the organization will require space and packaging. Moreover, these stocks could be damaged during transport or become obsolete. Thus, inventory represents a cost that has not yet

produced an income either from the producer or from the consumer. The stocks hide several additional problems.

- Motion: it entails the unnecessary movements made by workers or machines. These do not create any added value and consume time and energy. Furthermore, unnecessary motion will surely cause fatigue in operators that could lead to defects in products or to work accidents. These excessive movements cost time, and therefore money, and usually cause stress in employees and machines.

2.1.3 Main lean practices and tools

In this subsection a brief description of various important lean tools is provided. Many of these tools can be used alone, and are not usually combined with others, making implementation much easier. However, if several tools are used, these reinforce and strengthen each other and consequently more benefits may be obtained from their implementation. Below are listed various relevant and regularly applied lean techniques and practices:

- 5S: it refers to a workplace organization method formed by five stages (sort, set in order, shine, standardize and sustain) which are used for the consecution of lean production objectives. In other words, it allows the workplace to be organized cleanly, efficiently and safely in order to improve productivity, visual management and ensure the introduction of standardized work.
- Cellular manufacturing: it consists in encompassing group technology in areas or cells containing the work stations producing the same family of products. The goal is to improve the flow of the process, reduce motion within the factory and increase variety.
- Free pass: this method guarantees the quality of the supplier's product before it enters the factory.
- Hoshin Kanri (X Matrix): it is a single page document containing annual goals, long term strategic objectives, targets to enhance, top level improvement priorities and resources/owners. The objective is to align the long-term needs with the improvement initiatives, identify the most important activities and provide a list of metrics that should be improved.

- Jidoka: this Japanese word can be translated into "autonomation" of production and means to immediately stop production as soon as there is possibility of defects. It entails alert systems which detect failures whenever they occur.
- Just in time: this is one of the main pillars of lean and it is aimed primarily at reducing flow times within the production processes as well as response times from suppliers and to customers, it is based on the pull concept and on inventory reduction.
- Kaizen: this word means continuous improvement in Japanese. It comprises small steps of improvement usually suggested by the employees at the so-called "kaizen events". These regular reunions are team activities designed to eliminate waste and make rapid changes in the workplace.
- Kanban: it is a pull-based method to achieve JIT in lean manufacturing contexts. As part of a pull system, it allows to monitor what is produced, in what quantity and when. Its purpose is to ensure that is only produced what the client demands and nothing more. The system takes its name from the cards that track the production within a factory.
- Kanban deliveries with suppliers: it happens when a firm sends signals to the suppliers about the requirements of a product in order to shorten the supplying time. This technique usually integrates external vendors in the Kanban system of the company.
- Plan Do Check Act (PDCA): framed in the lean production paradigm it is a repetitive four-step method used for the control and continuous improvement of processes and products. It is also known as Deming Cycle.
- Production levelling (Heijunka): it is a Japanese word which means "levelling". Heijunka therefore aims to level production in terms of volume and product mix over a given period of time. Basically, it consists in producing intermediate and final goods at a regular sequence to meet with known regular and predictable patterns of demand.
- Pull system: beyond this technique, customer orders originate work through the production process.
- Single Minute of Exchange of Die (SMED): it is one of the main lean production methods. It reduces the changing times in equipment required to switch from producing the current product to the next product. This rapid changeover based on the pull concept enables one-piece flow, reduces output variability and production loss.

- Spaghetti chart: it is a visual representation of the physical flow of materials and people through the activities of a process. Usually this visual representation details the flow, the distance and the waiting times of the materials and the walking patterns of the line workers.
- Standard work in the workplace: for every workstation it is the definition of the most efficient methods to perform the activities within it, these activities are completed repeatedly and are documented in order to achieve continuous improvement in the workplace.
- Supply Chain Management (SCM): it consists in organising the flow of goods and services; comprises the movement and storage of inputs, of work-in-process inventory and of finished goods from the source to the point of consumption.
- Total Productive Maintenance (TPM): this holistic approach provides planned maintenance activities aimed to keep all equipment in top working conditions avoiding breakdowns and delays in processes.
- Value Stream Mapping (VSM): it is an effective waste identification method that analyses the current state and designs a future state for each family of products in a company, identifying the manufacturing steps that add value to the product and those that do not add value (muda) from the beginning to the delivery of the product to the consumer.
- Visual management: it is a technique employed to communicate controls and measures (i.e. stock levels, flow of work, order progress) using visual signals, boards or Kanban cards, instead of written instructions.

2.2 The green philosophy: environmental management and performance

The integration of environmental actions and organizational performance is one of the most relevant topics that has been growing in recent decades. The threat of climate change, the depletion of natural resources and the pollution of the environment are the main factors behind the international efforts to improve ecological awareness not only in companies but also in the entire supply chains. Moreover, firms must comply with environmental laws, while remaining focused on shareholder objectives.

In this section various relevant concepts related to the green philosophy and environmental performance will be examined in depth.

2.2.1 The origins of the green manufacturing paradigm

The concept of green manufacturing is quite new, in fact since the days of the first industrial revolution several studies have highlighted the numerous negative effects that production had on the environment. Nevertheless, in recent years more and more companies have transformed green manufacturing into a vital strategic position.

From the end of the seventeenth century to the beginning of the eighteenth century, with the invention of the steam engine, the industrial production system began to spread between companies. This system, compared to the previous handcrafted production, led to substantial increases in productivity. On the other hand, a significant growth of the consumption of fossil resources and energy occurred, resulting in the emission of large amounts of pollutants into the environment. All this not only led to the rapid depletion of natural resources, but also to the degradation of the environment and the emergence of problems that humanity had never experienced before such as acid rain, greenhouse effect, global warming, depletion of the ozone layer, etc. All these issues nowadays are progressively more significant, and were originated by the first industrial revolution, which marked the beginning of the manufacturing industry we know nowadays.

The situation got worse after 1850, when a very fast increase in the world energy consumption occurred and it has been sustained until now. Most of the energy resources consumed during this period have been coal, oil and natural gas which are well-known pollutants.

In summary, the manufacturing industry on one hand helps mankind to produce and accumulate wealth, but on the other hand it is one of the main existing causes of resources depletion and environmental pollution. Therefore, to solve this environmental problem one of the main fields of research in recent years is being the "green" theme in manufacturing. This concept aims to reduce the consumption of resources and pollution during production. Therefore, the concept of green manufacturing is considered a production approach that cannot be completely overlooked by today's organizations.

2.2.2 Principles, environmental wastes and guidelines of the green paradigm

The idea of green manufacturing as was described by Van Berkel et al. in 1997 "aims a continuous integration of environmental improvements of industrial processes and products to reduce or prevent pollution to air, water and land; to reduce waste at the source; and to minimize risks to humans and other species".

As well as the lean manufacturing concept, the green production paradigm follows a few rules which are essential to determine the aims and objectives of the entire production system. These principles should be followed by companies implementing green techniques to guarantee successful results (Dornfeld et al., 2012):

- A system approach must be used to evaluate and improve manufacturing processes from a green perspective: it is vital to not only consider the effect of process improvements towards the environment, but also to consider the effect of these transformations on other parameters that may also impact the environment and understanding the complexity of the entire production process.
- The entire process should be observed in both vertical and horizontal directions: this approach is crucial as environmental impacts may occur or may be exaggerated depending on the level of depth of the analysis. Moreover, this approach can lead to effective solutions to reduce environmental effects of production operations, and even more, enhance efficiency.
- Harmful inputs and outputs should be reduced or eliminated from production operations: damaging inputs should be replaced by other inputs that imply less damage to the environment or humans, or even firms should be able to find methods to recycle or reuse these inputs, reducing the impact of their manufacturing processes. Similar methods can be considered for harmful outputs using recycling, but also pollution abatement techniques.
- Net resource use should be reduced: it should be zero or as nearest as possible so that resources may be utilized at a proportion equivalent to the rate of replenishment present in the environment.

- Time based effects should be taken into account: it is important to consider the impacts of manufacturing, as they may happen at any stage of the life cycle of the products, from the design until the withdrawal.

Moreover, the environmental wastes, which are targeted as one of the main objectives of the green production paradigm, are produced by the unnecessary use of resources or the release of substances into air, water, or land that could harm the environment or human health. This may occur when companies use resources to produce products or services to customers, and/or when customers use and dispose products. More specifically, environmental wastes include:

- Energy, water or other raw materials consumed, more than those required to meet the customer needs.
- Contaminating substances and material waste released into the environment, such as atmospheric emissions, wastewater discharges and solid waste.
- Dangerous substances that are harmful to human health or the environment during their use in production or their presence in products.

Like lean wastes, environmental wastes do not add customer value and represent additional costs to companies and to the society in general. These may also have direct influence on the flow, time, quality and production costs, making them targets for lean initiatives. In many cases, the costs associated with pollution and energy waste, water and raw materials can be significant, so it is better to identify and eliminate wastes in general and environmental wastes in particular (EPA, 2007).

Therefore, to address waste elimination objectives, more and more companies have started adopting green initiatives as part of their operations. These initiatives are empowered by several drivers that motivate the manufacturing industry to move towards green manufacturing practices. These motivation factors are summarized mainly in these three groups (Dornfeld et al., 2012):

- Regulatory pressures: the increased awareness of the environmental problems caused by industrial wastes and emissions has compelled governmental agencies to release new and more severe policies, regulations and laws. However, not everything included in this category are pressures and obligations. Usually, public administrations also organize green manufacturing themed workshops and conferences to motivate firms to undergo the implementation of sustainability strategies.

- Economic incentives: in general, green manufacturing includes practices such as emission control and pollution prevention. These practices usually can help to reduce costs of both waste management and material consumption, and therefore can improve the profit margin of manufacturing firms.
- Competitive advantages: society is becoming more conscious of the environmental impact of manufacturing, and in particular, customers and other stakeholders typically prefer those organizations with a better environmental image in the market. Therefore, due to the implementation of green manufacturing, firms can improve their image, this may generate further revenues and increase their differentiation.

In contrast, even if green production is driven by the above-mentioned motivating factors, there are other challenges that may hinder its implementation. These barriers for green manufacturing are summarized into three main categories (Dornfeld et al., 2012):

- Economical barriers: the costs of implementation of a green production system are high and perhaps take a long time to be paid back. This has significantly delayed the generalization of the application of the green paradigm in manufacturing. However, the use of control and prevention systems instead of the classical end-of-the-pipe methods, which are becoming progressively expensive, has reduced the significance of this barrier in recent years.
- Managerial barriers: frequently firms do not have analytical and decisional tools to observe and characterize the effect of their operations. This affects directly the decision-making process which is not accompanied in some cases by real time performance data.
- Technological barriers: some processes in manufacturing are constrained to be harmful to the environment because they must rely on certain methods, technologies, or materials which may not be “green”. However, because of the current state of technology these cannot be omitted (i.e. spray-based painting processes).

In summary, the green approach has passed from being perceived by companies as a "necessary evil" or something inconvenient that had to be accepted, to be considered a "good deal". Firms that undergo green initiatives usually improve brand and corporate images, obtain greater customer satisfaction and achieve potential cost savings. However, these benefits require a long-term commitment and a compromise with short-term goals, as the green manufacturing approach is not yet well understood.

2.2.3 Main green practices and tools

To run successfully the implementation of the green manufacturing paradigm, it is recommended to consider the regular utilization of the following green practices:

- Green technologies for product design (eco-design): it means designing products considering the environmental effects of the entire life cycle. This covers from the materials used for its fabrication, taking into account the potential pollution during the use of the product by the customers or the waste generated with its withdrawal.
- Green technologies for production: with this approach companies aim to create products with advanced production techniques to reduce the consumption of resources, environmental pollution and waste, thus ensuring greater safety and health of workers and society.
- Green packaging: companies make efforts to produce and use environmentally friendly packaging that is reusable, recyclable, biodegradable and therefore does not harm human beings or the environment during the entire life cycle of the product.
- Green technologies for the recycling of products and resources: if a product is not recycled after its life cycle it will possibly end up being a waste of resources and consequently an environmental waste. The same applies to the resources used within companies, usually the potential of reuse is substantial, with many possibilities for the recycle of water, energy and some chemicals and metals. An example of this are the closed loop systems for recycling of water which are generally an economically and widely used practice. Consequently, green recycling is a systematic problem that must be considered from the beginning of product design until the end of its life cycle.
- Green technologies for the regeneration of products: consist in a set of techniques for the recovery of products at the end of their life cycle and the conversion of these into similar products but close to the previous one.

- Green technologies for a better management of the structure: involves the management of operations in order to keep in good operative and environmental conditions. These operations should be done through simple, ordinary and not resource-intensive activities. These may include activities such as the separation of waste, the minimization of stocks of chemicals and waste, the installation of overflow alarms and automatic shut-off valves, the elimination of leaks, frequent inspections to identify possible environmental problems and potential malfunctions in the production process, frequent preventive maintenance programs and optimization of machinery.

In conclusion, this section introduced the most relevant concepts and issues of the green manufacturing paradigm. During the development of this chapter it is noteworthy the parallelism with the lean production paradigm in some dimensions such as the identification of wastes, the establishment of principles and the use of different practices, aiming to achieve efficiency.

These common points between both lean and green paradigms reinforce the existence of this research and support the study of the relationship between lean and environmental performance, and the identification of their common points and divergences. These analyses will be developed during the subsequent chapters of this thesis.

Chapter 3. Literature review, research gaps and research questions

This chapter provides in its first section a comprehensive review of previous published research on the relationship between lean manufacturing and environmental performance. The second section is reserved to the research gaps found in the existing literature. The selection of the research questions is outlined in the third section. Finally, the fourth section illustrates the theoretical framework that guides the forthcoming empirical research.

3.1 Literature review analysis

The purpose of this section is to carry out a review of previous published research documents aimed at learning more about the relationship between lean and environmental performance, find common points, divergences, useful measures and good practices. First, the methodology adopted is detailed and the selection criteria of the papers, in addition are outlined various classifications according to the year of publication, source of publication and methodology applied. Then, the analysis focusses its attention on the environmental measures which are more frequently used and the impact that lean has on them. Afterwards, the relationships between the principal lean practice bundles (Shah and Ward, 2003) and environmental performance are classified. The literature review section concludes with a final matrix which links some important lean practices to various relevant environmental measures (Table 1), outlining some preliminary relationships obtained after the study of the literature.

This literature review analysis aimed to go deeper and deeper into previous published research, starting from general concepts to end up analysing the relationships of specific practices and measures.

3.1.1 Systematic literature review method

This chapter generally aims to analyse the extant literature utilising a systematic literature review methodology (SLR). In this sense, were replicated the stages developed by Garza-Reyes (2015). Figure 1 shows an overview of the SLR by describing its phases, objectives and methods adopted.

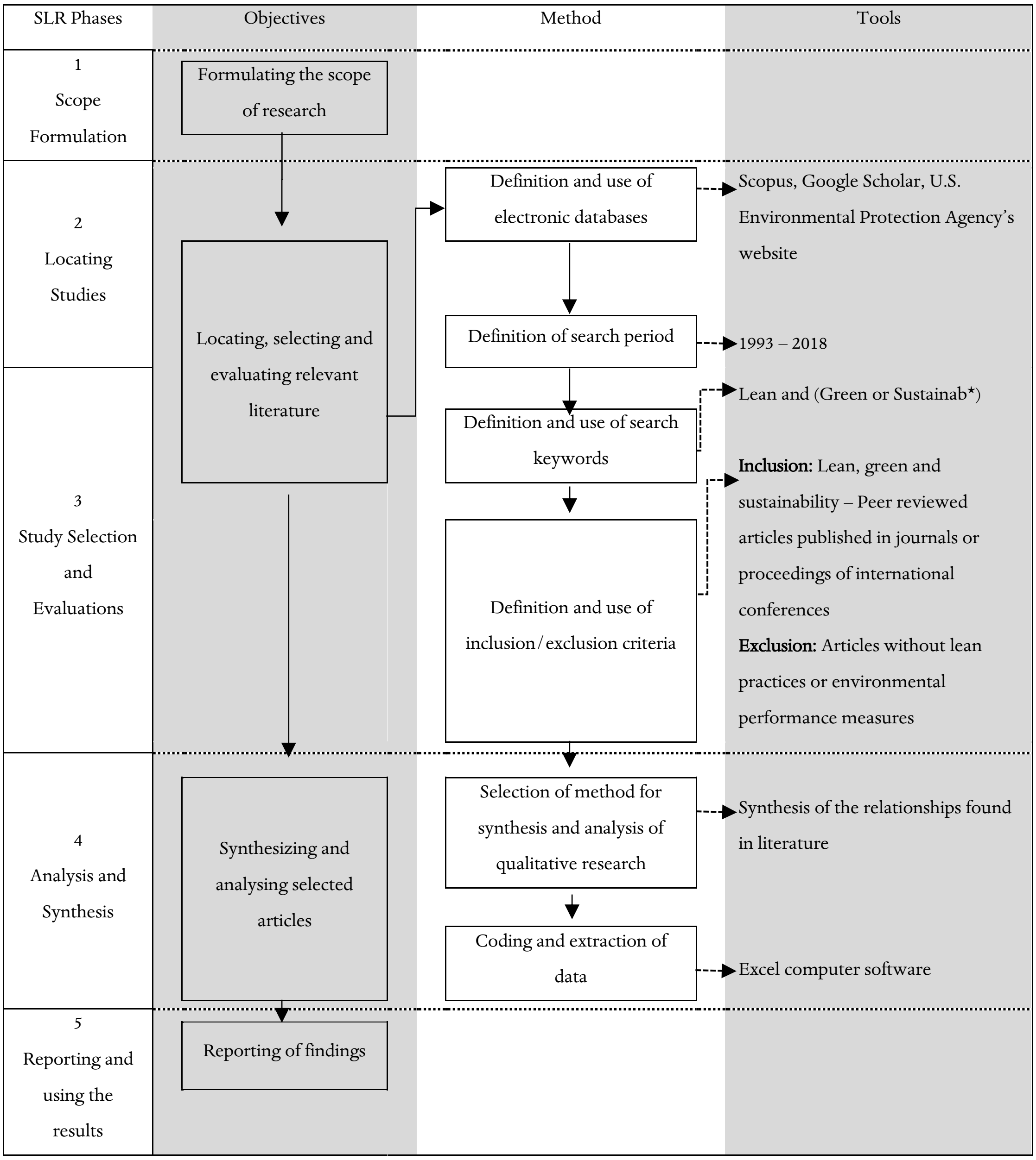


Figure 1. SLR phases, objectives, methods and tools (adapted from Garza-Reyes, 2015)

From the previous figure, the purpose of the SLR has been formulated in phase 1 as "the identification of the preliminary effects and relationships between various relevant lean practices and environmental performance measures". In the following subsections the whole analysis is provided starting with the description of the papers' selection method to then continue with the SLR following the phases noted in Figure 1.

3.1.2 Search and selection of articles

To examine this relationship between lean production and environmental performance were consulted the literature web databases Scopus and Google Scholar and the website of the U.S. Environmental Protection Agency (EPA). The reason to include the EPA website is that this agency has researched extensively in this area and has published many relevant reports. Consequently, the following keywords were searched: Lean and (Green or Sustainab*), using the asterisk in this word the database will include all the keywords which start with "sustainab", not discarding those referencing the same concept although they are not written equally as the keyword, for example "sustainability" or "sustainable". These keywords were searched in the title, abstract and keywords of the article and the time interval selected initiates from 1993 and finishes in 2018 (both years included), containing in this way the most relevant preliminary papers about this topic and the newest articles released. As initial date, 1993 was selected for this search due to the publication of a novel and relevant article in this field written by Corbett and Wassenhove (1993) which studies various analogies between environmental programs and successful practices in current use in operations management (including lean techniques).

The results obtained searching the keywords mentioned are shown in Figure 2. In summary, 3081 articles were found using keywords research.

Following the steps detailed in Figure 2, from the first results found in the database, and after applying the listed filters, 72 documents were chosen for the elaboration of the systematic literature review analysis and are listed in Annex 1.

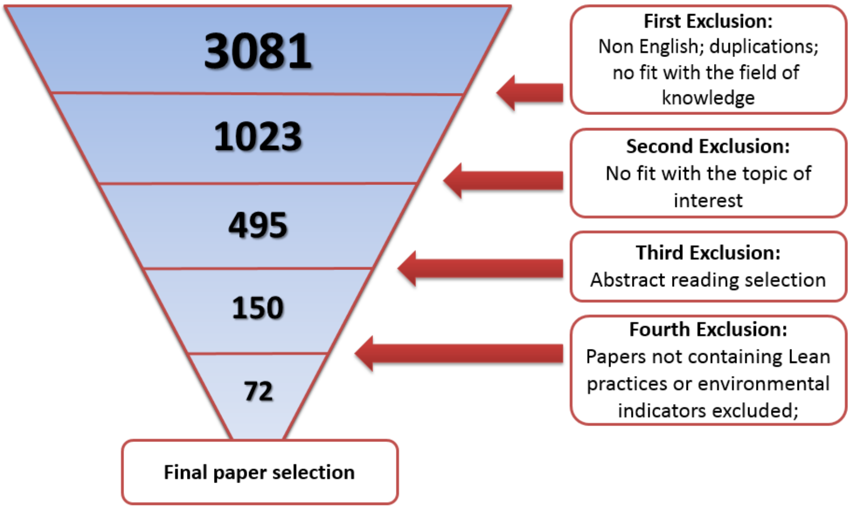


Figure 2. Article selection criteria

3.1.3 Classification of the papers

In this subsection the 72 articles selected are categorized according to various criteria in order to show the evolution of the publications in time, the sources of publication of the articles selected and the most used methodologies within their studies.

Figure 3 shows the publication dates of the documents emerging after the application of the selection criteria detailed in section 3.1.2 (see the complete list of publications in Annex 1). The papers are grouped in five-year intervals starting from 1993, except the last period that includes 6 years until 2018.

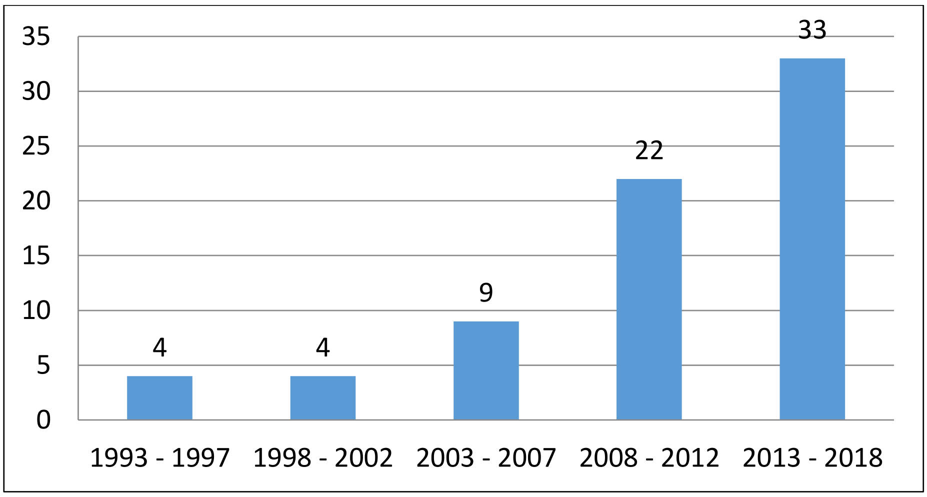


Figure 3. Publication dates of the documents

The data showed in Figure 3 highlight the increasing relevance in literature of the topic about the relationship between lean and environmental performance. As is possible to appreciate in the figure this increment is more pronounced from 2008 onwards.

Then a disaggregation of the set of 72 documents studied in four categories was made considering the source of publication, results are shown in Figure 4. Accordingly, 59 papers out of 72 (82%) were published in international academic journals, 8 were presented and included in proceedings of international conferences (11%), 3 documents out of 72 (4%) were reports made by institutions and the remaining 2 publications were books (3%).

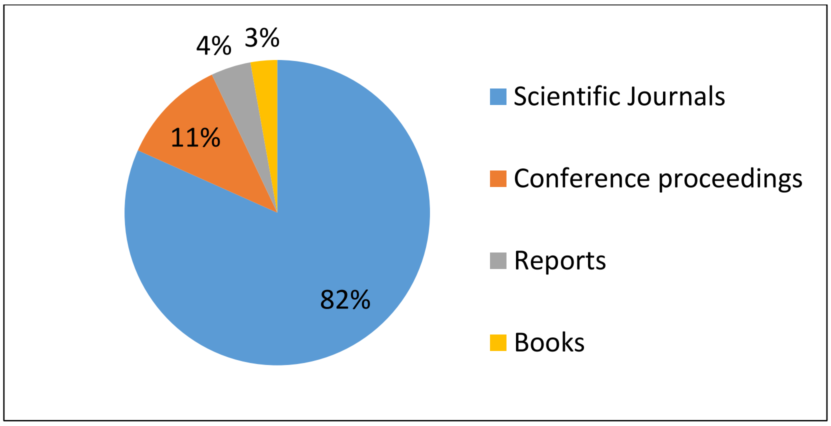


Figure 4. Paper classification according to the source of publication

Moreover, Figure 5 shows the assortment of the papers depending on which research methodology was adopted in each case, excluding the two books.

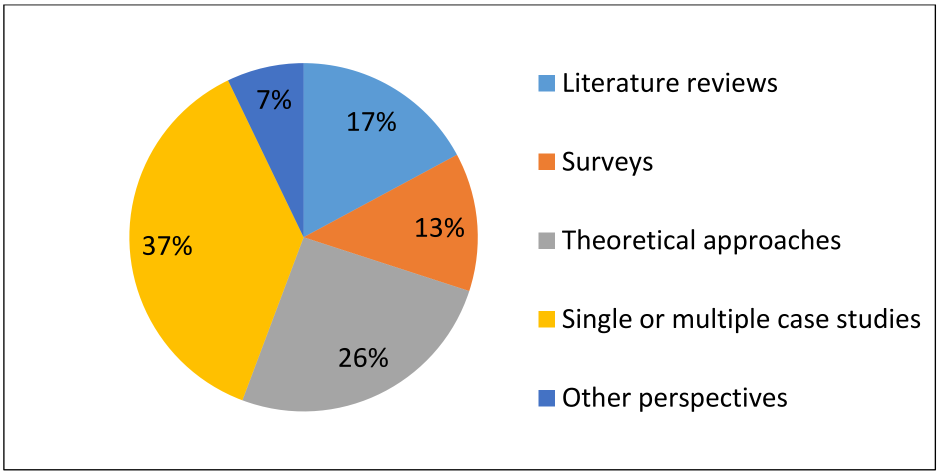


Figure 5. Research methodologies adopted

In particular, 26 papers out of 70 (37%) have used a single (20 articles) or multiple (6 articles) case study methodology, for example in this category seems interesting the work of Campos and Vazquez-Brust (2016), on it the authors conducted an in-depth case study analysis of the Brazilian subsidiary of a large multinational company using interviews, in-plant observations and document analysis. Carvalho et al. (2017) developed a case study from an automotive supply chain and demonstrated that not all companies belonging to the same supply chain can be lean or green. Another important work was presented by Galeazzo et al. (2014), making the analysis of three pollution-prevention projects undertaken by two manufacturing plants of two large multinational organizations. Lastly, in 2015 Piercy and Rich used a longitudinal multi-year case study methodology to analyse the sustainable benefits of lean operations beyond the environment including supply monitoring, transparency, workforce treatment and community engagement.

A total of 18 out of 70 papers (26%) used theoretical approaches. In this category, it is remarkable the work made by Bergmiller and McCright in 2009b that indicated that lean and green programs lead to better business results and integrated both paradigms in a single framework. Additionally, Verrier et al. in 2016 studied the synergies between lean and green wastes and the tools used for their elimination, the results were encompassed in a lean and green house model. For its part, Vinodh et al. (2011) explored various issues of sustainability applying lean initiatives and studied the techniques that would facilitate sustainability objectives using a theoretical approach.

For its part, 12 papers out of 70 (17%) developed a literature review analysis. In recent research, Chugani et al. (2017) with their systematic literature review study stated that lean and six sigma can support the conservation of resources, combat global warming and reduce energy consumption. Dües et al. (2013) explored and evaluated previous work focussing on the relationship and links between lean and green supply chain management practices. Further on, Garza-Reyes developed in 2015 a concept map identifying six research streams from literature and suggested various valuable research questions for future research in this field.

Moreover, 9 manuscripts out of 70 (13%) investigated the topic through a survey approach. In this case, Hajmohammad et al. (2013) confirmed the impact of lean and supply management on environmental performance, mediated by environmental practices, through a survey gathered from a sample of Canadian manufacturing plants. Rothenberg et al. (2001) examined the relationship between lean manufacturing practices and environmental performance in terms of air emissions and resource use, the study utilized two surveys of 31 automobile assembly plants located in Japan and North America.

Finally, the rest of articles correspond to 5 manuscripts (7%) categorised as "other perspectives" in Figure 5. Fercoq et al. (2016) studied the integration of lean and green strategies focused on waste reduction by means of the design of experiments methodology. Similarly, Hong et al. (2012) used structural equation modelling to demonstrate whether lean practices are an important mediator to achieve excellent environmental performance and King and Lenox (2001) conducted an empirical analysis of the environmental performance of 17.499 North American manufacturing companies during a long period, starting from 1991 and finishing in 1996. In addition, Venkat and Wakeland in 2006 used a simulation model to measure the emissions of various generic lean supply chains. As a final point, Yang et al. (2011) studied the impact of lean manufacturing and environmental management on the business performance of 309 international manufacturing firms using database archival information. In addition, their research provided evidences about the importance of environmental management practices as a mediating variable to resolve the conflicts between lean manufacturing and environmental performance.

3.1.4 The lean and environmental performance relationship: an overview

In this subsection, the articles of the set were classified again to know which is the general view of literature about the topic, whether authors suggest that may exist a positive, negative or mixed relationship between the adoption of lean and the improvement environmental performance. But before doing this, it was considered that 6 papers from the list did not suggest within their findings the existence of a positive, negative or mixed relationship. Consequently, were finally included in Figure 6 only 66 of the selected relevant documents outlined in Annex 1.

Therefore, from Figure 6 it is possible to elucidate that most of the studies in literature suggest that lean has positive effects on the environmental performance of companies. More precisely, the great majority of literature sustains that both lean and environmental performance activities have an important emphasis in waste reduction. On one hand lean manufacturing seeks the reduction of non-value-added activities and the improvement of efficiency (Womack and Jones, 1996). On the other hand, sustainability and green manufacturing have an environmental and ecologist point of view: eliminate waste to achieve pollution and emissions prevention as it is mentioned in one of the three pillars of the triple bottom line (3BL). Particularly, authors such as Garza-Reyes et al. (2018), Helleno et al. (2017), Piercy and Rich (2015), Chiarini (2014) and King and Lenox (2001) suggest that the application of some practices composing the lean transformation path go beyond economic results and lean waste (muda) reduction: these techniques may additionally enable the improvement of diverse environmental measures.

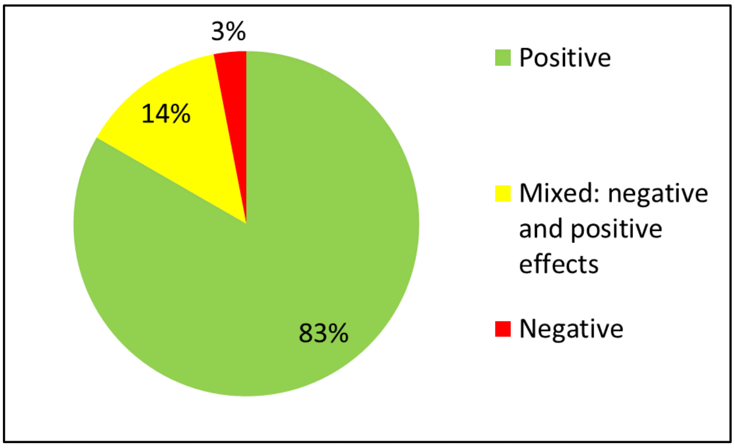


Figure 6. Relationships between lean and environmental performance

However, applying lean techniques some "blind spots" may appear during their implementation. This means that in addition to the lean waste reduction and continuous improvement concepts, which frequently produce implicit environmental performance, there are further "hidden" opportunities to achieve this purpose (EPA, 2003). Moreover, some practices as source reduction, production process improvements and facility downsizing which imply pollution prevention can be enclosed in a lean thinking view even if they are traditionally framed in the environmental management field.

Nevertheless, not all authors agree that there are only positive relationships between lean production practices and environmental performance. A 14% of the papers analysed states that lean may have both positive and negative environmental effects; it depends on the practices applied and the indicators measured. As was affirmed for example by Carvalho et al. (2017), Dües et al. (2013), Simons and Mason (2003) and Rothenberg et al. (2001), lean and green production are in some cases divergent. Among the causes of this contrast, some authors suggest that the search for greater levels of productivity and efficiency is not consistent with sustainable manufacturing.

Additionally, business growth generally implies more production, transportation, stock and deliveries; these additional activities usually generate extra wastes apart from those produced by the usual operations of the firm. For example, the integration with suppliers via Kanban (Monden, 1983) usually entails more regular deliveries, small sized batches and therefore a higher consumption of fuel for transportation. Another important point is that the financial benefits gained by environmental protection and pollution abatement techniques are not always significant and even more, sometimes are non-existent.

A minor part of the published research analysed somehow rejects this positive relationship between the two paradigms. Cusumano (1994) affirms that lean has the limit of producing increased negative product impacts and can intensify the emissions produced by just in time and Kanban. Moreover, Venkat and Wakeland (2006) similarly suggest that carbon dioxide levels can increase and propose that lean supply chains are not essentially green, remarking the distance as main impediment for environmental performance objectives.

3.1.5 Environmental performance measures in literature

To go deeper into the analysis and specifically into the environmental measures affected by lean, in this subsection the attention is focused on the environmental performance measures that have been considered in the literature when analysing the relationships between lean implementation and environmental improvements. For this aim, the list of environmental categories explained in 2007 by the U.S. Environmental Protection Agency (see Annex 2) was used as it is a summary of various basic measures focused on waste reduction goals and many important firms already use it in their reports. The measures included in "The lean and environment toolkit" of 2007 are: energy use, land use, materials use, toxic/hazardous chemicals use, water use, air emissions, water pollution, solid waste, product impacts, money saved and qualitative measures.

For each measure Figure 7 shows the number of studies suggesting that the adoption of lean practices has improved its performance (green colour), worsened its value (red colour), in some cases in some cases both improved and worsened its value (yellow colour). Moreover, the grey colour indicates the number of studies that claim that measure among their checklists for testing lean's environmental performance but do not provide a measure of this improvement (Faulkner and Badurdeen, 2014; Taubitz, 2010; Vinodh et al., 2011).

The measure regarding money saved and the qualitative measures were not included since they can cause confusion in the understanding of the graph and only measures referred to inputs used, non-product outputs released and downstream/product measures were considered.

Within the list of 72 documents analysed the EPA indicators most present in literature to measure the environmental performance of companies adopting lean practices are air emissions, energy use, solid waste, water pollution, toxic/hazardous chemicals use, water use and materials use (see Figure 7, the environmental measures are listed in descending order of citations).

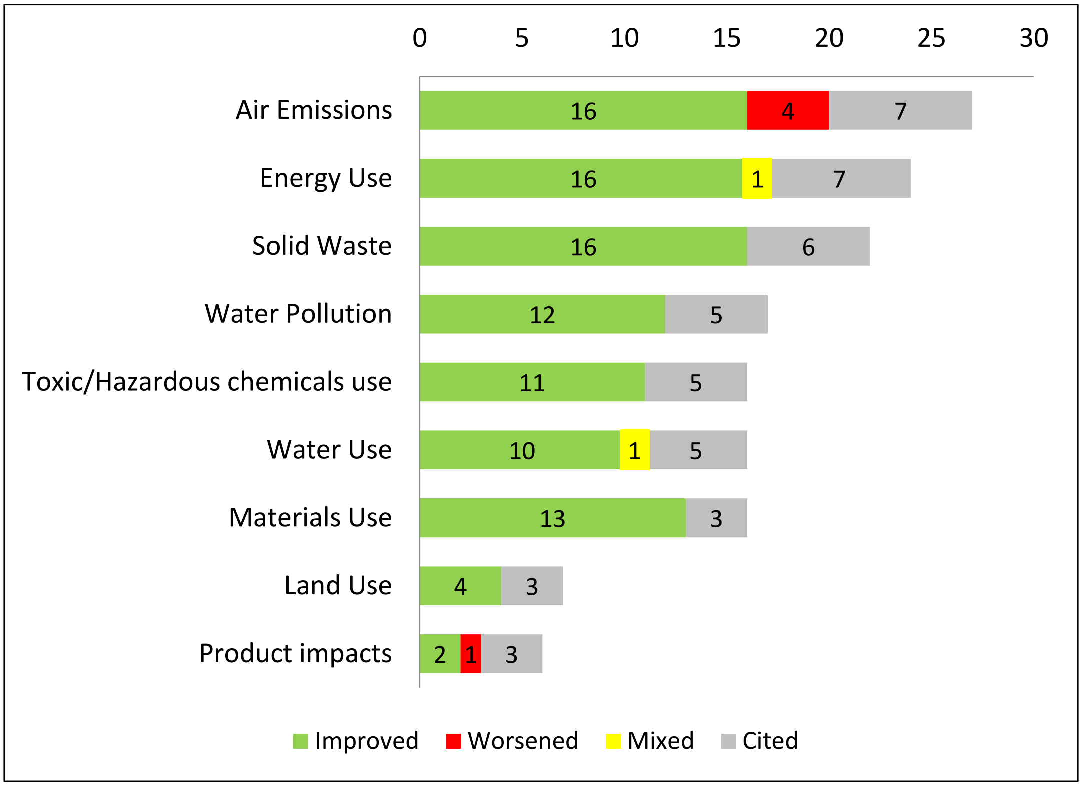


Figure 7. Distribution of the results of the environmental measures

As shown in Figure 7, the measures that are most benefited from the implementation of lean practices according to the literature are air emissions, energy use and solid waste (Garza-Reyes et al., 2018; Wiese et al., 2015; Hajmohammad et al., 2013; Zokaei et al., 2013; Deif, 2011; Fliedner, 2008; Gustashaw and Hall, 2008; EPA, 2007). These results held by these and other authors strongly sustain the affirmation of a direct relationship between lean and green paradigms.

However, it is interesting to note that for the air emissions measure there are four papers that suggest that this relationship is not positive, and some lean practices can be harmful to the environment (Venkat and Wakeland, 2006; Simons and Mason, 2003; Rothenberg, 2001; Cusumano, 1994), similarly product impacts (Cusumano, 1994) has one article sustaining negative results. In addition, energy use (Chiarini, 2014) and water use (Rothenberg, 2001) present one mixed outcome each which can also conflict with environmental performance, since both positive and negative relationships between these measures and lean can neither be confirmed nor rejected.

Additionally, but to a lesser extent materials use, water pollution, toxic/hazardous chemicals use and water use (Pampanelli et al., 2014; EPA, 2013; Chapman and Green, 2010; Vais et al., 2006) are also strongly positively related with lean practices. Land use (Aguado et al., 2013; EPA, 2007) and product impacts (Fliedner, 2008; EPA, 2007) are the measures that have fewer positive evidences in the literature.

As was stated before, the measure of money saved was removed from the graph to provide clearness. Nevertheless, the importance of lean practices leading to significant economical savings in the company is not overlooked, these savings are mainly gained from efficiency, materials use decrease and waste reduction in general (Galeazzo et al., 2014; Pampanelli et al., 2011; Miller et al., 2010).

3.1.6 Relationships between lean practice bundles and environmental performance

The purpose of this subsection is to understand which of the typical groups of lean practices are most closely related to green performance.

The lean paradigm is a multi-dimensional concept which is characterized by a certain number of practices aimed to accomplish the objectives of "doing more with less" and increasing the value deliverance to the customer (Womack and Jones, 1996). Moreover, the important work developed by Shah and Ward in 2003 proposed a model which categorizes these practices into four groups, also known as bundles. Other works have proposed similar classifications, see for example Panizzolo (1998), Flynn et al. (1995) and Chan et al. (1990), but this was used to compare the environmental effects derived from the application of lean because of its importance in operations management literature and its internal consistency between practices.

The aforementioned bundles (Shah and Ward, 2003) are presented below, and the results of this analysis are sketched in Figure 8:

- Just In Time (JIT): flow production, pull systems, cellular manufacturing, supply chain management (SCM including supply integration and monitoring), value stream mapping (VSM), quick changeover techniques (SMED).
- Total Quality Management (TQM): statistical process control, continuous improvement (*kaizen*), standard operation procedures, 5S, visual management.
- Total Preventive Maintenance (TPM): preventive maintenance, autonomous maintenance.
- Human Resource Management (HRM): multifunctional workers, training, team decision making, worker's autonomy.

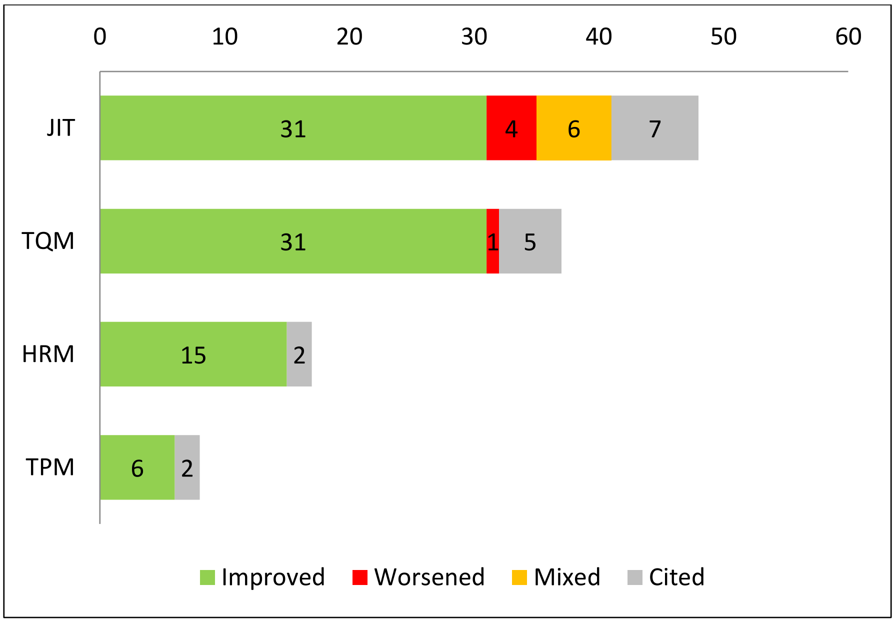


Figure 8. Distribution of the results of the practice bundles

Within the set of articles selected, according to Figure 8 the JIT methods are the most utilized and evaluated in order to study their relationships with environmental performance, followed by the practices comprised in the TQM bundle. In addition, HRM and TPM practices are the fewer cited in literature referring to environmental performance.

The JIT bundle seems to be one of the most positive bundles after the review of the literature. This bundle includes the VSM technique which is typically used by lean practitioners to see environmental wastes in processes (Gustashaw and Hall, 2008; EPA, 2007; Simons and Mason, 2003). Similarly, Piercy and Rich (2015), Wiese et al. (2015) and Hajmohammad et al. (2013) suggest that SCM provide means like consolidation of orders and improved fill rates for example, by which environmental actions can be encouraged, leading firms to superior environmental performance.

Likewise, TQM and the lean practices included in this bundle enhance environmental performance according to the literature analysed. Kaizen is considered in literature an important mediator to achieve environmental performance (Hong et al., 2012) and through continuous improvement teams, kaizen enhances mass and energy flows in manufacturing environments (Pampanelli et al., 2014), in addition helps identifying wastes and learning how to eliminate them along the value stream (Chapman and Green, 2010). Similarly, 5S is considered a good starting point for learning how to identify and eliminate waste (Taubitz, 2010), at the same time increases productivity and reduces defects, enhancing then better environmental performance at the source (Miller, 2010; Vais et al., 2006).

With less importance in literature but with remarkable positive results, the HRM bundle with practices such as employee training (Sobral et al., 2013) and people commitment techniques improves lean success, driving firms towards sustainable operations and facilitating the prevention of failures during the production process that might lead to rework or unnecessary resources usage (Wong and Wong, 2014; Rothenberg et al., 2001).

To end with the positive effects of lean, regarding to the TPM bundle authors such as Garza-Reyes et al. (2018), Cherrafi et al. (2017b), Chiarini (2014) and Fliedner (2008) determine that preventive and proactive maintenance are environmental improvement facilitators and can reduce numerous machine associated impacts, such as emissions to air, noise pollution and oil leakages and may eliminate process failures that generate rework, scraps and unnecessary resource consumption.

In opposition, the JIT bundle seems to be the most problematic since small lot delivery produces additional wastes and emissions to manage, authors consider it as the principal area where lean and green cannot be combined. JIT practices may cause further degradation of environmental performance and companies should take care, from an environmental perspective when implementing them (Zhu and Sarkis, 2004). Cusumano (1994) describes that in Japan, production plants have altered their JIT systems to reduce air pollution. Furthermore, frequent delivery practices may result in an increase of transportation which rises CO_2 emissions, contradicting the air emission reduction principles of green practices. Dües et al. (2013) explain that companies have to find new solutions to minimise the impact on the environment of JIT practices. They suggest that this can be done by, for example, selecting suppliers of a certain geographic area to enable truckload sharing for delivering or, when small amounts have to be delivered, managing the routes in order to supply multiple customers in the same area. Other scholars affirm that there may exist positive and negative effects at the same time such as the reduction of hazardous inventories versus the need of extra packaging (Corbett and Wassenhove, 1993). Moreover, Rothenberg et al. (2001) suggest that the focus on JIT principles, waste minimization and buffer minimization can conflict with some features of environmental performance, in particular with the VOC (Volatile Organic Compounds) emission. In addition, some SCM objectives which are included in this bundle can conflict with environmental interests as distances increase along the supply chain (Venkat and Wakeland, 2006; Simons and Mason, 2003) and can produce mixed positive and negative outcomes. These are the so-called trade-offs since not all companies belonging to the same supply chain can be absolutely lean or green and some strategies do not seem naturally synergistic. Authors remark the benefits of understanding these trade-offs and their possible optimization may enhance performance in the future (Carvalho et al. 2017; Mollenkopf et al. 2010).

To conclude, the TQM bundle presents one negative impact. Rothenberg et al. (2001) explain that goals like superior quality of products for example, may lead to greater consumptions in order to achieve the desired quality levels. These authors suggest that the use of water, for example, in some processes is critical for the quality of the product, consequently lean manufacturing plants may have greater water consumptions for the achievement of this superior quality.

3.1.7 Positive impacts of lean on environmental measures: preliminary evidences

This final phase of the SLR analysis was applied to the set of papers listed in Annex 1 and aimed to find the preliminary evidences existing in the literature about the links between each of the key practices analysed and the main environmental performance measures.

Then, Table 1 provides the positive relationships found in literature between the EPA's basic environmental measures and various relevant lean practices included in the Shah and Ward's bundles. The value inside the cells shows the number of documents that suggest a positive relationship between the practice in the row and the environmental measure of the column within their studies and examples of implementation. Additionally, the rightmost column of the table shows the degree of impact of each lean practice. Similarly, the last row indicates the environmental measures that benefit the most from the implementation of lean practices.

Nevertheless, prior to the analysis, it is worth highlighting that the numbers in Table 1 are not identical to the numbers included in the previous Figures 7 and 8. The reason is that in this table are analysed direct relationships present in literature, this denotes that if a paper uses two different indicators or practices in the same publication in this chart the study will be considered more times and in the previous figures once.

		Energy use	Land use	Materials use	Toxic/hazardous chemicals use	Water use	Air emissions	Water pollution	Solid waste	Product impacts	Money saved	Most impactful practice
	SCM	4	1	4	4	1	6	2	5	1	2	30
JIT	VSM	7	3	8	6	5	9	5	7	2	8	60
	SMED	2	0	1	0	0	2	1	1	0	1	8
	5S	5	2	5	3	2	3	2	4	1	3	30
	Kaizen	3	2	4	6	5	5	4	4	2	5	40
TQM	KPIs	1	0	1	0	1	2	0	1	0	1	7
	Visual management	2	1	2	1	1	2	0	1	0	0	10
TPM		2	0	1	1	0	2	1	3	0	1	11
HRM		2	0	1	0	2	1	0	1	0	0	7
Most impacted measure		28	9	27	21	17	32	15	27	6	21	

Table 1. Lean practices and environmental measures

The results outlined in Table 1 suggest that VSM with its waste identification techniques should improve positively the values of the measures corresponding to air emissions, money saved and energy use (Cherrafi et al., 2017b; Deif, 2011; EPA, 2007). The measures regarding the use of materials, solid waste and toxic/hazardous chemicals use are also considerably benefited by the VSM implementation (Pampanelli et al., 2014; Chapman and Green, 2010; Fliedner, 2008). Moreover, water use and water pollution are also positively affected but with less presence in literature (Pampanelli et al., 2014; EPA, 2007).

Secondly, continuous improvement or kaizen uncovers and eliminates hidden wastes, waste-generating processes and significantly enhances the measures corresponding to toxic/hazardous chemicals use, water use, money saved, water pollution, solid waste (Pampanelli et al., 2014; Pampanelli et al., 2011; EPA, 2007), materials use and air emissions (Garza-Reyes et al., 2018; EPA, 2013). Less evidence of positive relationships with kaizen was found for the energy use measure (Fliedner, 2008).

In third place, literature suggests that SCM produces diminutions in air emissions and reduces solid waste and toxic/hazardous chemicals use based on the analyses carried by Hajmohammad et al. (2013) and Zhu and Sarkis (2004) for example. In addition, packaging wastes and other unnecessary materials might be reduced using SCM (EPA, 2003) and strategies integrated in this practice like supplier selection could be useful in order to achieve energy saving gains as was remarked by Cherrafi et al. (2017b).

A similar number of studies affirm that 5S can assist maintaining a workplace clean and in order. Moreover, using its principles companies may reduce energy use, by evidencing for example those machines which should or should not be operating (Torielli et al., 2011; EPA, 2007). Similarly, 5S may enhance productivity facilitating the reduction of materials utilization (Vais et al., 2006; EPA, 2003), can improve solid waste treatment processes in firms (Cherrafi et al., 2017b), reduces the consumption and utilization of toxic/hazardous chemicals (Fliedner, 2008) and increases money savings from implementation in production projects (Miller et al., 2010).

The rest of relationships regarding to TPM, visual management, SMED, KPIs and HRM (noted in Table 1) are less present in literature, this happens perhaps because there is not an easy and direct connection between these practices and the environmental categories used.

Another explanation of these lower grade relationships is that literature research streams are more oriented versus the study of the trade-offs of lean and green strategies. This means that the study of the most conflictive areas between these two paradigms has been studied definitely with more depth than those practices that presumably do not seem problematic to the environment.

Concluding, in addition to the previous evidences obtained from literature about the green aspects of lean production and their points in common, this literature analysis went deeper and developed a sketch of the relationships between practices and measures. From the sum of the most related practices and measures in Table 1, it can be deduced that JIT and TQM (with their practices comprised) are the most impactful bundles on environmental measures; and air emissions, energy use, solid waste, materials use, toxic/hazardous chemicals use and money saved are the most impacted measures by the lean practices analysed. These are preliminary evidences found in literature about these positive relationships, therefore, further investigation is needed to know with more certainty how does lean affect in the firm's environmental performance and its direct consequences on green measures, by the means of its practices.

3.2 Gaps arising in extant literature

During the systematic literature review analysis, it was observed that the number of papers on the subject already described in this thesis has been progressively increasing over the years (see Figure 3) and has revealed the presence of two research gaps apart from the conclusions outlined in the previous sections. These open research opportunities are targeted below these lines and will be addressed in the following chapters of this thesis.

From the key papers identified using the search method outlined in section 3.1.2 only 3 articles could be found reporting various environmental impacts directly produced by specific lean practices.

The first of these analyses is based on the empirical observation inside five motorcycle companies (Chiarini, 2014), in it the author observed and measured some relevant environmental measures before and after 6 months of the implementation of five lean tools. Nevertheless, these analyses are very punctual since the author is measuring for a very short period, only five and very specific lean tools, using very specialized measures to the firms' activity and on companies of the same sector. According to the author these specific characteristics of the study can hinder the generalization of results, nevertheless he encourages for the development of further research in this field.

The second of these articles applies a framework that methodically guide companies to effectively integrate lean six sigma and green production systems (Cherrafi et al., 2017b), following up the projects in four companies and measuring before and 8 months after the implementation of the framework. It is possible that the effects of lean practices have not been reflected perfectly in this study since the efforts of lean implementation and its practices are also focused on environmental performance objectives, in addition it is noteworthy that this study actually analyses the integration of both lean and green paradigms.

Thirdly, Garza-Reyes et al. (2018) investigated the impact of JIT, autonomation, kaizen, total productive maintenance (TPM) and value stream mapping (VSM), on four measures for the compliance of environmental performance, i.e. materials use, energy use, non-product outputs and pollutant releases. Then, applied correlation analysis to model the relationship and effect of these lean methods on the environmental performance of 250 manufacturing companies around the world. Apart from the interesting contributions that were taken into account also in the study of the existent literature, this article has the typical limitations of a survey study, therefore, the authors suggest developing in the future qualitative and convincing empirical research with selected companies in order to extend and validate the findings.

Thus, the first and main gap found in literature is the need for a clear identification of the empirical effects of lean practices on environmental performance, as limited empirical research has been conducted in this field (Garza-Reyes et al., 2018). This research has been done very superficially, sometimes influenced by the consolidation of both paradigms for the achievement of environmental objectives (Verrier et al., 2016; Ng et al., 2015; Kurdve et al., 2014; Pampanelli et al., 2014) and without providing robust and generalizable conclusions. Furthermore, only 6 articles out of 72 (8%) (see Figure 5) used a methodology of multiple case studies. This means that most of the empirical studies were developed using a single case methodology without confronting the evidences between firms and not enabling a general empirical explanation of the phenomenon.

Secondly, it was also observed that the papers studied about lean and green relationships are often punctual analyses in time (i.e. Powell et al., 2017; Campos and Vazquez-Brust, 2016; Wong and Wong, 2014) while a medium-long term vision is lacking considering the evolution of the process of lean transformation in practice (see Table 2). It would be interesting to understand how environmental measures variate during the implementation of lean, this transformation process usually lasts more than a year since it represents a strategic-changing activity involving primary and support activities of the value chain like technology development, company's infrastructure, procurement and human resources management (Achanga et al., 2006; Porter, 1985). All these considerations were deemed to establish the second research gap that guided this thesis.

Analyses covered in literature	
Short term analyses (less or equal to 1 year)	✓
Medium-long term analyses (more than 1 year)	✗

Table 2. Identification of the second research gap

In summary, the environmental impacts of lean practices are frequently claimed as a connecting factor between lean and green manufacturing but the nature of the link and the specific effects, receive only superficial and punctual examination in literature. There is scope for further discussion, and particularly for deepen on the environmental effects of lean practices within companies over the years. As a final point, by studying these gaps more understanding will be gained on how lean practices impact environmental measures.

3.3 Setting research questions

Turning the research towards the empirical analysis and based on the preliminary exploration of the research area, literature and the gaps of the research noted above in this thesis, it was decided that the research questions should focus the research on:

- Identify and classify the existence and type of relationships between lean practices and environmental improvements in companies.
- Deepen on how and in what measures lean practices impact in reality and in a long-term context.

Designed to accomplish these scaled objectives, the following research questions were selected to guide the methodology of research that will be explained in chapter 4:

- RQ1: Do lean practices impact on environmental measures?

  The answers to this question will show the type of relationships occurred between practices and measures as a preliminary approach to the subject, whether they are environmentally friendly, neutral or harmful to the environment.

- RQ2: How do lean practices impact on environmental measures?

  This question is about the way and how the effects of lean practices impact on environmental performance measures. In addition, developing the study during a long period of time, it will be possible to understand how the variations on the measures are distributed over time since lean implementation is not an instant transformation in the company and takes long time. In this sense, it may happen that after the immediate implementation of lean the environmental measures of the company decrease because the effects of lean are not visible yet.

These research questions were deemed appropriate for moving the research in the right direction trying to meet the objectives set, fill the research gaps and achieve the expected final results. Subsequently, they also served to build the following theoretical research framework and to choose of the appropriate methodology to address the issues which are scope of this research.

3.4 Theoretical framework

Joining the objectives and research questions above detailed for this research, a theoretical framework is proposed in this section to systematise the empirical study of the influence of lean practices on environmental performance in an industrial context.

This is a first step providing a wide-ranging overview and understanding of the influence of lean practices on environmental performance measures before the description of the methodology used. Figure 9 illustrates the proposed framework.

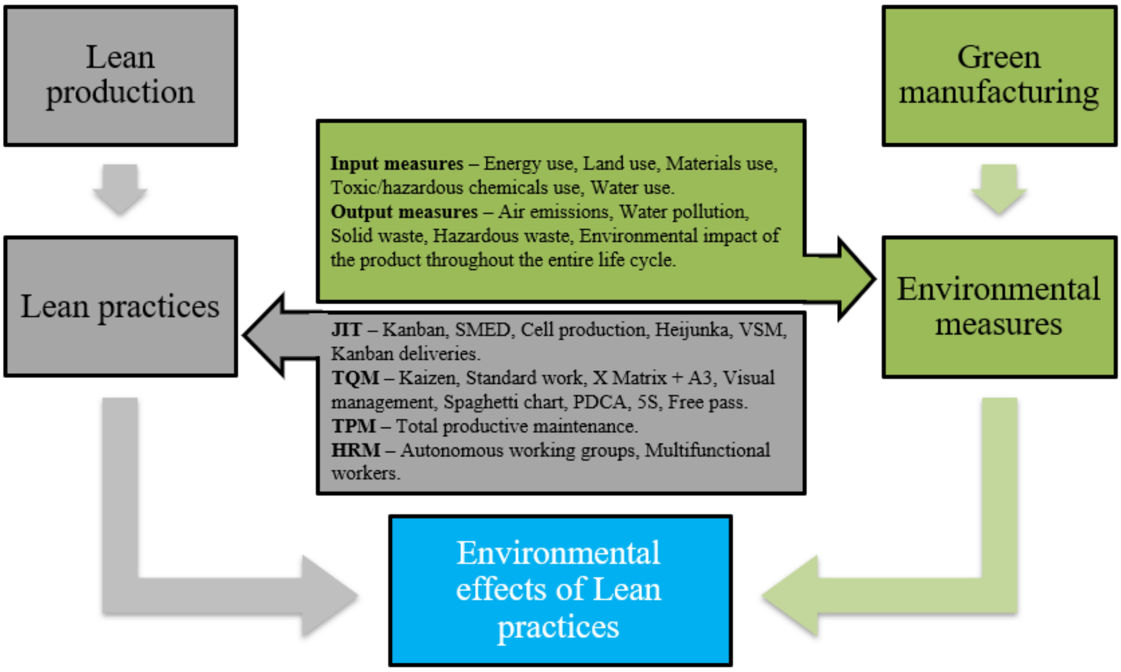


Figure 9. Theoretical framework of the research

As shown in Figure 9, from the lean production paradigm various lean practices were selected, some of them were included in the previous literature review study within the lean practice bundles delimited by Shah and Ward in 2003. In addition, other important practices were added to the study from other important works in the lean production field (Shah and Ward, 2007; Panizzolo, 1998; Flynn et al., 1995; Chan et al., 1990). It was not only intended to continue the study of the preliminary relationships seen in the literature review analysis, but to expand the study with more lean practices that are currently used in industry.

In contrast, related to the green production paradigm, the theoretical framework illustrates a certain number of categories to evaluate the influence of the predefined lean practices on companies' environmental performance (EPA, 2007). These categories might contain a large number of measures (see Annex 2), on the assumption that they measure the scope of the category. Regardless of this, apart from the categories mentioned only one extra category was added, and it is the "hazardous waste" measure, that was considered interesting for this study.

Obviously not all categories of environmental measures are of interest to all companies since they measure the parameters that most affect their activity. Therefore, will be finally included in the discussions of the thesis those that companies made available for this study.

In summary, in this section it was presented in a visual, theoretical and schematic approach the main purpose of this thesis, which is study empirically the effect of various lean practices on different environmental performance measures.

Chapter 4. Research methodology

With the purpose of achieving solid results for the contribution of new scientific knowledge, this chapter discusses the selection of the appropriate methodology for this research.

The studies about the impact of lean practices on environmental performance measures have not yet reached maturity, so the methodology of multiple case studies was chosen, looking at 5 lean companies from the Italian manufacturing industry for a period of at least 5 years, starting from the beginning of the lean implementation process (t_0), see Figure 10. The aim was to measure the performance of the environmental indicators in these 5 years deriving from the implementation of various lean practices.

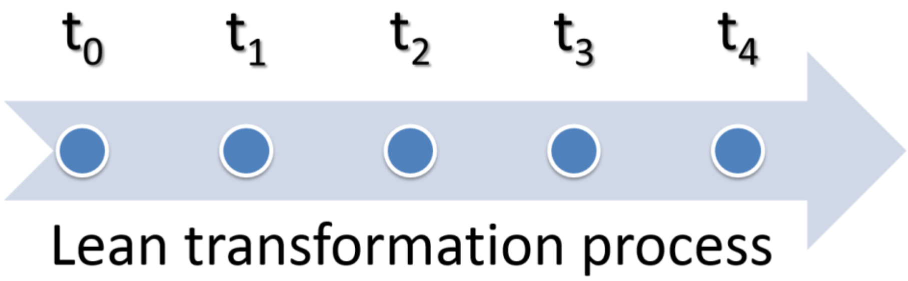


Figure 10. Time span of the study

As was noted before, this transformation process since it represents a change of firm's strategy usually lasts more than a year (Achanga et al., 2006; Porter, 1985) and the impact of lean on operations is not completely evident immediately after its implementation.

This section is organised as follows: first, the research approach selected is presented; second, the research protocol is explained, the method used for reliability of the instruments is described and the criteria of selection of the cases are listed; in addition some general data of the companies included in the sample are also provided and; finally, the procedures for data collection and analysis are described.

4.1 Research approach

In order to study the relationships in practice; fill the gaps described and answer the research questions developed; it is important first, to examine the level of implementation of the lean practices, then observe what is their real impact on companies' environmental performance measures and finally know how this impact happens during the lean transformation process of the firm.

Therefore, a multiple-case study approach was considered the most suitable method for this research. This approach based on observations, is very appropriate to interact with organizations, facilitates the development of in-depth investigations in different contexts of reality and provides an immediate validation of the findings which a survey cannot provide. Additionally, it permits the development of a cross-case analysis for comparing the relationship patterns emerged in each company and enables the elaboration of a general explanation of the phenomenon.

Moreover, the case study methodology permits the questions of why, what and how, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon (Voss et al., 2002; Yin, 1994). Additionally, the case study method is the most appropriate procedure both for developing and test new scientific theories (Eisenhardt, 1989), it can be used for identifying linkages between variables and provide practical tools for professionals who deal with the issues object of study in their own work practice (Voss et al., 2002).

Once the decision of using case study methodology is taken, it is important to decide how many cases should be developed. In this sense, the use of a multiple case study approach may reduce the depth of the study, especially when resources are constrained; however, external validity is augmented at the same time (Voss et al., 2002) and for theory building and testing purposes, the use of multiple cases is likely to create more robust and testable results than single case research (Eisenhardt and Graebner, 2007; Johnston et al., 1999). Therefore, considering the advantages and disadvantages of this methodology, it seems that it fits perfectly with the purpose of this study, and indeed the multiple case study methodology was chosen for this investigation.

Subsequently, the case studies were conducted in the same manner (see section 4.3) proposing the participants a structured questionnaire during the interviews (see sections 4.2.1 and Annex 3) to enable the aforementioned cross-case analysis aimed to identify compatible patterns across the companies (Yin, 1994; Eisenhardt, 1989) and pursue internal validity of the findings (Voss et al., 2002).

To conclude, during the development of the case studies and during the data collection process was adopted the so-called "triangulation between methods" including data from semi-structured interviews, personal observation, documentation reviews, internal reports and database research. Literature on qualitative studies suggests that the use of multiple data sources provides increased reliability of data (Barratt et al., 2011). Anyway, this topic of reliability will be deepened in section 4.2.2.

4.2 Research protocol

In this section some key points regarding the development of this research are explained. These describe how the theoretical insights already defined were reflected in practice in order to obtain the evidences from the case studies. In addition, the selection criteria adopted of the cases are listed.

4.2.1 Questionnaire

In the research design, 5 firms were used to collect data regarding the level of implementation of 17 lean practices and the evolution over time of 10 environmental performance measures according to the proposed theoretical framework (section 3.4).

The questionnaire used is presented in Annex 3 and was intended to assist research as a protocol for the semi-structured interviews and, at the same time it was devised primarily to "break the ice" and to obtain the first qualitative evidences that will be developed and extended throughout the interview. It was also used as a fillable form to obtain in a clear way the quantitative data that complemented the qualitative evidences.

For these purposes, the questionnaire was divided in three sections to be filled with the answers of the interviewees:

- Demographic data questions: containing open-ended and multiple-answer with percentages questions. The goal was to obtain some general information about the sample and to achieve firm characterization.
- Lean practices' section: provides a chart to be filled with useful data about the economic results of the company during time and lists various Likert scale questions to understand the level of implementation of the practices. These Likert scale questions served as a pretext to obtain a more detailed explanation from the interviewees about the implementation of the lean practices. Moreover, it was considered that a lean practice was totally implemented if the firm demonstrated a formal plan of implementation of the practice and if the company made specific and documented formation or workshops aimed at implementing such that transformation initiative.
- Environmental measures' section: containing two charts for qualitative and quantitative data collection about the evolution over time of the environmental measures of the company. The numerical data obtained were explained at the same time by respondents to justify the evolution and their relationship with the lean transformation over time. This section was also aimed to justify big increments or diminutions on the measures' values, to know if some exceptional circumstances occurred and which was their effect on these measures. The final objective was to obtain the maximum information about the environmental measures to then isolate in the best way possible external and circumstantial impact factors from the effect of lean practices on the value of the measures.
- Qualitative relationships' section: based on the previous information obtained, the respondents were supposed to fill the final chart of the document with the available evidences of positive or negative effects of lean on the environmental measures provided previously. Further justifications with archival data and reports were given by research participants to compliment the answers.

4.2.2 Reliability and avoidance of bias

A reliability analysis was employed to check whether the instruments used to collect evidences are reliable. This subsection provides an explanation of the techniques that were selected to avoid bias during the stages of this research, these will be also deepened in other sections.

The issues of reliability and validity are essential in research as there is a need to ensure that the data collected, examined and analysed are consistent and accurate to obtain reliable results (Saunders, 2011). During the development of this research, various methods were used to avoid bias and they are explained below these lines.

First, the elaboration of multiple case studies and cross-case analysis can increase external validity and help against observer bias. In addition, the use of multiple case studies avoids the risk of misjudging a single event and exaggerating available data, these risks may appear if only one case study is used but they can be mitigated if data are compared across cases (Voss et al., 2002).

Secondly, a standardized interview protocol was used at each meeting to avoid bias on the interviewer's part. Although the study is not a survey, it was decided to validate the questionnaire that guided the interviews with the companies. The objective was to eliminate irrelevant and ambiguous questions, obtain feedback on the questionnaire's logic and add extra relevant questions if necessary.

Robson and McCartan (2016) suggest a method for validation by addressing a small group of people to develop a previous study before the distribution of the questionnaires to participants. Therefore, a pre-test with four experts (2 academics and 2 practitioners) was developed: first, informing about the research aims; second, mailing the protocol and the questionnaire; third, interviewing by phone the participants regarding to the clarity of the concepts and the suitability of the questions; finally, the interviews to obtain the final feedbacks were performed. During the third stage some comments were extracted and helped to correct, rectify and validate the questionnaire.

Following, the entire research protocol and the questionnaire were again tested within a pilot case study in the so-called "Company Pilot" to proof the consistency and adequateness of the methodology to the aims of the research. A manufacturing company with high experience in lean and with significant concern in environmental issues was chosen, following the case selection criteria outlined in section 4.2.3, and was followed up the research protocol that will be explained afterwards in section 4.3. After this process some minor changes were again made to the questionnaire to facilitate the understanding of it by the participants. The pilot case was also useful to "break the ice" in the use of the protocol and the methodology. In this process some lessons were also learnt about how to gather and analyse the data and responses of the interviewees and consequently, were applied to the rest of the cases.

Thirdly, during the development of the case studies, triangulation of data was applied. This way, using retrospective data and multiple sources of evidence the threat of reactivity (researcher's presence may alter what is being observed), researcher bias (researcher's assumptions that may influence their perceptions and understanding) and respondent bias (behaviour alteration of respondents due to the awareness that they are being observed) were reduced.

Finally, although it is not considered as a method, it is remarkable the high involvement of the companies under study and their interest about the final results of the research. This also guarantees in some way the accuracy and veracity of the data.

4.2.3 Case selection criteria

A question arose as to the number of cases that should be selected for the study. Voss et al. in 2002 describe this dichotomy, proposing that fewer are the number of cases, greater is the chance for depth of observation. Conversely, multiple case studies can increase external validity and help against observer bias, creating also more robust and testable theories than single case research (Eisenhardt and Graebner, 2007; Johnston et al., 1999). However, as was suggested by Eisenhardt in 1989 a range of 4-10 cases usually should be enough, he also cautioned that if less than four cases are used it may be more difficult to capture the complexity of reality and if more than 10 cases are used it could become problematic for the researchers to analyse the information.

According to these premises, a sample of 5 companies was chosen following some strict criteria. Each of these criteria has been carefully identified and verified in such a way that it was aligned with previous assumptions. Where possible, the cases were preselected by viewing the data on AIDA and Accredia databases and the collection of the preliminary information (i.e. environmental commitment, lean strategy, number of customers, mission and vision) was carried out through the review of their corporate websites.

Consequently, the whole of the companies comprised in the sample respect the following parameters and include them all in their profiles:

- are based in Italy. In particular, are located in the Northeast area, historically characterized of a large number of industrial companies.
- are profiled in section C of the European NACE code corresponding to manufacturing activities.
- are engaged in lean transformation programs for a minimum of 5 years.
- show evident concern for their environmental impact and carry out measurements yearly of environmental measures at least from the starting year of the lean transformation process.
- have a lean promotion office and an environmental and safety office.

From a practical point of view, it was made sure that it would be possible to observe the processes, practices, operational and environmental data and that there would exist a full willingness of the company to make available their documents and historical data. It was also guaranteed the availability to interview the managers.

In the following Table 3 are summarized various important and up-to-date data of the companies selected for the study.

Case studies	Type of company (European NACE Code)	Location	Size (employees)	Turnover (millions of euros)	Start of the lean transformation	Research participants interviewed
Company Pilot	Manufacture of non-domestic cooling and ventilation equipment (2825)	Venice	225 (2016)	58,473 (2016)	2013	(1) Production and logistics manager, (2) Chief of environment and security management
Company A	Manufacture of metal forming machinery and machine tools (2480)	Vicenza	58 (2017)	18,884 (2017)	2013	(1) Lean manager, (2) Head of the environmental and security service
Company B	Manufacture of agricultural and forestry machinery (2830)	Padova	46 (2016)	15,014 (2016)	2010	(1) Kaizen promotion officer, (2) Safety and environment officer
Company C	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines (2811)	Padova	373 (2017)	71,700 (2017)	2013	(1) Production system coordinator, (2) Prevention and security manager
Company D	Manufacture of non-domestic cooling and ventilation equipment (2825)	Padova	416 (2017)	80,000 (2017)	2013	(1) Kaizen manager, (2) Safety and environmental manager

Table 3. Main data of the companies considered

4.3 Data collection and analysis

As was already introduced, the data collection was mainly performed through semi-structured interviews, assisted by other sources of evidence that will be described later. The data gathering was based on the literature review settled before relating lean practices and environmental performance, as well as on the theoretical framework developed in Figure 9. With this pretext, a set of questions was devised into a questionnaire (see Annex 3) and was used as a structured interview protocol to collect the data of interest from every research participant of this research. In this section, it is described the process of collecting and processing the evidences obtained following five steps. These are listed in Figure 11.

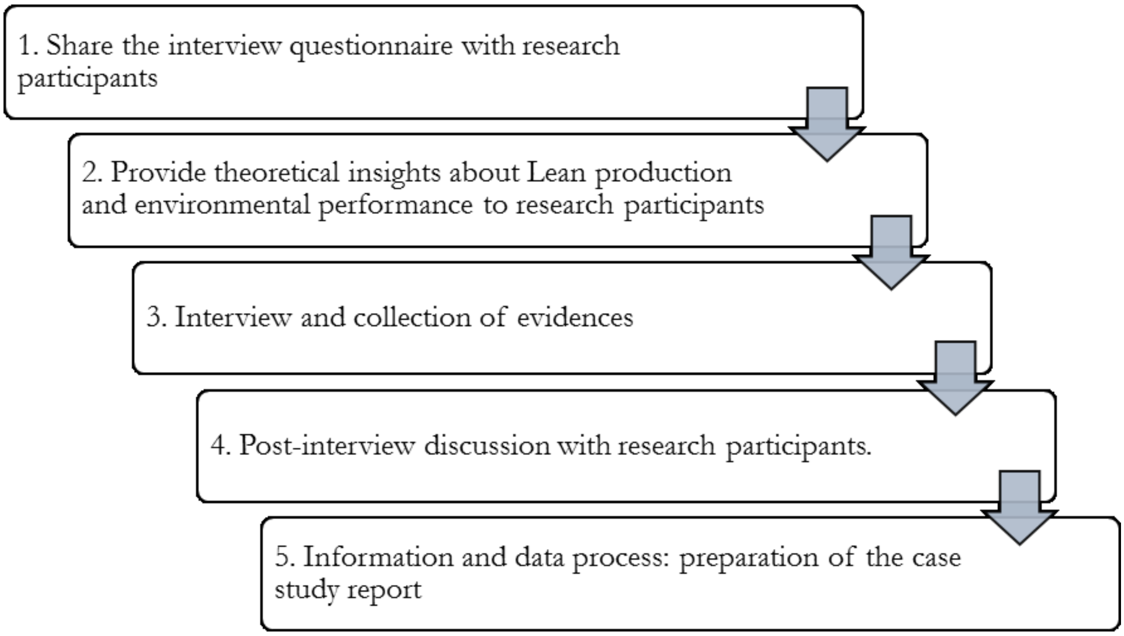


Figure 11. Steps followed for the development of the case studies

The first step noted in Figure 11 was carried out before performing the interview and consisted in informing in advance by email some evidences about the questionnaire. Then practitioners were interviewed by phone, by email or in person regarding the clarity and appropriateness of the questions. The purpose of this was to support the research by informing the participants before the meeting about which data will be useful for the development of the interviews. Moreover, this step was helpful to identify possible problems of understanding of the questions, solving them before they arose.

As second step, the main concepts of lean production and environmental performance were presented to each interviewee. The main concepts regarding lean practices and environmental measures were detailed showing their main definitions and making clear once more the objectives of the research. At this stage, the theoretical insights from chapter 2 and the theoretical framework presented in Figure 9 were particularly helpful.

During the third step, the most significant part was held: this is the phase of the interview and the collection of evidences with the support of the questionnaire. All the interviews described below took place in the presence of both researchers and interviewees. The questions were both closed and open-ended and the respondents were guided to reply in the order specified: first, demographic questions for categorization; second, the lean practice's implementation part; third, the section about environmental measures and their evolution over time; and finally, the section regarding to the qualitative relationships. At the same time was granted the freedom to deepen the subject of the answer to each question providing elements, data and demonstrations that the respondent considered valuable. Nevertheless, the same interview protocol was used at each meeting to avoid bias on the interviewer's part. Interviews were carried out to provide a deeper view of which lean practices were implemented by the companies and how the influence on their environmental performance measures occurred. While managers and practitioners were interviewed, their responses were compared with the archival data furnished. In summary, the information gathered in this stage was mostly interviewees' answers, supported by observation and archival documents provided by them.

In the fourth step, the evidences and relationships that emerged during the interview were presented, discussed with the interviewees, completed, concluded and approved in a definitive way.

After the interviews, the information and data were processed in the university department. Meanwhile, further follow-up questions were done by phone or were sent by e-mail. In all cases the companies' anonymity was kept in accordance with the general request for confidentiality. This was the last stage of the data collection.

Once this protocol was designed, the final preparation for data collection was to test it conducting a pilot case (Yin, 1994). This pilot case study was helpful to refine the data gathering plans and to gain experience in the interviews with the purpose of saving time and efforts in the successive cases. After the practical test in "Company Pilot" was considered a success, and the lessons learned during its performance were assimilated, the steps described above were applied equally to each of the case studies.

Moreover, in stages two, three and four, which constitute the main part of the empirical research, the interviews with the research participants were developed. For each company three half-day meetings were arranged (4 hours):

- The first, to introduce the research and collect the data about the lean implementation.
- The second, to know the environmental performance of the company and its evolution.
- The third, to collect the evidences about the relationships between practices and measures; ending up with a discussion and conclusion of the evidences.

The meetings were made on-site and in presence of the operations and lean managers and the environmental and security officers when required.

Additionally, as noted in section 4.2.2 all the information and evidences obtained were compared using triangulation between methods (Barratt et al., 2011). The use of multiple sources of evidence provides increased reliability of data (Yin, 1994). These were the main sources utilized:

- Internal documentation, reports, archival records and operating statistics.
- On-site observations during the elaboration of the interviews and evidences from discussion and throughout the follow-up process.
- Company websites and AIDA and Accredia public databases. These records contain comprehensive information on the Italian companies under study.

As a final point, the different case studies were compared in the cross-case analysis section, which allowed to highlight the environmental effects of lean practices in the studied companies. The data was analysed using the computer programme Microsoft Office Excel in order to code and summarize all the relationships and effects of lean under study.

Chapter 5. Analysis of the case studies

This section first synthesizes some useful information of the cases in an overview of the companies, to then be able to initiate the within-case analysis. In particular, the within-case analysis describes the main lean transformation activities involved, the environmental data provided by organizations and the impact of the practices on green performance for each company. In the end, a cross-case analysis is presented to provide a better explanation of the lean practices' behaviour and their influence on the environmental performance of the companies investigated.

5.1 Description of the companies

In this section a detailed description of the 5 business contexts studied is developed, synthetizing them to proceed afterwards with the within-cases analysis and the cross-case analysis. A general overview will be provided for each of the firms in historical and current terms.

5.1.1 Overview of Company Pilot

Company Pilot was founded in 1983 and it is an Italian firm dedicated to the production of air conditioners for large spaces. In 1987, this "new company" was the first in Italy to design and build refrigeration units with screw compressors. Its rapid development and success in the market happened due to what was then a real revolution, meant to leave its mark in the conditioning industry.

In 1992, Company Pilot was joined by an organization specialized in the conditioning of residential and industrial spaces. In consequence, during 1993 a division was created, this produces chillers and thermoregulators for industrial processes. Later on, in 1996 another branch was born, this one is specialized in chillers for food preservation and in medium and low temperature industrial processes. Simultaneously, the firm creates a service company engaged in after-sales assistance to all the branches created and, in the management and maintenance of the plants.

In 2001, Company Pilot buys a firm dedicated to the design and production of thermo-fan coils. The constant growth and the need to organize itself in an even more effective and competitive way in the global market led, in 2004, to the creation of a group. Nevertheless, the group kept Company Pilot as principal headquarters.

Afterwards, in 2005, two commercial branches were opened, one in Spain and the other in France. After that, in 2006, the group reached the highest levels of excellence achieved so far with about 350 employees and 5 production plants, reached a turnover of around 80 million euros and the 65% of the group's production was destined for the foreign market.

The good results obtained until that time created the necessity of sustain and improve the market position of the company, for that reason in 2006 the company started to make some experimentations with lean, however after some months the project was stopped.

In 2008 the new headquarters of the group were inaugurated, which host the production of Company Pilot and other branches in a new and technological plant framed in a project of quality and technical excellence. These are located within an area of 50.000 m^2 of which 22.000 m^2 are indoors. It is in this plant where the implementation of the lean production system begins once more, first in 2008 with some experimentations, but the project was again stopped to restart it definitively in 2013 until today.

It is remarkable that during this time, in 2010, the company made a clear leap in quality becoming part of a global group, leader in energy saving and air treatment systems. At that time the company had 1.000 employees and 5 production facilities, with an annual turnover of 230 million euros.

Today, the entire group is one of the most successful companies in the air conditioning sector, with 430 million of euros of turnover, 2.100 employees and 11 production plants. Professionalism and innovation are the characteristics that have led the group to achieve, since 1994, the highest quality levels with special focus on: durability, ease of installation and maintenance, elegance and sobriety of design, energy saving and respect for the environment. As can be seen, the company is significantly concerned about the impact of its operations and makes efforts to control and reduce the environmental effects of its production plants, trying to make compatible efficiency, quality and ecological objectives.

5.1.2 Overview of Company A

Company A is an interesting industrial organization that has been working in the design and production of bread processing machines for over 50 years. The company's beliefs are based on the ancient traditions and skills of the craftsman combined with modern technologies and innovation. Moreover, the real mission is to achieve simultaneously, customer satisfaction and high-quality products so that customers can enjoy a healthy, balanced and fair diet, as well as a tailor-made service that accompanies them step by step.

The history of Company A starts at the beginning of the seventies as a company that creates and develops bakery solutions. The first machines produced were the spiral mixer and the volumetric divider, rapidly were considered authentic technological innovations in the sector. They represented an added value in the business activity, and soon became reference for customers and competitors.

In the eighties the company encouraged a further development of the international markets, from the sales of complete industrial lines for bread-making.

The recent history of Company A underwent a turning point in 2010, promoting and researching innovation, which led the company to focus on the start-up segment. The main pillars of these innovative products for start-ups were their simplicity, excellent quality and at the same time guaranteeing energy savings and respect for the environment.

In 2013 the firm launches its lean transformation with the creation of the first kaizen team which operates within the production department. At the completion of this first kaizen event, the project was extended to all areas of the company. Thus, during these last years the renovation involved four aspects: the first was the employees in terms of change, learning and culture; the second was the splitting of the production plant in two areas: one for the production of medium-high volume machines and the other for low-volume products; the third was the establishment of flexible production lines; and finally, the fourth consisted in concentrate efforts towards the generation of the maximum value to the customer.

Another important objective pursued by the company in addition to quality and efficiency is the respect for the environment, which not only applies to its production processes but also targets with its products. In this sense, Company A offers products with reduced energy consumptions that constitute an important competitive advantage for the firm.

In conclusion, Company A is a manufacturing firm currently established in the Vicenza province (Italy), with about 60 employees that work in a plant of about 12.000 m^2. The industrial complex includes all the areas of the value chain such as production, administration and commercial departments.

5.1.3 Overview of Company B

Located in the Italian province of Padova, this firm is an important company producing small and medium capacity milling plants. More precisely, it is engaged in the design, manufacture and marketing of agricultural machinery and processing cereals. The firm is inspired by traditional values and the passion of caring about nature and living the countryside. Moreover, by using a policy of continuous investment in technology and human resources and assisting the customer with the most up-to-date and timely services, Company B is strongly projected towards the future.

The development of Company B began in 1983 when its main activity consisted in the production of mills for cereals. Later on, the 90s represented a fundamental milestone for the agricultural machinery sector as, in order to satisfy the various needs of the customers, the already wide range of spreader machines for fertilizing and sowing was increased with new models.

In those years, after some changes in management, the company experienced a constant growth trend that led in 2002 to the unification of production processes in the modern plant of Padova. Additionally, the pace of work required the enlargement of the production plant, reaching the current 30.000 m^2 of covered area between headquarters, offices and production in the Padova's factory.

After the start in 2010 of the lean transformation process with the implementation of various lean production techniques and the establishment of the kaizen office, the firm can now guarantee its customers greater quality and be competitive at the same time. The plant starts to achieve after the lean implementation remarkable results.

The respect for the environment is a priority aspect for the agricultural sector: both for those who produce machinery and for those who use them. For this reason, in the design of the machines, Company B carefully chooses the materials, lubricants and paints that are used in the production processes. In addition, the use of resistant materials guarantees an extensive products' life and, at the end of the machines' life cycle, these can be discarded easily and in compliance with the strictest environmental waste disposal regulations.

Finally, Company B also has an important international structure, which is well supported by representative offices that make possible that a 97% of the production is exported abroad, of which the highest percentages are covered by: states of the former Soviet Union (about 50%), United States of America (20%) and South America (10%).

5.1.4 Overview of Company C

Company C is a leading Italian company in the mechanical transmission industry. It designs and produces innovative and high-quality products that significantly contribute to improve the mobility of people and goods. This firm provides solutions for sea transportation and offers innovative technology for many uses in this industry. Moreover, the company offers customers high-added value through a high level of technology, quality and service.

The story of Company C began in 1929 when the company started the production of gears and precision parts for motorcycles. After some decades, the company creates its own space in the market and in 1965 joins a bigger group of the automotive industry. The firm turns into an industry that designs and builds transmissions for industrial, commercial and rail vehicles.

In the seventies the firm entered in the marine sector with the production of its first marine transmission in 1975.

During 1995, the firm takes important strategic decisions, radically changing its production mix: the terrestrial sector is abandoned (lift trucks, buses and metros, transmissions for railway vehicles) to focus exclusively on the marine sector, which has become the real core business.

In 2011 the plant located in Padova joined an important international group. After the fusion, Company B provides complete propulsion systems and components for all types of vessels such as motor yachts, military vessels, high-speed ferries and commercial vessels.

The organization is very committed to sustainability and efficiency in order to guarantee its economic and financial independence. According to the lean principles, since 2013 Company B has an agile organizational structure that constitutes the basis for its continuous improvement philosophy.

Besides this, among the main objectives of the strategy of Company C there is the one of promoting in the organization a constant attention to issues such as respect for the environment and care of employees' security. Consequently, some audit activities are frequently developed directly at the workplace in order to guarantee the achievement of such objectives.

The plant under study is located in a municipality of the province of Padova and engages currently 373 employees. The site covers an area of 75.000 m^2, of which 25.000 m^2 are indoors. The production structure is divided into 3 separate areas: mechanical machining, heat treatments and assembly.

5.1.5 Overview of Company D

Company D is an Italian company that produces equipment for the treatment of compressed gases, industrial refrigeration and air conditioning since 1982. Over the years the firm has developed a considerable commercial presence worldwide, gaining a reputation for the quality of its products, flexibility and customer orientation.

The firm makes clear on its strategy that their products are designed and made to meet the customer requirements, increasing the value for them and all along the supply chain, integrating partners and suppliers.

It is in 2004, when Company D creates a group of companies and becomes the most important branch within it. The dimension of Company D's group can be better understood by focusing on its milestones: employs over 400 people and produces over 50 ranges of products, in 2013 achieved a consolidated turnover beyond 75 million euros, with its production divided across three production plants, with 26.000 m^2 of indoor space and a total of 58.000 m^2.

Still in 2013, the company took advantage of several years of growth and decided to start the lean transformation of its facility in Padova. The aim of this strategic change was intended to be aligned with the mission of the company, improve and sustain quality for customers, flexibility and obviously, improve efficiency and economic results.

It is also remarkable the international presence of Company D since the exports of the entire group currently represent an 80% of its turnover, of which the 75% are inside the Eurozone. The main importer countries are Germany, France, Russia, United Kingdom and United States of America.

Regarding to the protection of the environment, since the beginning Company D has been developing solutions and has been showing a very high commitment for the achievement of energy consumption savings in its production processes and its products.

In 2017, Company D by itself reached an annual turnover of 80 million euros and 416 employees within the production plant located in the Padova province in Italy. Beyond the economic results achieved by Company D, the guiding values of the firm are the search for reliability and innovation pursued with expertise, without losing its attention in important issues such as social and environmental responsibility.

5.2 The lean and environmental performance relationship in practice

The data collected and described in the previous section provided a specific overview for each company in relation to their history, their initiation of the process of lean transformation and their concern for the environment.

Now to give a complete vision, this section exposes the evidences emerged from the five case studies and the within-case analysis developed for each of them. In particular, describes in detail the main lean transformation activities involved, synthetizes their environmental data and the impact of the lean practices on environmental performance for each company in accordance with the data provided by managers.

5.2.1 Analysis of Company Pilot (2013-2017)

Lean practices in Company Pilot

As was noted above, Company Pilot started in 2013 its transformation towards the logic of lean production after two unsuccessful attempts in 2006 and 2008. Then in 2013, the firm underwent the real and continuous transformation which has brought notable results in terms of respect of processing times, higher perceived quality, increased productivity, as well as of efficiency. For this reason, 2013 was considered the year of initiation of the actual lean transformation.

The transformation process started by the establishment of a kaizen office (kaizen promotion office). With this action Company Pilot confirmed the firm's willingness to work with a view of continuous improvement, dedicated exclusively to the production processes. In this office, the kaizen events are periodically carried out, usually with a monthly frequency: various issues have been addressed from the implementation of the 5S, to the improvement of the supply chain and the redesign of the layouts of some production lines. Therefore, it can be said that during this time Company Pilot has been looking for a management/operating configuration in line with TPS and with a view to continuous improvement.

In addition, during these years, the company has been involving the production lines in a procedure of identification and separation of those activities that add value from those that do not give added value (VSM). With the elimination of these non-value assets, the occupied spaces in the working areas were decreased significantly. Some of the lean wastes identified were reduced with the quick changeover optimization provided by SMED. Other wastes such as the unnecessary motion within the process were reduced by the means of the spaghetti chart, or the observation of the paths and movements made by the workers of the production line. In addition, the transition from batch production to one-piece flow and the application of production levelling allowed:

- the reduction of materials inside the lines;
- further diminution of occupied spaces;
- workforce reduction;
- resilience to manufacturing nonconformities and the introduction of innovations.

While the lines were under transformation, a system for the management of materials through a Kanban logic was introduced. The use of the Kanban system in Company Pilot ensures that each operating station produces only what is actually required by the downstream station. In this way, the warehouse is under control and the production keeps pace with shipments. Company Pilot also integrated some of its key suppliers in this Kanban system, giving flow and speed to the process. Currently, the firm is trying to increase the number of codes managed by supplier's Kanban to have an even more pulled production starting from the upstream levels.

Another successive focal point of the company's transformation after the Kanban implementation was the transition to a pull logic of the entire production process. The company made the necessary changes to start production only following customer orders, and currently the company dedicates a 100% of its production to fulfil the orders. This way of working means that the materials flow within the production process as they are called (pulled) directly from the downstream department that uses them, and all the systems start working after the emission of the customer's order. In this approach, the materials even when they come from suppliers are not stored in the warehouse but pass through it for acceptance and they are immediately transferred to the assembly line, achieving the so-called free pass or quality at the source.

After being proposed in the kaizen events, the adoption of the rules of 5S completed the first phase of the lean transformation in Company Pilot and involved the entire production plant. In addition, to the traditional rules of 5S, the "S" of security entered into force to cover the social aspect and not only economic and environmental issues. The company seeks to achieve sustainability in all its dimensions.

Simultaneously, standardization understood as the definition of new criteria and work procedures and the division of processes in micro activities was partially achieved. After the implementation of these two methods, the firm understood that the simplest things are the best, as they are easier to understand and implement.

In line with this, the company pursued a more flexible line distributing the employees in working groups and assigning them different tasks. In this way, autonomy, flexibility and multifunctionality were achieved.

During the development of the projects of improvement with both strategic and operational focus, the firm utilised practices such as PDCA and Hoshin Kanri to control and manage their development, and visual management to program and schedule in an autonomous way the activities of production and daily improvements. These techniques mainly provided speed in the diffusion of knowledge about the production operations and of the management guidelines within the process.

In summary, the degree of implementation of the lean practices in Company Pilot is summarized in Figure 12, measuring in a 1 to 5 scale whether the practice: (1) is not known by the company, (2) is known but not implemented, (3) was tested but not implemented, (4) is implemented but it is among those less used and (5) is among those that the firm uses regularly.

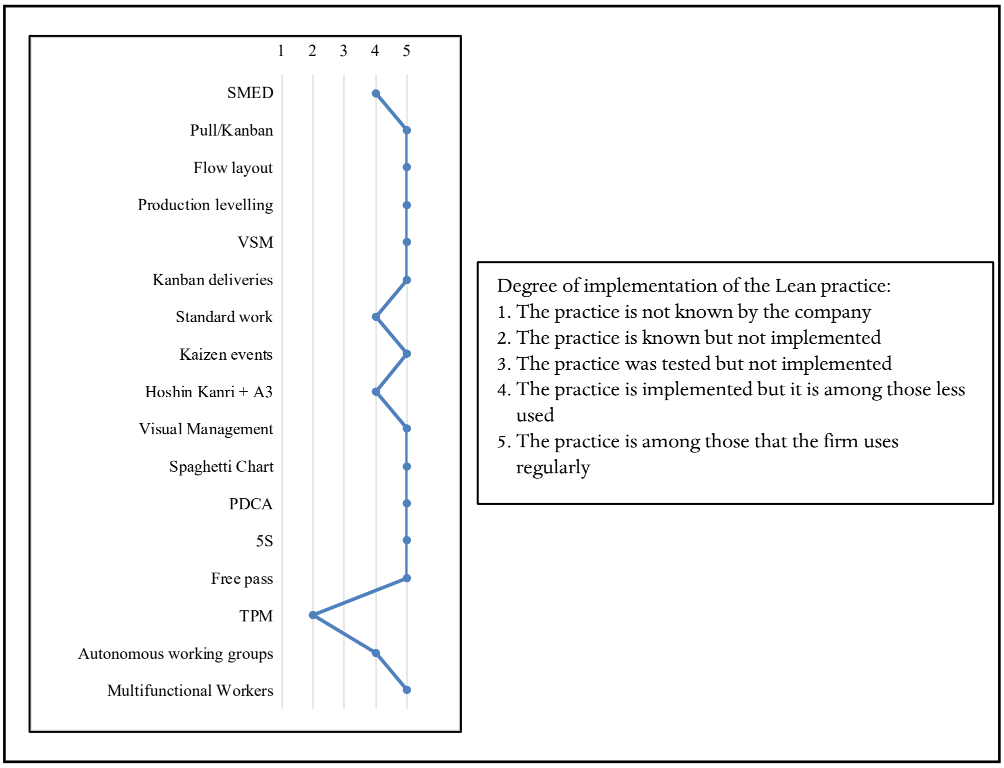


Figure 12. Lean profile of Company Pilot

Impact of lean on the environmental performance of Company Pilot

After describing the lean transformation process of Company Pilot, the study is focused on the description of its effects on the environmental measures of the company with the testimony of the interviewees and the data provided.

Thus, asking the research participants about the concern that the company has regarding to environmental performance, they answered that three measures are subject to measurement and control in Company Pilot: energy use, solid waste and hazardous waste.

First, the travel times of materials within the lines have been standardized and lowered. Supplies are done more frequently for large materials using the "logistics train" system, which picks up materials and transports them in the so-called “Kanban boxes” after a Kanban order. The train avoids transport waste and allows small quantities of different products to be transported with frequent deliveries to the work stations. At the beginning of each line, the trend of the company and the productivity of the line are shown by means of visual management techniques, using graphs and indicators. Therefore, the Kanban “logistics train” used in the production lines was determinant to reduce unnecessary motion, unnecessary waiting times and, in general, to lower the energy consumption within the plant.

Second, actions developed like, for example, the reorganization of the flow of incoming products under the rules of 5S+S enabled important improvements. In this case, the reception area had the typical management of stacked warehouses, characterized by the disorder and difficult identification of the discharged materials. Frequently, materials from different supplies were stacked one above another, and sometimes the areas dedicated to arrivals and shipments were overlapped.

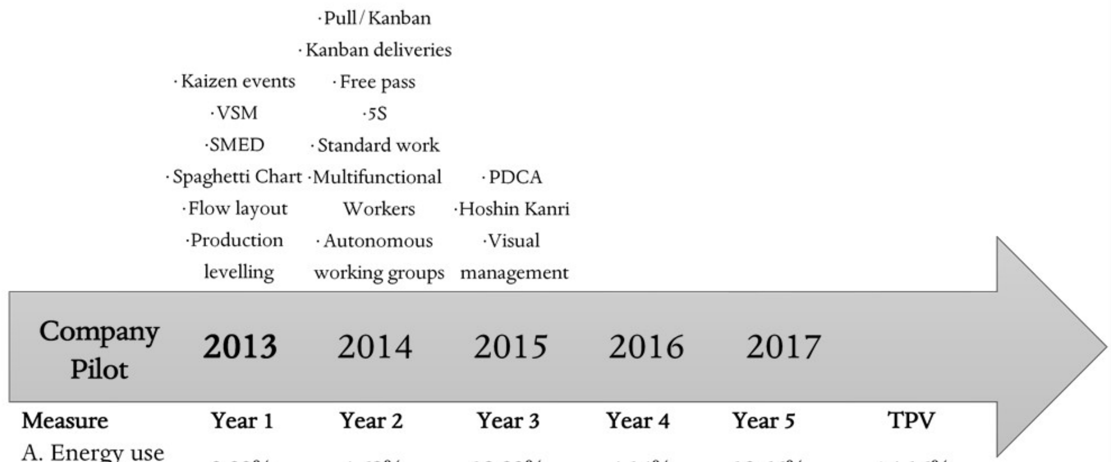
To solve this problem, the teams decided to separate, physically and visually (with lines of different colours on the ground), the areas of acceptance and shipping; since they perform totally different tasks, the areas must be different (Figure 13). For the area of shipping, red stripes were chosen, while for the acceptance area the yellow colour was selected. After that, further subdivisions of the space were made to sort and standardize the unloading and storage operations, increasing the cleaning and assigning to the materials deposited there, a direct correspondence with the area where they have been storage. Then to allow the FIFO method to be implemented, the zones were structured as paths, and various guidelines were defined for unloading, these guarantee that in each path there is only the material of a certain supplier, so that there can always be the way free for the forklift, and to assure safety, a manoeuvring space has been left behind, in this manner the passageway for the material to be taken is never obstructed by other deliveries.

Figure 13. Ground lines in Company Pilot

This new procedure also allows the worker to view the material he is unloading, immediately identifying damaged, non-compliant or missing material. To achieve all of this, it was necessary to train the staff to use these new tools, were analysed the micro-activities of unloading and storage, and was drawn up for each of them a new standard procedure. In summary, the application of the 5S+S rules was very useful for the identification of damaged material and avoidance of more waste in storage areas. In addition, the firm declared that the use of 5S+S worked also as a facilitator of further energy use reductions and to sustain the results achieved developing periodic audits with a standard checklist.

Third, after the development of various kaizen events and the application of the VSM and 5S+S, it was concluded that some processes needed an improvement. Several analyses of micro-activities were carried out in different processes and the assignment of various functions to each employee was useful to achieve standard work and reduce the levels of solid and hazardous waste. In addition, the audits regarding the organization of the workplace, the use of visual management techniques for maintaining a clean and organized workplace and the inspection of the use of materials involved in the Kanban process were also enablers of the reduction of material and hazardous wastes. Now, the company is nearer to the "ideal state" of operations and tries to use only the materials needed for each product with the less waste.

Finally, even if Company Pilot declares environmental benefits from the implementation of lean practices, the long-term trend of the measures is essentially constant as is outlined in Figure 14. Please note that all the values of the environmental indicators have been normalized with respect to the company's turnover measured in real and constant prices and for privacy reasons have been expressed in annual percentage variations.



Measure	Year 1	Year 2	Year 3	Year 4	Year 5	TPV
A. Energy use (KWh)	0,00%	4,69%	18,83%	-4,14%	-12,66%	+4,16%
H. Solid waste (tonnes of waste)	0,00%	10,56%	7,81%	-13,75%	-5,68%	-3,03%
I. Hazardous waste (tonnes of waste)	0,00%	1,02%	-4,49%	22,28%	-15,94%	-0,83%

Figure 14. Evolution of lean and environmental performance in Company Pilot

The figure shows an implementation chronology of the practices that have been applied by Company Pilot, including those that the firm has been using regularly and those that are used less frequently. Moreover, beneath the figure are listed the environmental indicators measured by the company and for each one the performance variation year by year over the interval considered. The last column on the right outlines the total performance variation (TPV) over the whole 5 years, calculated:

$$TPV = \frac{V_5 - V_1}{V_1} \times 100$$

Were V_5 corresponds to the value of the environmental indicator the fifth year and V_1 is the value of the same indicator measured the first year of the interval considered. Accordingly, as can be deducted from the data available:

- Company Pilot only measured three environmental indicators out of the total of measures under study.
- The firm has been achieving irregular environmental results. The improvements or undesirable results of a year were offset with negative or positive results of the successive years to end up in 2017 with similar results to the beginning of the lean transformation.

- The most environmentally friendly results of the measures occurred 3 years after the implementation of lean, just when the lean implementation reached some maturity returning to initial levels since the firm obtained worse or even adverse results during the first 3 years analysed.

In summary, throughout this long-term analysis carried out in Company Pilot, notorious reductions and improvements of the measures occurred, to be stabilised during the last years. Thus, independently of these variations the values ended up being essentially similar to the ones achieved the first year of the lean transformation and in proportion to the variations of the activity occurred during the period.

5.2.2 Analysis of Company A (2013-2017)

Lean practices in Company A

At the end of 2013 Company A launched its lean transformation process with the arrangement of its first kaizen event when the volume of sales and turnover were decreasing due to the economic crisis. This created the need to review the organization of the company with the aim of recovering margins and revenues and becoming leaner to be more competitive. Consequently, using the kaizen technique and enrolling both managers and employees, the company gradually began to look at the flow of value within the factory, to identify muda and organize the processes according to the lean logics; all this by developing the ability to work in a team on specific issues according to the site.

The first step was the training of the kaizen working group for the improvement project of the factory: it was decided to develop closer collaborations between the operations department with the purchasing office, and between the engineering and technical office. During the kaizen events it was decided to develop and apply the VSM technique, spaghetti chart and was designed the "concept layout" of the company for the next years. Starting from this first event, the kaizen methodology has been applied throughout the whole company.

Afterwards, Company A started to apply the VSM tool with the aim of define the current state of things, follow the production process starting from the customer and going back till the suppliers and trace carefully a visual scheme of the flow of materials and information for each activity. To obtain this information the kaizen group developed the so-called "Gemba walk" starting from the expeditions and going back up the flow, and with paper and pen collected all the useful information about the process. In this manner, the phases of waiting materials were indicated, their movements within the plant and the activities carried out on the product were highlighted.

The mapping of the processes showed that the time of accomplishment of every single phase was rather low, but the total time between the arrival of the raw materials and the delivery of the finished product to the customer was significantly high, equal to three working days. The main causes of this situation were summarized in two factors: the number of material movements inside the factory, among the excessive intermediate buffers between the activities, and the high number of finished product inventories in the shipping department that constituted a bottleneck. Some negative consequences of the high work in process (WIP) were also unveiled such as a waste of space, an increase in the handling of products beyond the necessary, a greater risk of damage and in the end an unreliable delivery system.

The spaghetti chart was used in the company during the process mapping, specifically in the assembly process, with the goal of measuring all the movements performed by the operator while assembling the machine within the cell. In Company A, before the lean transformation, the assembly took place in independent production cells. This type of organization involved an area in the middle of the plant where the assembly happened and an area around it with shelves where the necessary parts were stored in order of utilization during the process of assembly. Whenever the operator finished an operation, he had to move towards the shelves to pick up the next lot and return towards the machine to perform the new operation. This produced excessive movement and therefore a waste of the operator's time. One of the analysis conducted showed that the operator made around 1.200 steps that multiplied by 0,8 meters of average stride length required around 1 km of total distance to be walked for the assembly of one product.

The excellent results reached applying kaizen led to change the way assembly was carried out: the goal at this point was the transition from the independent cells system to a flow line divided into different phases or levels. To achieve this, the basic concepts of flow layout and production levelling (Heijunka) were used to lead the transformation. The final aim of the idea was to build a zero-waste assembly line, eliminating all the muda from assembly and reach a cycle time that approximates the ideal cycle time. The first wastes eliminated were those related to movement, placing upstream of the assembly line a supermarket with the function of a small buffer of components, then an operator or "picker" provides the materials needed for assembly to the various stages along the lines.

With the new design of the line, the machine is no longer assembled in one phase and the operator does not take every single component necessary from the shelves anymore, but it is produced according to a continuous flow formed by different phases and all the useful materials for the assembly are supplied to them by the picker. Producing in a continuous flow means making one product at a time, with each of them passing immediately from one phase of the process to another, without intermediate staging. In this perspective, the spaghetti chart no longer makes any sense, as the material movements are ideally insignificant.

After the definition of the layout of the plant, the Kanban method for the different types of components and the Kanban deliveries with those suppliers which are placed near the factory and make frequent deliveries were adopted by Company A. This process requires that, when the picker takes the last piece of a purchased part, a purchase order is created by SAP. The supplier receives the notification, delivers the component in the quantity and quality established on a free pass logic, based on the agreed lead time and on the appropriate container which is placed directly in its place in the plant. At the time of delivery, an exchange of the ordered code takes place. Once the empty container of the product has been collected, it is the supplier's duty to fill it as soon as possible. This way the full container will be ready for delivery when necessary. Visual management and coloured signals are used to complete this process.

Then, depending on the type of supplier, agreements were made on lots, transport, containers and other issues necessary to start the new order system. For example, the supplier undertakes to shorten the delivery lead time and Company A to notify it in advance if the production of a certain type of product is about to finish, thus establishing a compensation system. Furthermore, all the containers and shelves have been standardized and have been supplied by the firm to each of its suppliers.

Afterwards, to support the daily kaizen activities carried out, the Deming Cycle or PDCA was applied. In the first kaizen meetings were discussed problems that for years had only been exposed and never formalized and therefore never solved because no one faced them. After a while, in addition to the daily problems, numerous improvement proposals came directly from a large part of the staff, who realizing how the PDCA worked, became much more collaborative in proposing solutions and improvements and in getting involved in it.

Taking advantage of the benefits of the production levelling and the creation of the continuous flow within the factory it was then decided to implement the 5S logic and to standardize activities as further methods to obtain a more efficient, cleaner and tidier workplace.

Finally, it is worth noting that during this time the firm has applied multifunctionality in some workplaces but with less success since it is one of the less used lean practices. Even with TPM they have only done some testing. In brief, the degree of implementation of the lean practices in Company A is summarized in Figure 15.

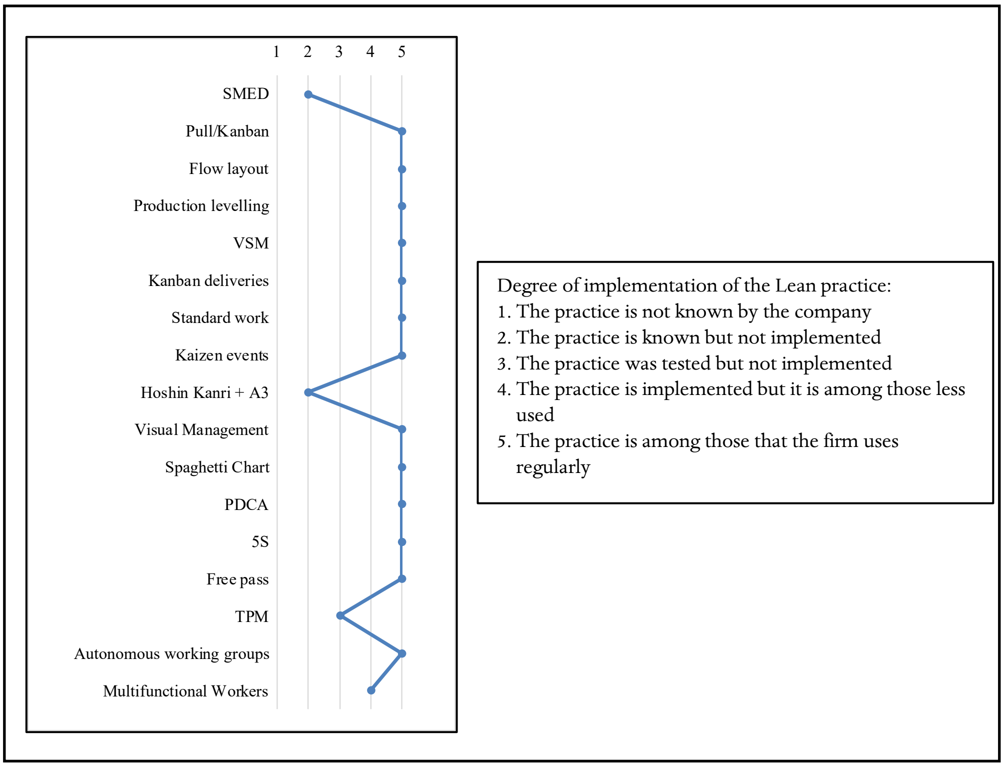


Figure 15. Lean profile of Company A

Impact of lean on the environmental performance of Company A

First, using Kanban and following the pull logic, therefore not producing more to accumulate stocks of finished products, it was possible to eliminate the orange area dedicated just to the storage of various types of surplus materials and the mechanics area was reduced significantly (see Figure 16). As a result of this, the company went from producing in an area of over 10.000 m^2 to one of just over 7.000 m^2 with about 3.000 m^2 of free space (-35%), now available for possible future applications and investments and results in a better use of the industrial land.

The change of the company towards a pull system was the main but not the only responsible lean practice of the shop-floor reduction and the elimination of the storage. Were also decisive other techniques such as the transition to a flow line production process, the improvement proposals obtained at the kaizen events and the establishment of a tidy and clean workplace under the rules of 5S using, for example, the signalling of spaces or zoning.

These five years of changes made possible a better use of land and opened the possibility for future projects to facilitate more production in less space that is one of the major milestones to preserve the environment.

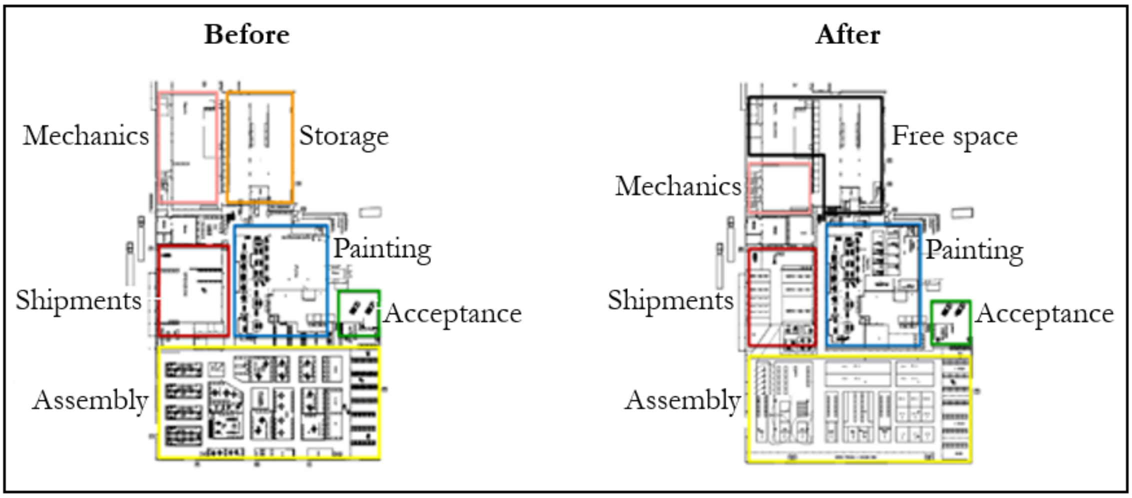


Figure 16. Plant's layout before and after lean implementation

After 2013, the company has experienced a continuous and remarkable reduction of the materials consumption used for the production. The implementation of regular kaizen events was useful to target problems right away to try to eliminate them as quickly as possible. A large part of these problems was associated with the production process and were identified by the operators, their resolution usually involved easy changes, movements of machinery and adaptations to achieve at the end, more efficiency and less use of materials.

In addition, mapping the value stream (VSM) was determining to identify the real flow of materials and afterwards to eliminate the elevated WIP and the high waiting times within the process, as a consequence of them the company had several movements, handling of products and a greater risk of damage that implied reworks and more material needs for replacing damaged WIP, causing waste.

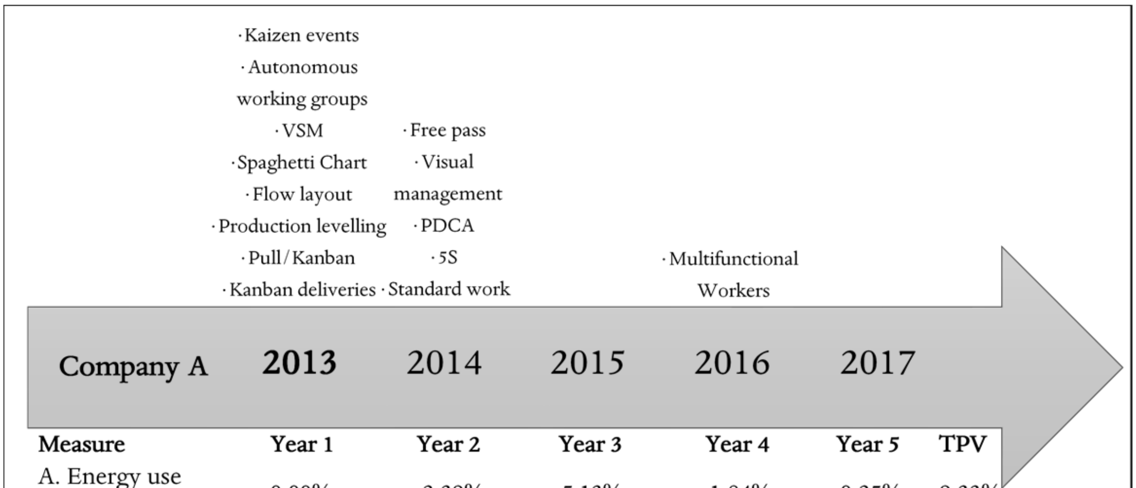
At the most operational level, the firm applying standard work techniques and the 5S rules achieved the standardization of the activities made by the working force, these contributed to reduce rework and to achieve the consumption of materials only in the necessary quantities required for production. These homogenous and organized way to do activities also permitted the reduction of the use of materials.

Moreover, the strategic integration of suppliers in the company's supply chain has enabled the elimination of quality control in acceptance (free pass): if a defective piece is purchased, it is directly detected during assembly. This immediately activates an alarm and it is reported to the kaizen team, according to the "autonomation" logic (Jidoka). Afterwards, thanks to the daily activities of continuous improvement, the teams try to understand the causes of the problem and if necessary, they go and verify the supplier's process with the aim of eliminating the root causes of defects. In this way the company reached lower levels of defects enabling less materials consumption, rework and waste.

Energy consumption levels of the production plant have been also decreasing over the years since the beginning of the lean transformation. The benefits of the reorganisation of the layout and the levelling of the production line were crucial to the energy savings achieved (i.e. elimination of the warehouse, reduction of movements, less waiting). In addition, research participants declared that daily improvements obtained during the kaizen events and the use of visual management to, for example, "turn off a machine when is not in use, made small day-to-day improvements which aggregated made a significant effect".

On the contrary, these positive effects regarding the energy use in the plant were partially offset using Kanban deliveries. With this lean practice the dimensions of the batches have been reduced, but the delivery frequency was also increased producing more movements inside the company which imply higher energy consumptions. To solve this problem which is not only an environmental problem, also supposes an increase in transporting costs, the firm has implemented a policy for the reduction of suppliers, in order to have as many as possible within the province of Vicenza. The idea for the future is the implementation of the so-called "milk run", or the organization of a process of collecting materials from suppliers. This project aims to find the right trade-off between storage costs and transport costs, finding the optimal number of withdrawals to minimize the total cost and being economically and ecologically sustainable as far as possible.

Finally, in Figure 17 the same analysis as in Company Pilot was performed for Company A. In this case, the figure demonstrates environmental benefits from the implementation of lean practices in the long-term.



Measure	Year 1	Year 2	Year 3	Year 4	Year 5	TPV
A. Energy use (KWh)	0,00%	-2,39%	-5,13%	-1,84%	-0,25%	-9,33%
B. Land use (m^2 of the plant)	0,00%	-28,28%	-11,97%	1,87%	0,25%	-35,52%
C. Materials use (euros/turnover)	0,00%	-1,56%	-4,76%	-3,33%	0,00%	-9,38%

Figure 17. Evolution of lean and environmental performance in Company A

The lean implementation process and the environmental results of Company A can be summarized as in Figure 17. From Company A's timeline, it must be emphasized that:

- The firm used environmental measures related only to the first three classes: energy use, land use and materials use. Therefore, for most of the environmental categories, Company A does not measure any indicators.
- For all three types of indicators the participants reported a reduction during the 5 years under investigation. This means that even if a negative effect of Kanban deliveries was identified during the study, the positive effects of other practices countered this issue.
- However, it should be noted that the best results of the environmental indicators happened just after the implementation of lean during the first three years. In 2016,

the company experienced a deceleration in the improvement of its energy use levels and even more, kept almost constant for the last two years the measures of land use and materials used.

In summary, during this long-term analysis, important reductions of the measures occurred, to be stabilised during the last two years. Consequently, the environmental improvements achieved during the primary years of the lean transformation were much clear and visible than those of 2016 and 2017.

5.2.3 Analysis of Company B (2010-2014)

Lean practices in Company B

Since the start of the lean transformation path in 2010, the company has been using a mixed pull system. This solution combines the use of the supermarket for most of the parts used in the production and "made-to-order" production for the rest of the components, which represents a minor part of the total. The idea is to supply the lines using mainly a supermarket and using an internal Kanban system. Moreover, big and/or expensive parts are managed on-demand, supplying the lines only when these are needed. The advantages brought by the Kanban system were, among others, the simplification of the production processes. This leaded to reduce the use of the MRP tool and to improve the ability of responding against changes in demand.

As regards the layout, the firm adopted the solution of a "flow layout": a single assembly line shared by all the different models of machines. The shift from unbalanced cells to a continuous flow of production and an effective design of all the parts involved, using Kanban techniques, have allowed to:

- Reduce non-value-added activities and the assembly time.
- Respect considerably the takt time.
- Increase productivity and flexibility to changes in demand.
- Reduce the stock substantially.
- Eliminate overtime hours.

Afterwards, the SMED technique was applied to sustain the flow layout and the reduction of the set-up times. In this context, some of the actions taken were:

- Design of quick fastening and coupling devices to eliminate screws or other complex systems to be managed.
- Avoidance of the transport of disassembled or semi-finished parts from one part of the plant to another during shutdown.
- Placement of a tool trolley near every machine.

Subsequently, all internal and external flows of the plant were drawn using the value stream mapping method. With the data obtained from the application of this methodology, various improvement projects were developed with the aim of achieving the objectives that meet the needs of the final customer as much as possible. For example, from the observation of the VSM it was possible to notice the presence of "transportation muda". Some parts start their "journey" from the supplier warehouse, then are transported to Company B's warehouse, hence are addressed to a subcontractor that carries out some external processing and, finally, they return to Company B where the painting and assembly operations are carried out. This was an important observation to keep in mind when drafting the future state map.

From the current state map, it was also possible to realize the times necessary for carrying out the various processes and at the same time the number of workers employed in such activities. Consequently, the VSM tool was found to be of fundamental importance in order to be able to simultaneously visualize, in a single sheet, critical information and therefore have a general view of the situation.

Furthermore, for Company B was determinant to develop a "kaizen approach" that makes it possible to progress step by step towards long-term objectives, continuously adapting to the changing conditions of the competitive environment. In this case, the firm carries out training of employees through learning paths, kaizen events and workshops for the assimilation of lean techniques. Additionally, during the kaizen events, which are developed regularly, was born the idea of implementing the 5S and PDCA rules together with weekly audits (Figure 18) in the processes to guarantee the adequate development of the 5S activities of sorting, setting in order, shining, standardizing and sustaining; achieving continuous improvement in practice. Furthermore, the use of the spaghetti chart was recommended to calculate the length of the movements within the factory by the employees, which had never been done before.

0 = NON CONFORME 1 = MOLTO POCO CONFORME 2 = POCO CONFORME 3 = ABBASTANZA CONFORME 4 = TOTALMENTE CONFORME						
1. SEPARARE	0	1	2	3	4	Commenti/Note
1. Tutti i codici non necessari sono rimossi dall'area						
2. Tutte le attrezzature e gli utensili non necessari sono rimossi dall'area						
3. Tutti i codici e le attrezzature appartenenti ad altri reparti sono stati rimossi dall'area						
4. Le attrezzature, gli utensili e i codici rotti o difettati sono stati segnalati e rimossi se inutilizzabili						
5. Esiste un'area di quarantena per i codici di dubbia utilità ed è regolarmente gestita						
2. ORDINARE	0	1	2	3	4	Commenti/Note
6. Tutti i codici sono posizionati nelle aree a loro riservate						
7. Tutti gli utensili e le attrezzature sono al loro posto (se non in uso)						
8. Esiste una posizione ben definita per ogni codice e attrezzatura						
9. Le aree di lavoro e i camminamenti sono ben definiti e non ostruiti						
10. I dispositivi di protezione individuale e le attrezzature di emergenza sono utilizzati da tutti e immediatamente accessibili						
3. PULIRE	0	1	2	3	4	Commenti/Note
11. Il pavimento è pulito e non presenta tracce di acqua, olio e scarti di lavorazione						
12. I banchi di lavoro sono liberi da sporcizia (olio, poveri, scarti di lavorazione)						
13. I cestini e i contenitori per la spazzatura sono presenti e regolarmente svuotati						
14. Gli attrezzi da lavoro sono puliti e mantenuti in buono stato						
15. Il piano di pulizia esiste, è rispettato ed eseguito autonomamente						
4. STANDARDIZZARE	0	1	2	3	4	Commenti/Note
16. Le idee di miglioramento sono analizzate e, se approvate, vengono attuate						
17. Le informazioni sul carico di lavoro quotidiano sono disponibili e a conoscenza di tutti						
18. Le modalità di stoccaggio dei codici sono chiare e rispettate						
19. Le procedure di lavoro standard sono definite, chiare e rispettate						
20. La tabella dei suggerimenti appesa al totem è regolarmente utilizzata						
5. SOSTENERE (e rendere SICURO)	0	1	2	3	4	Commenti/Note
21. I suggerimenti dallo scorso Audit sono stati visionati e, se possibile, già attuati						
22. Gli operatori dell'area sono adeguatamente istruiti su come portare a termine le proprie mansioni						
23. Il piano di Audit è regolarmente condotto e aggiornato						
24. Le attività legate alle 5S sono eseguite con cadenza quotidiana						
25. Le informazioni sulle prestazioni delle attività di lavoro sono documentate e rese disponibili						

Figure 18. Form for calculation of 5S audit scores

The standardization of the operations was another priority for Company B. The actual times that the workers employed in performing their activities were collected and examined using time and motion methods. Furthermore, these times are continually reviewed and corrected according to the kaizen approach.

In summary, the changes described above follow the principles of the lean philosophy, however the firm declares the difficulty to implement some of the practices currently used since they comprise several changings in the organization culture, which are difficult and time-consuming tasks. Other practices which are not actually implemented such as free pass and Kanban deliveries, turned to be challenging since various suppliers had problems to follow the premises required by the company and these practices require strong collaboration. Consequently, Company B is the firm with less lean practices implemented within the case studies using only 9 practices, 6 of them regularly, out of the 17 under study. Its lean profile is outlined in Figure 19.

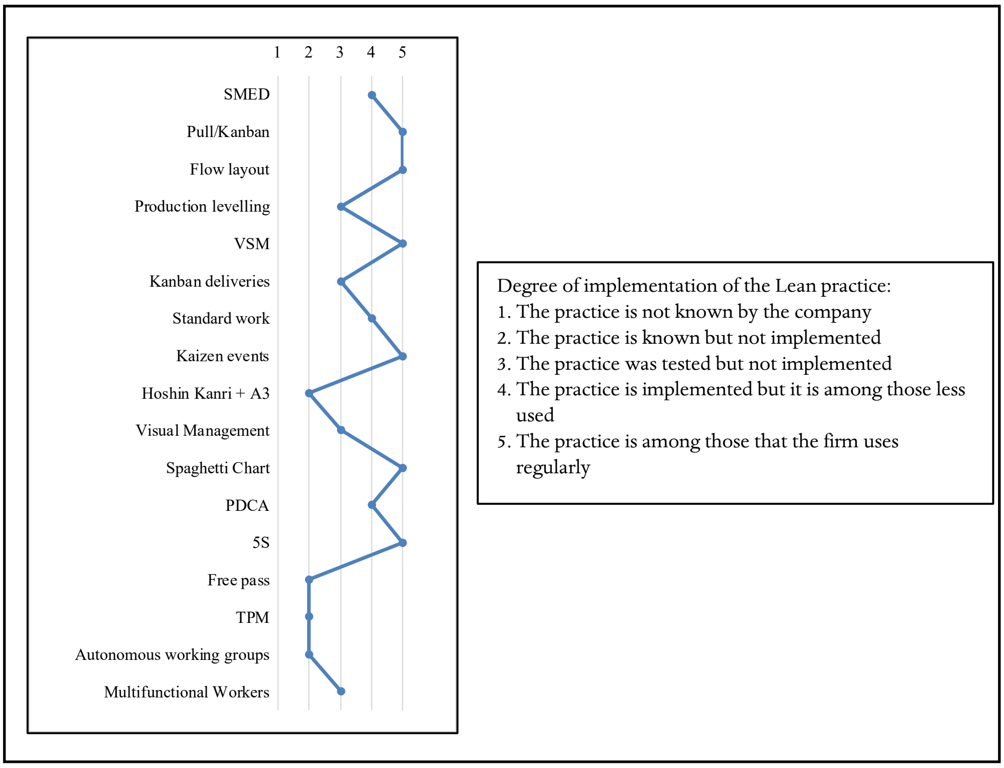


Figure 19. Lean profile of Company B

Impact of lean on the environmental performance of Company B

During the implementation of lean beyond the changes and improvements in the processes and within the production plant, further effects on the environmental performance of the company were declared by the research participants.

Among all the advantages deriving from the use of Kanban, the company observed a 90% stock reduction and consequently a remarkable reduction in the use of packaging and energy. This was supported by a strict control of the stock under FIFO rules and a regular use of reusable packaging like plastic pallets with standard dimensions which facilitated the movement of products within the plant. Moreover, other improvements that were observed using a pull philosophy in the plant were:

- The reduction of worker movements with the introduction of the new picking Kanban-based structures. Now, supplying the workplace is much more efficient and comfortable, instead of wasting time and energy going and coming from the warehouse every time a piece is needed.
- A significant elimination of waiting times and the unnecessary energy involved. This improvement derives from the other positive effects of pull.

The establishment of kaizen events, 5S and PDCA and their weekly audits in the workplace sustain the continuous improvement approach and make possible the easy identification and reduction of material waste and facilitate more efficiency in the workstation. More specifically, after introducing the 5S philosophy, a weekly plan for checking the maintenance status of each workplace was developed. The plan settles that once a week the employees of a specific area must stop for enough time to conduct, together with the kaizen promotion office, an analysis of the conditions of the entire working area. In order to adopt a standard measurement, a checklist was devised and, through a list of questions the management is allowed to evaluate, from time to time, the commitment to apply the principles suggested by 5S. In addition to these practices, VSM was also advantageous to identify the point of use of raw materials and their flows; the flows of components in and out of the plant and internal and external processes; and enabled further reductions in material consumptions.

Furthermore, the use of pull and flow layout in the painting process meant painting more pieces in each cycle, therefore led to a dramatic reduction in the use of water and materials of the plant. The painting process had never been done in this way because a single-piece was painted in each cycle without a well-organized sequence of lots defined from the beginning. Since each type of material has its characteristics, the painting depends on them and for this reason the loading of homogeneous material for painting is in rigorous order avoiding the need to change painting features frequently, which means, to have further substantial wastes of time, materials and energy, which was no longer acceptable for the managers Company B.

In general, these practices produced a positive impact in operations; reducing considerably the assembly lead time (about 30%) and the movements within the plant (about 60%), making clear energy savings. Some of these improvements were also enabled by the application of SMED: using quick fastening devices many set-ups were shortened (energy consumption reductions). Moreover, many assembly errors were avoided (materials and waste reductions), as the parts to be managed are simpler. Finally, the number of material movements in the plant was significantly reduced, avoiding extra electricity consumptions.

Conversely, it is remarkable that even if these lean practices made great improvements in the energy consumptions of the company, this measure has been almost constant during the long-term period analysed. Research participants declared that some of the activities like welding are very costly in terms of energy use and gas use. In Company B are trying to find a solution to this issue making cost studies to decide whether make these pieces or buy them. Till now, due to the scale of production of these components it is more convenient to make them internally.

Additionally, the company affirms that it has made some trials with Kanban deliveries. They noted that the movements derived from Kanban and the deliveries were increased, this is a source of energy waste, maybe insignificant, within the production plant. Nevertheless, the company is aware of this issue and is looking for new solutions.

To conclude, in Figure 20 the evolution of the environmental measures developed with the data from Company B is outlined. The figure shows the variations (%) year by year during the lean transformation process noted on the top of the timeline and illustrates that no measures got worse, only the energy used remained constant after various variations and the rest followed an improving trend after the long term analysed.

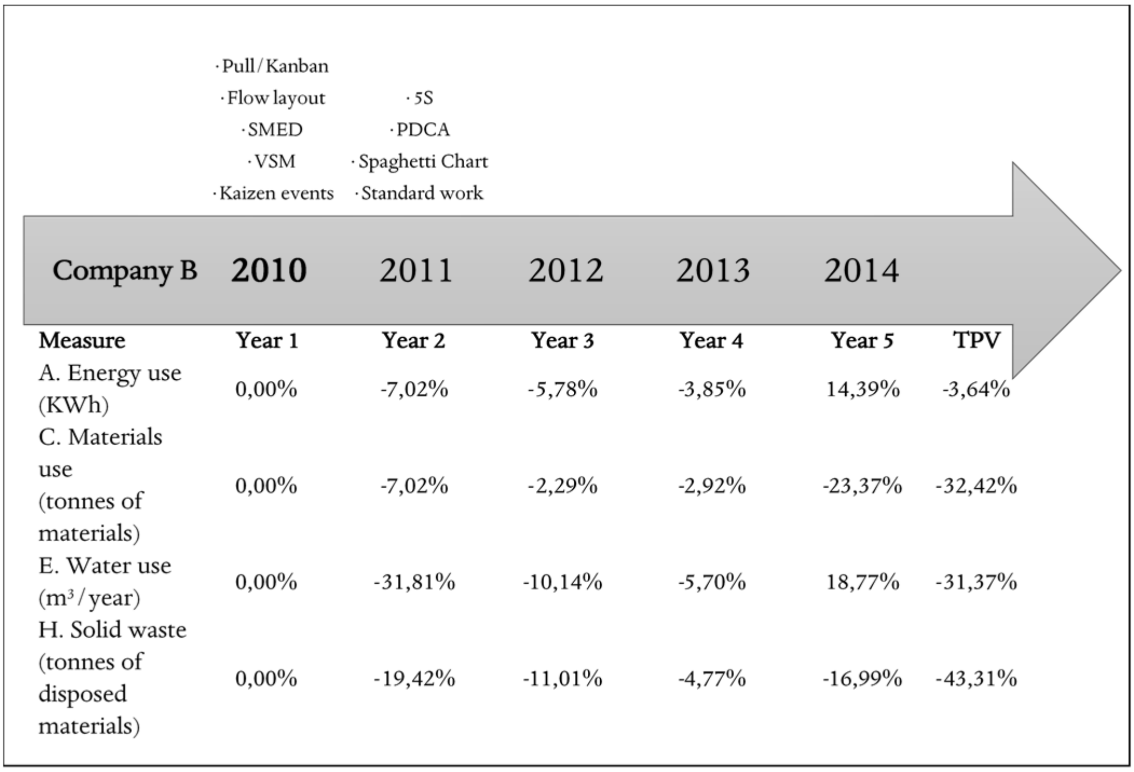


Figure 20. Evolution of lean and environmental performance in Company B

The lean implementation process and the environmental results of Company B were summarized in Figure 20 before these lines. From the graphic and based on the previous information described above by the research participants it can be concluded that:

- The firm developed measures yearly for almost half of the environmental categories investigated (4 over 10 categories). For the rest, Company B did not measure any indicators during the five years period.
- For the energy use and water use measures, the company experienced reductions on its value until the fifth year analysed. On one hand, the energy use measure got worse the last year reaching similar levels to those of the launch of the lean implementation. On the other hand, the water use measure remained below the levels of 2010 as occurred with the materials use and solid waste measures, that have experienced a sustained reduction of their values during the reporting period.
- During the first two years after 2010 most of the large reductions of the consumptions of the plant occurred. In the case of the use of materials and solid waste, their measures improved again even the last years. On the contrary the energy and water used measures got worse.

To sum up, the application of these typical lean tools has contributed to the reduction of the environmental impact of the firm. As illustrated in Figure 20, the use of materials and water and the solid waste generated were reduced. That is not the case of the energy consumed by Company B, which had slight diminutions over the years to end up remaining essentially constant at the end of the period examined.

5.2.4 Analysis of Company C (2013-2017)

Lean practices in Company C

After the start of the lean transformation in 2013, the concepts of the "lean thinking" applied by the Italian plant have been operationalized through the so-called "zero defects" project.

Following the lean principles, the kaizen technique was applied in Company C to seek continuous improvement. In this context, the firm introduced the "Kaizen Journal", which is used for the collection of problems and related corrective and improvement actions. This journal was born during the team discussions in various phases of the project, and especially during the waste analysis. Two relevant ideas proposed were, for example, the implementation of the so-called low-cost intelligent automation (Jidoka) for material handling and the use of quick die changing methods and colours to accelerate the set-up (SMED). The figure of project manager was established for every improvement project launched to assure the correct implementation of the ideas suggested. In addition, a clear deadline for each idea of implementation was also defined in order to control the scheduling of the project.

At different times, regular kaizen events were conducted on the main lean techniques to be applied, i.e. flow layout, 5S and TPM and subsequently three workshops were developed. During these meetings, solutions for the daily problems at the workplace were exposed and shared between the participants.

The re-organization into a flow layout assembly line began in 2013 and led to the reduction of the number of lines from 12 to the current 7. The project was a very important step in the process of the reconfiguration of the plant according to the lean principles and implied the application of practices such as Kanban deliveries, free pass and the use of the spaghetti chart (see Figure 21) to study the movements of materials and workers among the lines. Applying this last practice, the company discovered, for example, that many components were stocked far from the locations where they were actually used. This entailed long walks of the worker to pick up what was needed, which caused waste of assembly time. After the line reconfiguration, this problem was reduced significantly.

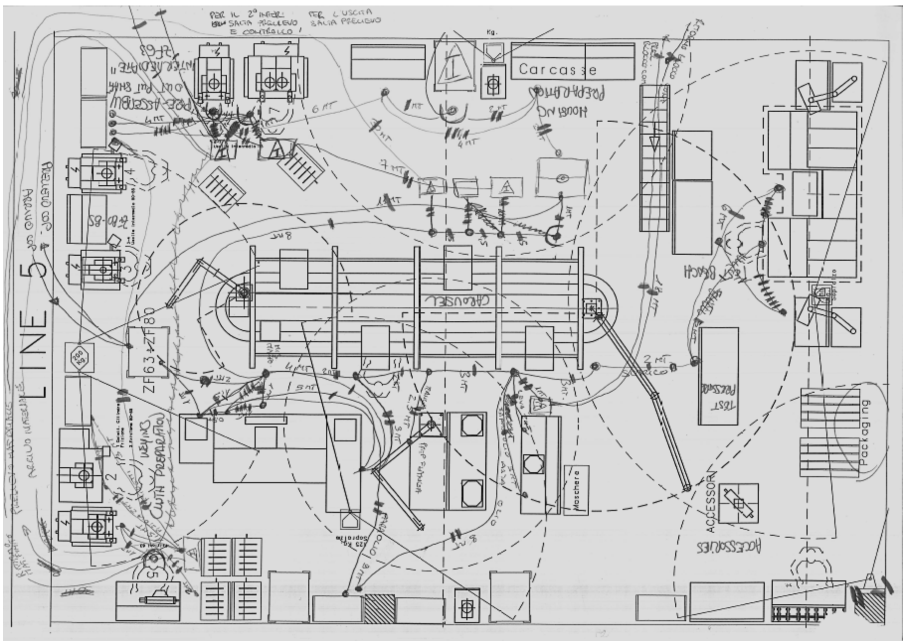


Figure 21. Spaghetti chart developed for line 5

Moreover, various 5S workshops were developed, these were aimed to instruct participants to create and maintain a clean workplace. These workshops took place in two consecutive days: within the first day, theoretical training about the 5S rules were developed, followed by an audit designed to understand the current situation of the working place. On the second day the 5S process was completed, the new solutions were defined and implemented, and the final audit was followed by a final discussion among the members of the team to share improvement ideas and the possible solutions in the immediate future to everyday issues.

Even the workshops on the TPM practice took place during two consecutive days in a similar way to the 5S workshops. The first day was dedicated to the theoretical training, the initial audit and the cleaning of the plant to prepare the second phase of the project. In the second day it was also carried out a final audit and the completion of the general plan for maintenance. The company expressed a high interest in TPM, as they believed that "its implementation should enable great efficiency improvements", and this actually happened.

Afterwards, another important technique adopted by Company C is the so-called in the plant's environment as "changeover optimization" or SMED which aims to reduce the incidence of set-up time on the loss of time and efficiency through the reorganization of activities and the elimination of unnecessary operations. During the kaizen events developed for the implementation, it was repeatedly mentioned that improving does not mean working faster but working avoiding unnecessary movements and operations. After the theoretical explanation of the approach, a pilot project was conducted in the plant in order to record and analyse a specific set-up. Recording was essential for the next phase in which the film was reviewed several times to enable the generation of new solutions and ideas for discussion between the team members.

At the same time, the company promotes the employees' involvement facilitating them to work in interdisciplinary groups through an interchange system. By doing so, the workers are quicker to find the right solution by analysing a task from different points of view.

For a long-term success, the company develops two strategies. First, trying to combine the effects of the introduction of radical innovations with small daily improvements (kaizen).

Secondly, using some useful tools for recognizing and managing new improvement opportunities such as:

- Value stream mapping, which is essential to identify within processes the improvement opportunities that will be discussed during the kaizen events.
- Plan Do Check Act and Hoshin Kanri to solve problems in a systematic way and achieve continuous improvement at the same time.
- Visual management, which allows the company's situation to be known punctually and immediately through graphs that summarize the most important indicators and key success factors.

In summary, Company C has implemented several important lean practices and the managers interviewed demonstrated their commitment towards continuous improvement. These practices and tools are regularly used for waste reduction and improvement aims, and even now, the firm is still making some testing to improve processes applying practices such as: Kanban, production levelling and standard work. Concluding, Figure 22 shows the degree of implementation of the various lean practices under study in Company C.

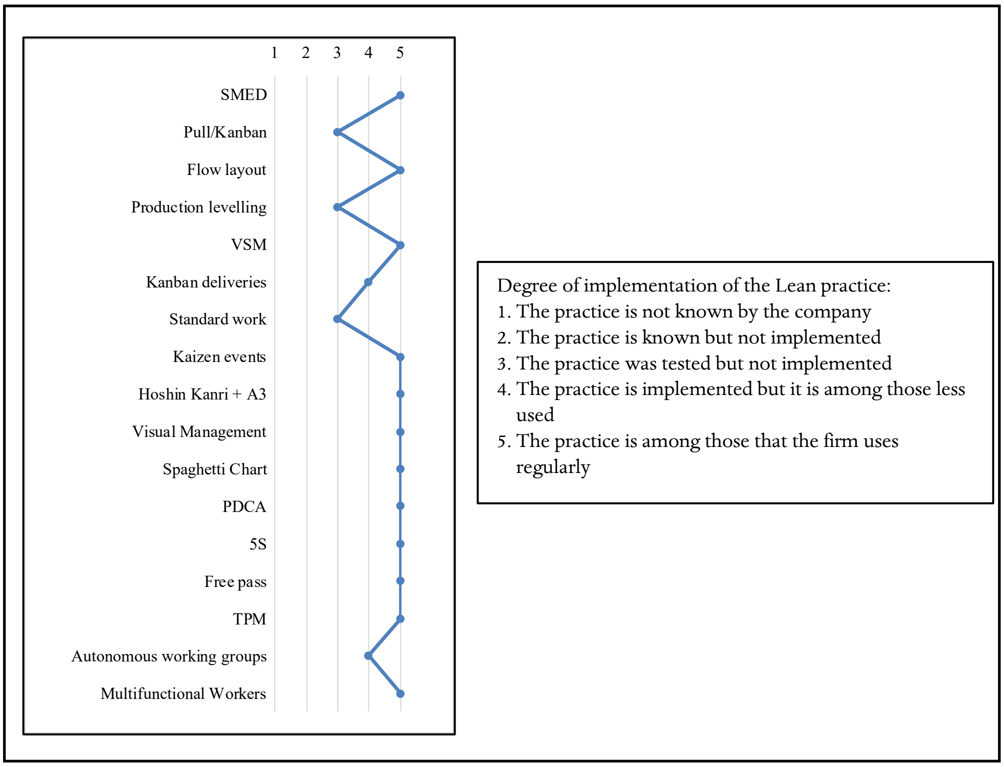


Figure 22. Lean profile of Company C

Impact of lean on the environmental performance of Company C

In Company C, before the lean transformation, the assembly was organized to meet the requirements of mass production with a large automatic warehouse that furnished the work areas monthly. However, the assembly department was not supplied directly, and the material was stored in 3 large areas from which the workers had to pick up the parts and take them to their working station. After that, the products to be assembled and shipped had to go through 8 different areas of assembly with waste of time and a very high probability of error. Following some changes in management and various kaizen events, a project to solve this was launched and the flow line was implemented. In addition, the automatic warehouse was replaced by a supermarket guided by the rules of Kanban deliveries and free pass.

The results of changing to a flow line were immediately visible, the use of energy was strongly reduced by the elimination of the automatic warehouse and from the reduction of movements within the plant by the implementation of the supermarket. Also, the flow line permitted to produce more products with the desired quality and reducing the number of product rejections and therefore, the quantity of material waste generated. Hence, the positive effects coming from the flow layout regards the reduction of solid waste productions and energy consumption. Lastly, employees' innovative ideas were crucial in improving both economic and environmental performance.

In Company C, kaizen was indirect responsible and supporter of the positive effects that followed the implementation of the flow line. However, with the ideas arisen from the waste identification process, by the means of the kaizen events and kaizen journals, the company reduced punctual solid waste generation and energy consumption. Also got from the employees' innovative ideas to adapt in the workplace and improve efficiency.

The adoption of the "zero defects" project required starting several additional actions for the transformation of the company into a real lean enterprise. Among the most important and priority for the company was the one related to the implementation of the Total Productive Maintenance, 5S and PDCA approaches, that needed a cultural change and were essential for the success of the entire lean transformation and for enabling continuous improvement. After the implementation, the performance of the production line was immediately impacted, and the reduction of rejections and solid waste was evident, enabled by the development of standards for basic maintenance and cleaning.

In addition, workers have been trained to take better care of equipment and machinery and have been sensitized to turn off all the machines when are not needed. In particular, after some kaizen events, it was decided to hibernate the machines between the end of a working day and the start of the next one, saving in this way hours of energy. Moreover, in the two days of the weekend the machines were turned off to avoid substantial waste of energy and air emissions. In this way, the plant obtained a notable air emissions' reduction and energy savings from (i) maintenance management inspired to TPM principles, (ii) managing appropriately the start and shutdown of installations and machinery, and (iii) from the use of changeover optimization (SMED) which reduces high waiting times. In this way the company recognized that was undergoing benefits in terms of cost, waste and pollution reduction and a better and longer life of the machines and facility.

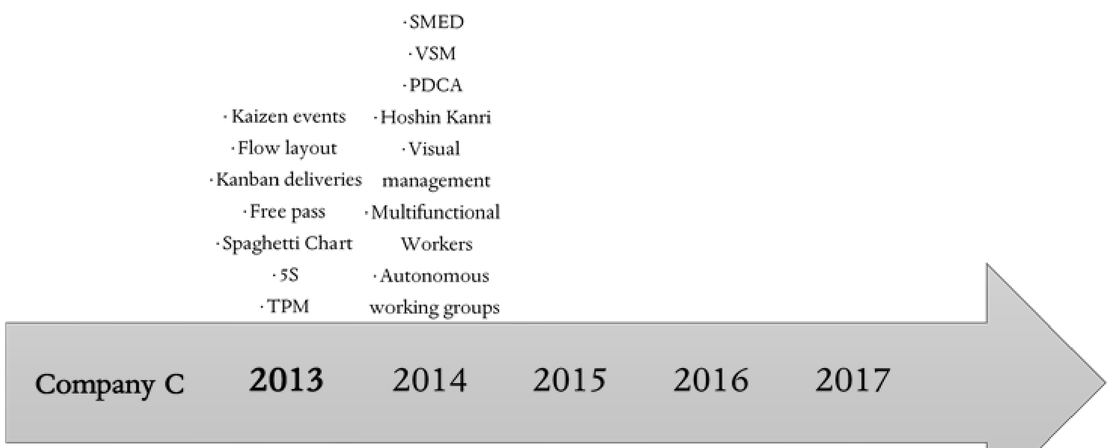
Overall, the firm underlined the importance of cleaning the machines, workplace and the plant in general. However, for this frequent activity under the rules of 5S and TPM, the use of water seems to be unavoidable. In fact, a negative trend in the use of water along the period analysed has been observed, nevertheless, the increase in water consumption was also due to some exceptional losses that have occurred in 2016 and 2017 as reported by the plant manager during the interview.

It is worth noting that Company C improved its environmental measures by the regular use of some of the most relevant lean practices (see Figure 23), and from the data provided by research participants it is possible to elucidate that:

- As seen for Company B, also Company C does not measure any indicators for more than a half of the environmental categories, using 4 out of 10 of the measures under analysis.
- For the energy use, air emissions and solid waste indicators the participants described a large reduction throughout the 5 years under examination with outstanding environmental performances during the first year after the lean implementation to then obtain irregular results tending to reduce these indicators. As was noted before,

the water used by the plant increased dramatically during 2016 and 2017 but due to exceptional circumstances.

- Most of the positive results obtained by Company C were obtained the year after the lean transformation to then worsen or reduce its environmental performance. In various measures, a decrease occurred again during the last year analysed.



Measure	Year 1	Year 2	Year 3	Year 4	Year 5	TPV
A. Energy use (GWh/millions of euros of turnover)	0,00%	-25,93%	5,00%	-9,52%	15,79%	-18,52%
E. Water use (m^3/millions of euros of turnover)	0,00%	4,52%	-9,19%	125,60%*	-8,97%*	+94,92%
F. Air emissions (tonnes/millions of euros of turnover)	0,00%	-18,31%	15,52%	-8,96%	-0,49%	-14,51%
H. Solid waste (tonnes/millions of euros of turnover)	0,00%	-10,53%	0,00%	5,88%	-8,33%	-13,16%

*Exceptional water consumptions

Figure 23. Evolution of lean and environmental performance in Company C

To conclude, the company experienced some negative results during the implementation of lean. To counter these problems, the firm remarks the usefulness of control and preventive tools provided by lean to identify "at the source" the wastes of the processes and, in particular, the environmental wastes.

5.2.5 Analysis of Company D (2013-2017)

Lean practices in Company D

The lean transformation process in Company D starts after various years of good economic results and the request of undergoing a strategic change towards efficiency, quality and flexibility. For this aim, the managers of Company D decided in 2013 to appoint the new kaizen manager who would supervise the implementation of the new philosophy and would be reference person to valuate and select priorities.

With the commitment of the company managers, the transformation starts with the “training phase” aiming to inform, motivate and familiarize employees to the new work routines. In this sense, during various kaizen events, were carried out presentations of the available lean practices and tools and their area of application; an introduction on the benefits of the lean transformation, as well as on its pre-requisites and boundary conditions; and finally, were completed awareness actions on the phenomenon of "waste", since eliminating waste must became one of the new major objectives. Subsequently to the implementation of lean, these meetings have been repeating routinely.

Once kaizen was introduced, the second lean practice implemented in Company D was VSM. At that time, the firm considered that VSM would give the opportunity to see where the waste is generated, and to focus the improvement activities that make the leap to quality of the company's performance. The organization of the plant employees in multifunctional groups was determinant for the lean implementation and particularly for the development of the current and future state maps; in Company D, for the implementation of the VSM, a specific group headed by a “value stream manager” was created.

Furthermore, the analysis of the processes carried out until that time showed the necessity of adapting the entire plant to a JIT logic. For that purpose, the company made mainly three important changes: the first was the implementation of a Kanban system and the use of the supermarket for the reduction of the takt time, the second consisted in following the rules of one-piece flow for the design of the plant layout and finally, the levelling of production (Heijunka) to achieve higher standards of flexibility.

To sustain all this system, it was also necessary to involve the suppliers in the new pull logic. For that reason, a system of Kanban deliveries with suppliers was implemented, by the means of the automatic emission of supply orders when a part was needed at a certain moment of requirement of materials. The firm makes sure that the materials are of the required quality, which is well known by the supplier companies. With this, Company D started achieving free pass of the supplies in the area of receptions and now avoids strict quality controls which are a well-known source of muda.

At the same time, the Company D realized the need to organize the plant in a more visible and orderly manner. The kaizen team noticed the existence of numerous objects and even useless machinery that had to be removed, and furthermore, they realized that if no measures were taken to solve this issue, the accumulation of needless materials and machinery could happen again and again. For this reason, and after some kaizen meetings, the teams agreed and approved the implementation of the 5S rules for all the production plant. As usual, this method was supported by other practices like standardization of the workplace functions, spaghetti chart and PDCA for an immediate and long-term success.

In addition, under the responsibility of the kaizen manager the maintenance of the machinery started to be managed by the TPM guidelines. The main reason for this change was the acquisition of new technological and expensive equipment, that according to the top management, needed a proper organization of planned, preventive and autonomous maintenance for a long-term durability. The results of the application of this technique were dramatically visible and losses associated with work stoppages, quality non-conformities and additional costs were reduced.

During 2017, in the Padova plant the kaizen office decided to perform some testing with quick changeover techniques (SMED) to obtain further takt time reductions and with the A3 Matrix technique (Hoshin Kanri) as a future method to clarify and communicate the strategic objectives of the firm to the employees.

In summary, throughout the period analysed Company D has shown a high commitment with efficiency and regularly applies practices from all the lean bundles under study (see Figure 24).

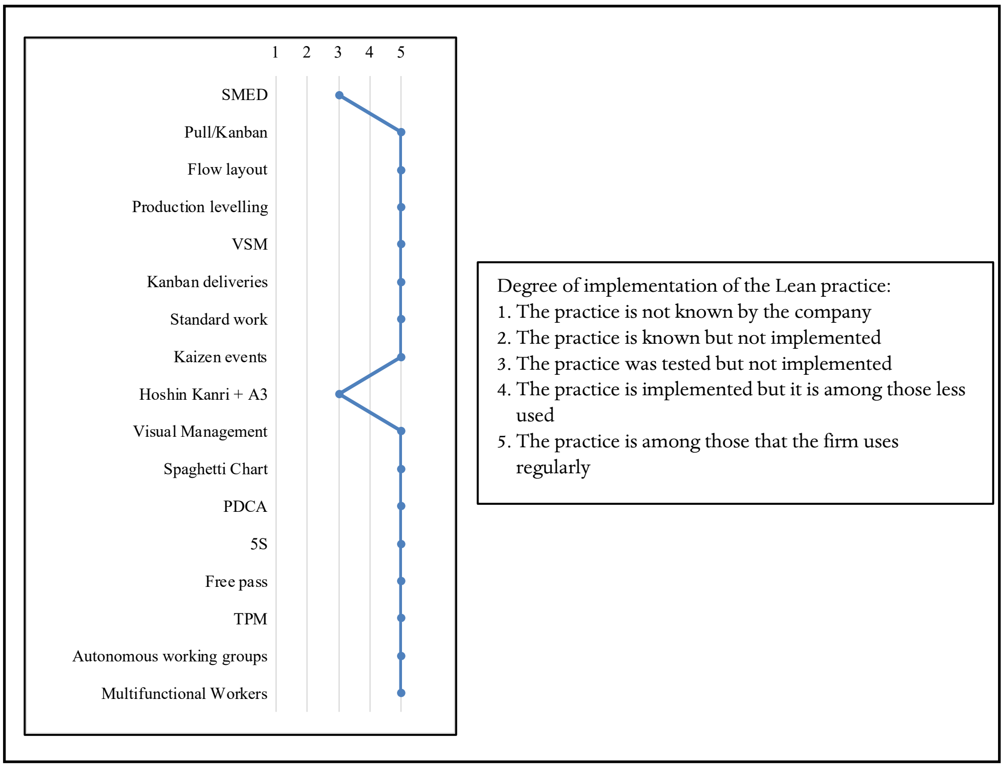


Figure 24. Lean profile of Company D

Impact of lean on the environmental performance of Company D

Since its foundation Company D develops solutions based on energy savings and, both company processes and products, reflect this approach that has always had respect for the environment.

From the data provided by Company D can be observed that the general trend of each environmental measure category during the period analysed is to increase its performance. However, the firm has achieved contradictory results in one of the indicators of each category measured. More in detail, during the period analysed, for each category the company measured various indicators (2 for energy use, 3 for air emissions, 3 for solid waste and 3 for hazardous waste) and, in summary, most of them were improved in the long-term, but for each category one of the measures considered eventually got worse (see Figure 26).

First, the methane gas consumed by the plant (energy used) has been decreasing during the period analysed, on the contrary the electric energy utilized has worsened during the same period which is contrary to the general strategy of the firm. This trade-off situation was produced mainly by using Kanban, flow layout and production levelling, which reduced considerably the stock within the factory, causing a minor use of energy since the warehouse was reduced. However, the use of Kanban systems, Kanban deliveries and the introduction of more robotics and automatic processes produced increments in the consumption of electric energy that, at any rate, are totally offset by the diminution of gas consumption, and even producing a positive balance in general.

Second, Company D performs measures every two years of the air emissions produced in compliance with the environmental regulations. Between 2013 and 2017, the emissions in terms of dusts produced and inorganic compounds released were dramatically reduced mainly due to the application of practices such as 5S, standard work and kaizen. The standardization and the solutions adopted in the kaizen events were of vital importance to for example, reduce the rework that caused this kind of wastes. Another solution implemented was the installation of new suction systems after the proposal of some workers, which reduced notably the emission of dusts. However, as was noted before one of the air emissions measure did not achieve positive results, this is the case of the emission of solvents. The continuous increase of this measure was produced due to the implantation of a new painting spray-based method, which is not actually related with the implementation of lean. To counter this problem, the company is studying various solutions proposed by the teams during the scheduled kaizen events.

Third, regarding to the solid waste produced, the company measured three parameters yearly: ferrous scrap (kg), plastic packaging (tonnes) and wooden packaging (tonnes). The ferrous scrap amounts were reduced due to the use of the standardization at the workplace, enabled by the new work techniques adopted under the rules of 5S and standard work. These were responsible of the elimination of defective parts and rework, which directly imply higher amounts of solid waste and energy. In addition, the plastic packaging waste (i.e. plastic wraps, boxes and pallets) was also reduced by Company D, this was produced mainly by the replacement of these by wooden packaging. The implementation of the free pass system, flow lines and the pull system (Figure 25) reduced the motion within the factories and because of this the total levels of packaging used were reduced. However, as expected by the company, the levels of wooden packaging waste increased over the years.

Figure 25. Flow lines in Company D

Fourth, the hazardous waste produced in terms of oil and refrigerant gas were reduced due to the application of the quality tools provided by lean. In this sense, standard work, 5S, visual management and, to a lesser extent, PDCA and kaizen events, were determinant to reduce rework and to do the operations right at the first time. These practices had an important effect on the levels of gas wasted and produced the total elimination of the oil wasted during the years analysed. On the other hand, the water used in the paint booth with the new painting process was doubled. This increment, however, is not linked with the implementation of lean in Company D.

All this previous information about lean practices and environmental measures in Company D is schematized in Figure 26. The following timeline starts in 2013 and finishes in 2017 outlining that:

- Company D only used 4 environmental categories out of the total under study during the period analysed. These categories contained more than one measure including 2 indicators for energy use, and 3 for each category air emissions, solid waste and hazardous waste.
- As was described before, most of the indicators reported by the participants experienced a large reduction during the 5 years under investigation. In addition, the use of electric energy remained essentially unchanged, and some of the measures

such as the emission of solvents, the wooden packaging wasted and the water used for painting got worse over the years, mainly not because of the effects of lean.

- Nevertheless, it is also important to highlight that Company D had very irregular consumptions during the period analysed and for this reason it was sometimes difficult to judge the evolution of the indicators. To overcome this issue, the conclusions were also based on the statements made by research participants.

It should be noted that the measures corresponding to the air emissions included in Figure 26 were measured every two years in compliance with the law. In addition, since the company did not report data of oil waste for the years 2014 and 2017, the variations were calculated with respect to the previous data available reflecting the decrease in oil waste reported by the interviewees.

In summary, the case of Company D is very particular and as was noted by the company, lean practices and in particular JIT practices, produce both negative and positive impacts on the environmental measures that the firm uses regularly. However, generally these negative effects of lean were overcome by the "good part" of the practices implemented. In the end, lean turned out to be beneficial for the entire process even if there are some conflictive activities like the Kanban delivery system, that turned out to be harmful for the environment and is currently a major concern for the firm that needs to be solved as soon as possible. Other process activities were also considered contaminant, but research participants confirmed that were not in direct connexion with lean practices.

Company D	2013	2014	2015	2016	2017
	· Kaizen events · VSM · Multifunctional Workers · Autonomous working groups · Pull/Kanban · Kanban deliveries · Flow layout · Production levelling	· Free pass · Visual management · 5S · Standard work · Spaghetti Chart · PDCA	· TPM		

Measure	Year 1	Year 2	Year 3	Year 4	Year 5	TPV
A. Energy use (KWh)	0,00%	1,44%	-1,27%	5,93%	-3,05%	+2,85%
A. Energy use (m^3 of methane gas)	0,00%	-14,41%	36,49%	-16,19%	-4,85%	-6,85%
F. Air emissions (mg/m^3 of dusts)*	0,00%	-	-32,66%	-	-82,21%	-88,02%
F. Air emissions (mg/m^3 of inorganic compounds)*	0,00%	-	79,21%	-	-76,99%	-58,77%
F. Air emissions (mg/m^3 of solvents)*	0,00%	-	20,96%	-	162,73%	+217,80%
H. Solid waste (tonnes of wooden packaging)	0,00%	64,87%	-8,91%	111,86%	-56,82%	+37,39%
H. Solid waste (tonnes of plastic packaging)	0,00%	-19,17%	7,67%	-9,59%	2,31%	-19,50%
H. Solid waste (kg of ferrous scrap)	0,00%	-32,32%	-30,08%	26,01%	-33,07%	-60,09%
I. Hazardous waste (tonnes of painting water)	0,00%	72,50%	-59,46%	29,82%	161,25%	+137,19%
I. Hazardous waste (tonnes of oil)**	0,00%	-	-30,06%	-13,45%	-	-39,47%
I. Hazardous waste (tonnes refrigerant gas)***	-	0,00%	-40,88%	-90,26%	850,00%	-45,31%

*Indicator measured every 2 years
** Second and fifth years data not available
***First year data not available

Figure 26. Evolution of lean and environmental performance in Company D

5.3 Cross-case analysis

After the within-case study analyses, the data collected from the companies were also compared through a cross-case analysis. The cross-case analysis allows for examination of key variables, themes and patterns across cases, as well as differences among cases (Voss et al., 2002; Yin, 1994; Eisenhardt, 1989).

In particular, from this analysis it is possible to identify the lean practices that these companies consider most important and their degree of implementation. On the other hand, this analysis allows to evaluate the most used environmental measures. Finally, it was deemed interesting to understand the relationships between lean practices and green performances to point out those practices which enable sustainable performance in the long-term.

Table 4 shows, for each of the 17 lean practices investigated, the number of firms that have implemented them at level 5 (the practice is among those that the firm uses regularly). Accordingly, the lean practices that are regularly used by all five companies are: flow layout, VSM, kaizen events, spaghetti chart and 5S. In addition, other practices such as Kanban, visual management, PDCA and free pass were used by 4 out of 5 of the companies analysed. Moreover, 3 out of 5 firms adopted production levelling, Kanban deliveries and multifunctional workers and 2 out of 5 implemented standard work techniques, TPM and autonomous working groups. Each of the remaining practices, i.e. SMED and Hoshin Kanri, was implemented by one of the five companies under study.

Lean practice	Number of companies using regularly this practice
Flow layout	5
VSM	5
Kaizen events	5
Spaghetti chart	5
5S	5
Pull/Kanban	4
Visual management	4
PDCA	4
Free pass	4
Production levelling (Heijunka)	3
Kanban deliveries	3
Multifunctional workers	3
Standard work	2
TPM	2
Autonomous working groups	2
SMED	1
Hoshin Kanri – X Matrix + A3	1

Table 4. Practices used within the companies

Regarding the environmental measures, Table 5 summarizes the information obtained from the case studies and shows for each firm analysed the general environmental results obtained during the period under study. As it is noted, the measures are classified according to whether they have been measured and depending on their overall result (essentially unchanged, improved and worsened). Please note the cells that show the result "improved" marked with an asterisk correspond to measures that have been assessed with 2 or more indicators and one of them has not been improved.

Environmental measure category	Company Pilot	Company A	Company B	Company C	Company D
A. Energy use	Essentially unchanged	Improved	Essentially unchanged	Improved	Improved*
B. Land use	-	Improved	-	-	-
C. Materials use	-	Improved	Improved	-	-
D. Toxic/hazardous chemicals use	-	-	-	-	-
E. Water use	-	-	Improved	Worsened	-
F. Air emissions	-	-	-	Improved	Improved*
G. Water pollution	-	-	-	-	-
H. Solid waste	Essentially unchanged	-	Improved	Improved	Improved*
I. Hazardous waste	Essentially unchanged	-	-	-	Improved*
L. Environmental impact of the product throughout the entire life cycle	-	-	-	-	-

*One of the measures included in this category did not improve

Table 5. Summary of environmental results over 5 years

Furthermore, Table 6 shows in the second column the number of firms which measure at least one indicator of each category mentioned in the first column. In this sense energy use is the only measure that is present in the five cases followed by solid waste, which was measured by four companies; other measures such as materials use, water use, air emissions and hazardous waste, were used by 2 out of 5 of the companies analyzed; land use was measured only by 1 of the 5 companies analyzed; and finally, for the rest of categories, the firms did not make assessments during the periods examined.

Environmental measure category	Number of companies measuring this category	Number of companies improving this category
A. Energy use	5	3
H. Solid waste	4	3
C. Materials use	2	2
F. Air emissions	2	2
E. Water use	2	1
I. Hazardous waste	2	1
B. Land use	1	1
D. Toxic/hazardous chemicals use	0	0
G. Water pollution	0	0
L. Environmental impact of the product throughout the entire life cycle	0	0

Table 6. Measures used within the companies analysed

The third column on the right in Table 6, specifies the number of companies that have improved these measures after having implemented lean practices. As can be seen, 3 out of 5 of the companies that assessed their energy consumption, improved this measure. Again, 3 out of the 4 firms that measured their solid waste production improved its value. In addition, for the materials use and air emissions measures, 2 out of 5 companies developed measures and both companies improved their environmental indicators. The cases of water use and hazardous waste are slightly different, since two of the five companies made measurements and only one firm for each measure obtained improvements. Only one evidence was found in the five cases for the land use measure, and this was increased after the implementation of lean.

Looking at Tables 4, 5 and 6, it should be noted that all the practices that were listed for this study were applied in at least one firm of the five under study, however for the environmental measures regarding the use of toxic/hazardous chemicals, water pollution and the impact of the product throughout its life cycle (EPA, 2007), no evidence was found between the five cases analysed.

At this stage, after having highlighted the level of implementation of the various lean practices and the types of environmental measures used by companies, in the second part of the cross-case analysis it will be highlighted the possible relationships between lean practices and the improvement of green measures. Accordingly, it is possible to compare the evidences found for the energy use (Figure 27), solid waste (Figure 28), materials use (Figure 29) and air emissions (Figure 30) measures.

As was noted before, two of the companies that used the energy consumption measure did not improve their values, they remained constant, so it was not possible to consider them for this analysis. The same happened for the solid waste and the hazardous waste measures, which both remained constant in one of the firms analysed. On the contrary, it was possible to include solid waste in the cross-case analysis since three companies assessed and improved this measure. This did not occur with the hazardous waste category, as was only obtained a positive evidence from a single company. A similar thing happened with the water use measure, two firms carried out measures of this category, however, one of them improved its value and the other got it worse. In brief, these measures used by the firms under study (hazardous waste, water use and land use) were not considered for the cross-case because it was not possible compare the improving evidences at least between two companies.

For this purpose, the analysis started from the data outlined in tables 5 and 6, observing in particular the first four rows. With reference to the energy used, three companies out of the five that measured this indicator have stated that they have improved it (i.e. companies A, C and D). Figure 27 shows the common lean practices regularly used (level 5 in the lean profile) by the three companies.

A. Energy use improvement		
Company A	**Company D**	**Company C**
		SMED
Pull/Kanban	Pull/Kanban	
Flow layout	Flow layout	Flow layout
Production levelling (Heijunka)	Production levelling (Heijunka)	
VSM	VSM	VSM
Kanban deliveries	Kanban deliveries	
Standard work	Standard work	
Kaizen events	Kaizen events	Kaizen events
		Hoshin Kanri – X Matrix + A3
Visual management	Visual management	Visual management
Spaghetti chart	Spaghetti chart	Spaghetti chart
PDCA	PDCA	PDCA
5S	5S	5S
Free pass	Free pass	Free pass
	TPM	TPM
Autonomous working groups	Autonomous working groups	
	Multifunctional workers	Multifunctional workers

Figure 27. Lean practices that support energy use reduction

The observation of Figure 27 suggests that the lean practices that may support the energy use reduction are: flow layout, VSM, kaizen events, visual management, spaghetti chart, PDCA, 5S and free pass.

These practices usually produce reduction of the motion within the factory and an increment of environmental and efficiency awareness within the employees, reducing the energy consumption of the plant. Furthermore, Kanban, production levelling, Kanban deliveries, standard work, TPM, autonomous working groups and multifunctional workers were present in two of the three companies that reduced their energy consumption. These constituted weaker evidences but it was thought that were worth mentioning in this analysis.

Now turning the attention to the levels of solid waste generated, in the long term these were reduced in companies B, C and D. All these firms applied various practices from the JIT and

TQM lean practice bundles (Figure 28), these were: flow layout, VSM, kaizen events, spaghetti chart and 5S.

H. Solid waste improvement		
Company B	**Company D**	**Company C**
		SMED
Pull/Kanban	Pull/Kanban	
Flow layout	Flow layout	Flow layout
	Production levelling (Heijunka)	
VSM	VSM	VSM
	Kanban deliveries	
	Standard work	
Kaizen events	Kaizen events	Kaizen events
		Hoshin Kanri – X Matrix + A3
	Visual management	Visual management
Spaghetti chart	Spaghetti chart	Spaghetti chart
	PDCA	PDCA
5S	5S	5S
	Free pass	Free pass
	TPM	TPM
	Autonomous working groups	
	Multifunctional workers	Multifunctional workers

Figure 28. Lean practices that support solid waste reduction

Making the same analysis as before, when the number of rejections from production is reduced, because of the continuous quality improvement; and less packaging is used due to the reductions of movements within the factory, less solid waste is generated. Moreover, other practices regularly implemented but in two of the three firms that improved this measure were: Kanban, visual management, PDCA, free pass, TPM and multifunctional workers (see Figure 28).

Now referring to the third row of Table 6, the lean practices used regularly by the two companies (i.e. company A and B) that have reduced the use of materials are shown in Figure 29. Both firms use a set of practices from the JIT and TQM bundles, these are: pull/Kanban, flow layout, VSM, kaizen events, spaghetti chart and 5S. These practices mainly reduce rejections and waste from defects which imply a reduction of the rework. In addition, as a consequence of the continuous improvement and standardization enabled by these practices, the company is nearer to the "ideal" use of raw materials needed to produce a product.

C. Materials use improvement	
Company A	**Company B**
Pull/Kanban	Pull/Kanban
Flow layout	Flow layout
Production levelling (Heijunka)	
VSM	VSM
Kanban deliveries	
Standard work	
Kaizen events	Kaizen events
Visual management	
Spaghetti chart	Spaghetti chart
PDCA	
5S	5S
Free pass	
Autonomous working groups	

Figure 29. Lean practices that support materials use reduction

In relation to the fourth row in Table 6, the crossed evidences found in cases C and D are quite different from those presented above. Both firms applied practices regularly from the four lean bundles: JIT (flow layout and VSM), TQM (kaizen, visual management, spaghetti chart, PDCA, 5S and free pass), TPM and HRM (multifunctional workers). In this regard, these practices generally conducted to the reduction of motion, standardization achievement and continuous improvement beside a proper management of proactive and preventive maintenance. These actions altogether enabled the reduction of the air pollution in companies C and D and are outlined in Figure 30.

F. Air emissions improvement	
Company C	**Company D**
SMED	
	Pull/Kanban
Flow layout	Flow layout
	Production levelling (Heijunka)
VSM	VSM
	Kanban deliveries
	Standard work
Kaizen events	Kaizen events
Hoshin Kanri – X Matrix + A3	
Visual management	Visual management
Spaghetti chart	Spaghetti chart
PDCA	PDCA
5S	5S
Free pass	Free pass
TPM	TPM
	Autonomous working groups
Multifunctional workers	Multifunctional workers

Figure 30. Lean practices that support air emissions reduction

As final analysis, those practices which are present in all the companies that have improved at least one environmental category among all involved in the analysis are identified. These practices were named as "core practices" and are always present and regularly used within the firms that have improved their environmental measures. Only four firms were included in Figure 31 since Company Pilot did not have an actual improvement on its environmental measures.

As can be observed in Figure 31, the main shared practices enabling environmental performance among the cases studies were flow layout, VSM, kaizen, spaghetti chart and 5S. These practices are comprised within the JIT and TQM lean bundles and this fact gives further consistence to the statement that these two bundles are more environmentally sound and efficient than TPM and HRM bundles.

Environmental performance improvement			
Company A	**Company B**	**Company C**	**Company D**
		SMED	
Pull/Kanban	Pull/Kanban		Pull/Kanban
Flow layout	Flow layout	Flow layout	Flow layout
Production levelling (Heijunka)			Production levelling (Heijunka)
VSM	VSM	VSM	VSM
Kanban deliveries			Kanban deliveries
Standard work			Standard work
Kaizen events	Kaizen events	Kaizen events	Kaizen events
		Hoshin Kanri – X Matrix + A3	
Visual management		Visual management	Visual management
Spaghetti chart	Spaghetti chart	Spaghetti chart	Spaghetti chart
PDCA		PDCA	PDCA
5S	5S	5S	5S
Free pass		Free pass	Free pass
		TPM	TPM
Autonomous working groups			Autonomous working groups
		Multifunctional workers	Multifunctional workers

Figure 31. Core lean practices enabling environmental performance

To conclude, in this section was developed a cross-case analysis to highlight the key evidences and understand the general patterns across cases. These analyses developed in this part of the thesis complement the single evidences outlined for each company in the preceding section 5.2 and they will be compared in the subsequent chapter 6, dedicated to the discussion of the results.

Chapter 6. Discussion and conclusions

Once the cross-case analysis has been concluded, it is time to sum up the several results obtained from both theoretical and empirical parts of this thesis, to then explain in sections 6.1 and 6.2 the theoretical and empirical implications of them; describe in section 6.3 which were the limitations encountered, and which are the open research opportunities found; and finally, in section 6.4 underline the general conclusions of this research.

Based on the preliminary exploration of the research area described in chapters 2 and 3, and regarding the objectives and gaps of knowledge, the research questions proposed and addressed in this thesis were:

- RQ1: Do lean practices impact on environmental measures?
- RQ2: How do lean practices impact on environmental measures?

The answer to the first research question (RQ1) was originated after making a deep analysis of the extant literature. As was noted in section 3.1.4, most scholars demonstrate that lean leads to green and more specifically, helps creating a cultural background in companies that leads to environmental objectives such as waste elimination and pollution prevention, which are mandatory for environmental performance (EPA, 2003). Thus, the affirmation that lean leads to green is considered rightful by the majority of scholars and those organizations that are following a lean transformation process will improve resource efficiency and therefore will increase their ecological outcomes (King and Lenox, 2001).

In contrast, there are some existing divergences that may affect the environmental performance achievement in the lean process application, these are identified as trade-offs in literature.

Nevertheless, according to the existing literature, most of the lean practices might be favourable for the achievement of ecological objectives (Cherrafi et al., 2017b; EPA, 2007) and most of the environmental-improving practices can be comprised in the JIT and TQM lean practices bundles (Shah and Ward, 2003). In addition, the remaining bundles regarding HRM and TPM were not examined by an elevated number of publications relating them with environmental performance purposes. However, a few published researches suggest that these bundles may not affect negatively the environment and furthermore, propose that the practices comprised in these two bundles may have a positive influence on the environmental performance of firms (Garza-Reyes et al., 2018; Piercy and Rich, 2015; EPA, 2003; Florida, 1996).

The last analysis carried out within the SLR gives details about the effects of various lean practices on various relevant environmental measures, showing off effectively that lean practices mostly have a positive impact on the environmental performance of organizations, as was suggested by previous publications. This contribution may be useful to understand the order or priority of application of the practices to obtain specific environmental outcomes from lean production. Moreover, this examination gives light about which techniques shall be used by companies to increment specific measures, for example if a lean company has high air emissions, it should be advantageous to apply VSM if it is not already applied or even adapt it to unveil environmental opportunities and/or complement it with other practices like SCM, kaizen and 5S as well.

Thus, it can be concluded that the answer for the first research question (RQ1) is "yes", according to the great majority of the research documents analysed, lean practices impact on environmental measures and this impact may depend on the practices applied.

The answer to the second research question (RQ2) was addressed with the multiple case study developed in chapter 5 corresponding to the empirical part of this thesis. The single evidences obtained during the within-case analyses (see section 5.2) and the relationships obtained from the cross-case analysis (see section 5.3), built up the answer to the "how" of this second research question which is shown below these lines.

In fact, although the companies under study are increasing or decreasing their activity, after the start of a lean transformation process, the general trend in the cases analysed is to improve and sustain their environmental measures in the long term. Moreover, making an overview of the implementation of lean in the sample of firms, the most regularly used lean practices are those belonging to the JIT (i.e. flow layout, VSM, Kanban) and TQM (i.e. kaizen, spaghetti chart, 5S) bundles which correspond to those most analysed in literature. On the contrary, the practices within the HRM (i.e. standard work, autonomous working groups) and TPM bundles, are among the least used by the set of companies investigated.

Regarding the environmental performance, the firms measured mainly their use of energy and their levels of solid waste generated. Other measures such as materials use, air emissions, water use and hazardous waste were also frequently utilized for assessments in the case studies. Nonetheless, energy use is the measure most used by companies. On one hand this depends on the "mandatory nature" of this input: the quantity of energy used must be paid to external energy companies and this makes it easy to measure the consumption in a simple and precise way. On the other hand, the use of energy has important economic and environmental implications for companies. Secondly, the generation of solid waste within the plant is also another important measure featuring in the sample of companies. Again, something similar to what happens to the energy consumption, occurs to the water use measure, but since its value usually is not very significant for many companies only two firms made an annual monitoring of this indicator. To a lesser extent, as it is rather difficult to measure the use of materials accurately, this indicator was only assessed by two companies. The measures of toxic/hazardous chemicals, water pollution and the impact of the product throughout its life cycle were not utilized by the cases, this occurs maybe because of the difficulty for organizations to obtain measures of these indicators or because of their particular characteristics.

In brief, the most improved measures after the implementation of lean practices in these case studies are energy use, solid waste, materials use and air emissions. These are perfectly in line with the preliminary evidences obtained from the literature review analysis, expressing the relevance of the aforementioned measures in the assessment of the environmental effects of lean.

Then, the evidences obtained from the data of the five case studies analysed are outlined in Table 7, where the green coloured cells indicate that the practice in the row is correlated with the improvement of the measure in the column. Moreover, inside the cells are indicated the companies in which these relationships have occurred. Please note that Company Pilot was not included in Table 7, since none of its measures was improved during the period under study.

	A. Energy use	B. Land use	C. Materials use	D. Toxic-hazardous chemicals use	E. Water use	F. Air emissions	G. Water pollution	H. Solid waste	I. Hazardous waste	L. Product's impact throughout the life cycle
SMED	C	-	-	-	-	C	-	C	-	-
Pull/Kanban	A, D	A	A, B	-	B	D	-	B, D	D	-
Flow layout	A, C, D	A	A, B	-	B	C, D	-	B, C, D	D	-
Production levelling	A, D	A	A	-	-	D	-	D	D	-
VSM	A, C, D	A	A, B	-	B	C, D	-	B, C, D	D	-
Kanban deliveries	A, D	A	A	-	-	D	-	D	D	-
Standard work	A, D	A	A	-	-	D	-	D	D	-
Kaizen events	A, C, D	A	A, B	-	B	C, D	-	B, C, D	D	-
Hoshin Kanri	C	-	-	-	-	C	-	C	-	-
Visual management	A, C, D	A	A	-	-	C, D	-	C, D	D	-
Spaghetti chart	A, C, D	A	A, B	-	B	C, D	-	B, C, D	D	-
PDCA	A, C, D	A	A	-	-	C, D	-	C, D	D	-
5S	A, C, D	A	A, B	-	B	C, D	-	B, C, D	D	-
Free pass	A, C, D	A	A	-	-	C, D	-	C, D	D	-
TPM	C, D	-	-	-	-	C, D	-	C, D	D	-
Autonomous working groups	A, D	A	A	-	-	D	-	D	D	-
Multifunctional workers	C, D	-	-	-	-	C, D	-	C, D	D	-

Table 7. Summary of the positive relationships between practices and measures

Below these lines the main evidences found during the case study analysis (Table 7) regarding the environmental effects of lean practices are summarized. First, the effects that were acknowledged by the companies within the sample are described, followed by the regularly utilized practices that contributed to achieve the listed environmental improvements:

- Energy use reductions: enabled among others by flow layout, VSM, kaizen events, visual management, spaghetti chart, PDCA, 5S and free pass. These practices usually produce a reduction of the motion within the factory and an increment of the environmental and efficiency awareness within the employees because of its focus in continuous improvement, reducing ultimately the energy consumption of the plant.
- Solid waste decreases: data suggests that these reductions were possibly facilitated by flow layout, VSM, kaizen events, spaghetti chart and 5S. When the number of rejections from production is reduced, because of the continuous quality and process improvements; and less not reusable packaging is utilized due to the reductions of movements within the factory, less solid waste is generated.
- Materials use diminutions: came from the application of pull/Kanban, flow layout, VSM, kaizen events, spaghetti chart and 5S. These lean practices mainly reduce defects and rejections probably originated by the motion and transportation of materials within the plant, and therefore entail a reduction of the rework. In addition, the continuous improvement and standardization enabled by these practices, helped to reduce the use of materials.
- Air emissions savings: mainly enabled by flow layout, VSM, kaizen, visual management, spaghetti chart, PDCA, 5S, free pass, TPM and multifunctional workers. These practices helped the reduction of motion, standardization achievement, appropriate monitoring, continuous improvement and proper management of proactive and preventive maintenance, which subsequently reduced of the air pollution levels.

Additionally, further evidences regarding other lean practices were found. For example, research participants suggest that TPM, SMED and production levelling benefit the reduction of the use of energy and the air emissions of the plant; standard work techniques may lessen the use of materials and the generation of solid waste within the entire process; and a free pass quality system, Kanban systems and visual management avoid defective parts from supplying, reducing again the use of materials and solid waste. In other cases, the establishment of a continuous flow and a well-designed Kanban system permitted notable water use reductions as it permitted a correct organization of the process. Again, these same practices by organizing the subdivisions of the plant also enabled outstanding reductions of the space occupied by one of the factories investigated, this permitted other subsequent improvements such as energy savings for example. In this sense, it is worth noting that the objective of shop-floor reduction is a well-known common point between the lean and green paradigms. In relation to the generation of hazardous waste; practices such as VSM, standard working techniques, kaizen events, visual management, PDCA and 5S were deemed useful by research participants for the correct identification of waste sources and proper handling of harmful materials wasted.

In this last analysis a graph was developed in Figure 32 with data from Table 7. In it, the "y" axis represents the number of environmental measures incremented out of the total 10 investigated. In turn, the "x" axis indicates the number of times a lean practice has been accompanied by positive environmental results in the whole sample. Therefore, at top right of the graph it is possible to observe those lean practices that may have a positive impact on a high number of environmental measures and had a higher frequency of occurrence in the sample. These practices are flow layout, VSM, kaizen, spaghetti chart and 5S; and are coherent with the "core practices" showed in Figure 31.

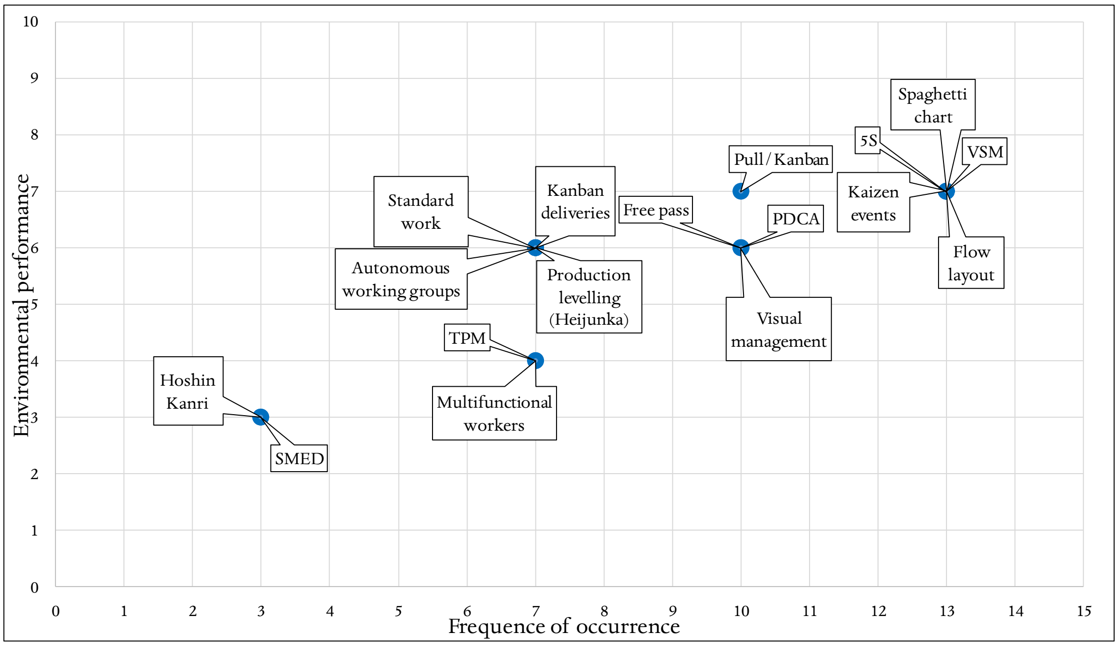


Figure 32. Importance of the lean practices for the environmental performance achievement

Therefore, synthesising the data of each of the companies analysed, as it is revealed above, most of them using lean practices have made it possible to improve most of their environmental performance measures. However, during the interviews a few exceptions were identified by research participants. Consequently, some of the firms investigated obtained undesired results:

- Company Pilot declared environmental direct benefits from the implementation of lean practices, but in contrast the long-term trend of the environmental measures remained constant due to factors not related to the lean practices' implementation and utilization.
- A contrary situation to the previous one happened in Company A which declared that the energy consumption was incremented by the implementation of Kanban deliveries with suppliers which lead to higher delivery frequencies and more movements inside the company. However, the "energy use" measure still improved its value due to other positive effects enabled by other practices.
- Again, Company B did not improve its "energy use" measure even if lean practices made great improvements in the energy savings of the company. Managers suggested that regular activities of the firm are very costly in terms of energy use and gas use and moreover, they noticed after some experimentations with Kanban

deliveries that this practice may be harmful for the environment in terms of energy consumption.

- Company C also noted a divergence during the implementation of lean in its production plant. Accordingly, for the frequent activity of cleaning under the rules of 5S and TPM, the use of water seems to be unavoidable and this reflected in a negative trend in the use of water along the period analysed.
- The case of Company D was rather particular since were found negative or constant trends on each of the environmental categories analysed, some of them caused by lean (mainly by Kanban techniques) and others not (new painting spray-based method). However, all these negative effects were countered by other positive effects of lean on relevant indicators included in the same categories.

In summary, after observing the negative environmental effects obtained from the research participants it can be suggested that Kanban deliveries was the main divergence found between lean practices and environmental performance. The use of energy derived from the motion and the frequent deliveries were pointed by companies A, B and D as the major problematic issues of lean for the achievement of green objectives. However, it is remarkable the importance of factors besides lean practices (i.e. spills, exceptional rejections and other incidents) to the assessment of the lean implementation's environmental performance as these factors can hide the real effects of lean, even if they are positive or negative.

Regarding to the evolution of the environmental measures among time within the firms under analysis, it has been already suggested that the general results were mainly optimistic for most of the categories measured. For companies A, B and C the best environmental results occurred immediately after the implementation of lean and being evident for the first three years for Company A, the initial two years for Company B and for the first and third years after the lean transformation for Company C. Furthermore, Company D obtained positive results almost during the entire period under analysis with some punctual exceptions. Alternatively, Company Pilot experienced an irregular trend where the last years compensated the effects of the first years alternating positive and negative results in the beginning and in the end of the period investigated. In this sense, the results are in line with Achanga et al. (2006) and Porter (1985) as the lean transformation process took more than a year within the cases, however the lean effect were mainly visible during the first years of implementation to then reduce their impact over time.

Nevertheless, it has been demonstrated that the combination of various lean practices usually produce strong positive results on certain environmental measures of firms, more than they would do separately. This partially occurs due to a "multiplier effect" that makes more environmental improvements from a pre-existent one. For example, if a company reduces its warehouse it will enhance immediately its land use indicator, and subsequently, will reduce for instance the energy consumption of the plant. Or if a firm builds upon the TQM bundle, the reduction of defective parts will lead to less material waste generated but also will entail less materials use and a reduced energy consumption. These further improvements are mainly caused by the identification of the so-called "blind spots" (EPA, 2003) that may appear during lean implementation. This means that in addition to the lean waste reduction and continuous improvement concepts, which frequently produce implicit environmental performance, there are further "hidden" opportunities to achieve this purpose.

Below in this chapter, the theoretical implications of the findings of this study will be discussed first, accompanied by providing the plausible explanations to the findings produced in this study. Consequently, the discussions about implications for practitioners are followed up. Another section identifies the limitations existed in this study and the recommendations for further research to finally end up with the conclusions of this thesis.

6.1 Theoretical implications

The scope of this thesis was to investigate the relationship between lean and environmental performance; first in a theoretical and wide-ranging point of view with an analysis of the relevant literature in the field, to then evolve in an empirical study aimed to investigate the impact that 17 important lean practices (i.e. SMED, pull/Kanban, flow layout, production levelling, VSM, Kanban deliveries, standard work, kaizen events, Hoshin Kanri – X Matrix, visual management, spaghetti chart, PDCA, 5S, free pass, TPM, autonomous working groups and multifunctional workers) have on 10 commonly utilised measures of environmental performance (i.e. energy use, land use, materials use, toxic/hazardous chemicals use, water use, air emissions, water pollution, solid waste, hazardous waste and environmental impact of the product throughout the entire life cycle).

The results obtained during this thesis fill the research gaps previously established in section 3.2 and extends the existing knowledge in the lean and green field by:

- Exploring and providing a better understanding of the effect that the implementation of lean manufacturing practices has on the environmental performance of manufacturing companies.
- Explaining the given relationships and effects of lean on environmental performance in the long term. No preceding studies had investigated all the same lean methods and environmental measures of performance included in this study in such a long period.
- Providing insights on new positive and negative environmental impacts of lean that have not been considered so far by literature.
- Assorting lean practices according to diverse criteria and providing evidences about which of them should be more environmentally friendly and which not. Moreover, this thesis provides insights about which practices are more likely to improve environmental performance in companies.
- Analysing the evidences found in the cases separately and altogether. During the development of the case studies was found out that frequently it is the combination various lean practices what makes the process significantly more environmentally friendly.

The theoretical-practical nature of this thesis enabled the obtention of relevant results that constitute important contributions for the lean and green field of knowledge. Moreover, mainly due to the empirical focus of this thesis, the managerial implications are multiple, and are described below in the next section.

6.2 Managerial implications

The findings of this study raise several managerial implications that are beneficial for company managers who aim to get a better understanding of the relationship and effect that lean practices have on the environmental measures of their operations. These are described below these lines.

Firstly, in an operational level, it was found before and during the development of the interviews and the case studies that the company managers interviewed were receptive to cooperate with this research, and they reacted positively and recognised the possibility of gaining greater environmental benefits from the application of lean practices. Thus, this research holds important implications for manufacturing managers, who can develop a richer consciousness on the relationship and effect that some of the most essential lean practices have on the environmental performance of their operations.

Secondly, in a more strategical level, the awareness on the effects of lean on the environmental performance of the company will assist practitioners and managers to make better decisions and formulate more effective strategies for simultaneous or sequential implementation of both lean and green paradigms. This will facilitate approaching sustainability objectives and for instance, compliance with environmental regulations.

Thirdly, this research should encourage business managers and practitioners to monitor in a proper way their operations and their environmental performance measures in order to identify those hidden opportunities for environmental performance enhancement, also known as "blind spots" in literature.

Finally, this study may help to increase both the image of the company and its corporate social responsibility since climate change, environmental degradation and natural resources scarcity are some of the major issues currently faced by humankind.

6.3 Limitations and suggestions for future research

Some limitations that limited the extent and scope of this research were encountered in the development of this research and must be acknowledged. These should be considered by upcoming studies to define the agenda for future research.

Firstly, during the literature review analysis, an elevated number of publications relating the HRM and TPM bundles with environmental performance objectives was not found. Various scholars in this field suggest that these lean bundles do not impact negatively on the environment (Garza-Reyes et al., 2018; Piercy and Rich, 2015; EPA, 2003; Florida, 1996). Special difficulties in observing the effects that these bundles have on environmental measures were found, especially regarding to the HRM bundle, thus, it might be interesting to seek more evidences about which practices comprised in these bundles may improve environmental performance in companies and in which measures the major effect occurs.

Secondly, the generalisability of any findings may be limited due to the presence of specific companies' cases. This study was carried out only within the boundaries of the manufacturing sector. Consequently, the results have some limitations as they cannot be easily generalized to other industry sectors and may require special attention to different practices and measures depending on the sector. More specifically, the cause-effect relationships between the use of a lean practice and the expected result of a specific environmental measure depends on the contextual conditions that are internal and external to the organizations. Thus, further research is required to complete this research and provide more insights of the impact of lean practices on the environmental performance of firms operating in other sectors, even in others beside industrial ones, such as healthcare, services, construction, logistics and so on. As the manufacturing sector, these are also under strong pressures to operate competitively and at the same time they must make sure the achievement of their quality objectives and legal standards about their responsibility to the environment. This research may help to develop these further studies since the research process described during this thesis is completely replicable.

Thirdly, this research used case studies and necessarily relied on participants' recall and memory of events in the time periods analysed. While this enabled participants to "look back" and consider the scale of the changes that had occurred, they were doing so with the advantage of retrospection and this could have affected their recall of events. To counter this limitation, archival data provided by the company were used to support the participants' description of the events. Regardless of this, it would be challenging to repeat a similar study in companies that are about to develop a lean transformation path and are concerned about environmental impacts of their operations but anyway, this type of research would be biased because managers would already try to pursue environmental efficiency objectives simultaneously with the lean transformation.

Then, within the research's questionnaire (see Annex 3) Likert scale questions were used to assess the level of implementation of the selected lean practices within the cases. This may be a limitation because restricts the ability of respondents to express opinions a priori, however it was easily overcome since the answers were also complemented with the qualitative answers and data provided by the respondents. As was stated during this thesis, the questionnaire was used mainly as a support to obtain clearly the preliminary answers from the respondents and these were deepened throughout the interview.

In addition to this, further difficulties were found during the data collection phase, these were:

- Often companies are mainly focused on the implementation of lean while they give less attention to the identification of environmental measures and their assessment, consequently some difficulties were found in collecting a complete set of data for each firm and during the entire time span of research.
- There is not a predefined list of measures, companies have developed indicators based on their characteristics and therefore, each of them used different environmental measures. To confront this issue, the macro-categories proposed by the EPA in 2007 were used and later, the environmental measures provided by the companies were framed in these categories.

To conclude, the whole of these limitations was overcome during the development of this thesis, however these are considered significant as they constitute an important opportunity to deepen in them in further research studies.

6.4 Conclusions

This thesis was aimed to analyse, through an empirical research, the impact of lean practices on one of the main dimensions of sustainability such as the environmental performance of the company. First, a literature review was developed to synthesise the main results so far achieved and to set up the subsequent empirical research. In particular, the systematic literature review has allowed to identify the preliminary evidences on the lean practices and environmental measures to be investigated. Then, a multiple case study analysis of five industrial firms that have started a lean transformation process was developed in order to examine in depth whether the implementation of various lean practices can impact the environmental performance measures of the company. Subsequently, both within-case and cross-case analyses have been carried out.

Beside the literature most scholars sustain that lean leads to green and moreover, facilitates the achievement eco-friendly objectives like waste elimination and pollution prevention, which are essential for the achievement of environmental performance aims (EPA, 2003). In fact, the affirmation that lean leads to green is considered truthful in literature and those businesses that are undergoing a lean transformation process may enhance resource efficiency and therefore should increment their ecological outcomes (Garza-Reyes et al., 2018; King and Lenox, 2001).

On the other hand, there are some existing divergences that may trouble the environmental performance achievement in the lean process application. These are known as trade-offs in literature and were highlighted in this thesis. The most conflictive bundle is JIT, that confronts low inventory levels with more transportation of goods, handling and packaging and consequently additional pollution and fewer environmental performance (higher energy use, CO_2 emissions or additional package for example). Furthermore, larger is the distance of transportation or more are the production lines involved, less environmentally friendly is the process (Venkat and Wakeland, 2006; Zhu and Sarkis, 2004).

Nevertheless, most of the lean practices are beneficial (Cherrafi et al., 2017b; EPA, 2007) and most of the environmental-improving practices can be framed in the JIT and TQM bundles. In addition, the bundles of HRM and TPM did not present an elevated number of publications relating them with environmental performance objectives. Literature sustains that these bundles do not affect negatively the environment (Garza-Reyes et al., 2018; Piercy and Rich, 2015; EPA, 2003; Florida 1996) but it might be interesting to know which practices comprised in these bundles mainly improve the environmental performance of the company and in which measures occurs the major impact.

As regards to the multiple case study analysis developed in this thesis, the results obtained are aligned with the preliminary evidences found in literature and provided new knowledge insights and further research directions for the lean and green field.

In accordance with the literature review analysis the empirical evidences suggested that most of the lean practices implemented by the five companies under analysis enabled significant environmental improvements in the long-term. Those practices that resulted to be the most effective to reduce the use of energy, solid waste, materials use and air emissions were mainly from the JIT and TQM bundles which correspond to the preliminary evidences found in literature. On the contrary, the practices within the HRM and TPM bundles, were those less utilized by the companies investigated and therefore, those that least impacted on the environmental measures.

In all companies the use of the lean practices has made it possible to improve environmental performance. However, there are a few exceptions that were described during this thesis, for example Company A and Company D declared that the energy consumption was incremented by the implementation of Kanban deliveries with suppliers and Company B pointed this divergence when testing this same practice, while Company C obtained positive outcomes applying it. In this sense, a possible trade-off was found regarding this lean practice which was not already acknowledged in literature and should be handled with attention by managers. To counter this problem, Company A proposed the use of the "milk run" technique in order to concentrate suppliers in the same geographical region and find the right trade-off between storage and transport costs to minimize movements, stock, energy and total cost in general.

Another example of divergence between lean practices and environmental performance was found in relation to the water consumption levels in Company C, which was noticed after the implementation of 5S and TPM. In this perspective, it is crucial for managers to assess and supervise carefully the impact of the lean practices implemented since the positive effects of a group of practices can hide the negative effects of one of them, obtaining less performance than their potential. For this purpose, Company C deemed useful the control tools provided by lean such as VSM, 5s and visual management among others, to prevent environmental wastes at the source.

Still from the empirical analysis, even if the results turned out to be positive or negative after the implementation of lean, it is obvious that other factors within the factory may affect the environmental performance of the company. Thus, if an undesired spill eventually occurs, the annual values will be probably changed. However, this research remarks again the importance of assessing the effects of lean on the environmental measures and the relevance of understanding the source of waste. Accordingly, this study intended to avoid the issues caused by punctual events with a long-term analysis.

Finally, from the evidences obtained during the case study analysis, even if research participants declare that they are environmentally concerned, take care of the environment and demonstrated a great interest in this research, they could do more in this regard. Since lean provides practices and tools that enable environmental performance going beyond economic results, organizations logically prioritize these last objectives and they do not develop a proper control system of their environmental effects in short, medium and long term. Consequently, from the academic field, it is important to empirically demonstrate the effects of lean and show managers and practitioners that obtaining economic and environmental performance is easier than expected, by the means of lean.

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Annex 1 – List of references within the SLR

Authors	Title	Year	Method	Publication
Aguado et al.	Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation	2013	Single or multiple case study	Journal
Bergmiller and McCright	Are Lean and Green Programs Synergistic	2009	Survey	Conference
Bergmiller and McCright	Lean Manufacturers Transcendence to Green Manufacturing	2009	Survey	Conference
Bergmiller and McCright	Parallel Models for Lean and Green Operations	2009	Theoretical model	Conference
Caldera et al.	Exploring the role of lean thinking in sustainable business practice: A systematic literature review	2017	Literature review	Journal
Calia et al.	The impact of Six Sigma in the performance of a Pollution Prevention program	2009	Single or multiple case study	Journal
Campos and Vazquez-Brust	Lean and green synergies in supply chain management.	2016	Single or multiple case study	Journal
Carvalho et al.	Modelling green and lean supply chains: An eco-efficiency perspective	2017	Single or multiple case study	Journal

Authors	Title	Year	Method	Publication
Chapman and Green	Leaning-toward-green	2010	Single or multiple case study	Journal
Cherrafi et al.	A framework for the integration of Green and Lean Six Sigma for superior sustainability performance	2017	Single or multiple case study	Journal
Chiarini	Sustainable manufacturing-greening processes using specific Lean production tools: an empirical observation from European motorcycle component manufacturers	2014	Single or multiple case study	Journal
Chugani et al.	Investigating the green impact of Lean, Six Sigma and Lean Six Sigma: A systematic literature review	2017	Literature review	Journal
Corbett and Klassen	Extending the horizons Environmental excellence as key to improving operations	2006	Literature review	Journal
Corbett and Wassenhove	The Green Fee: Internalizing and Operationalizing Environmental Issues	1993	Theoretical model	Journal
Cusumano	The limits of lean	1994	Theoretical model	Journal
de Freitas et al.	Impacts of Lean Six Sigma over organizational sustainability: A survey study	2017	Survey	Journal
Deif	A system model for green manufacturing	2011	Single or multiple case study	Journal

Authors	Title	Year	Method	Publication
Dhingra et al.	Does lean mean green?	2014	Literature review	Journal
Diaz-Elsayed et al.	Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments	2013	Single or multiple case study	Journal
Dornfeld et al.	Green Manufacturing: Fundamentals and Applications	2012	-	Book
Duarte and Cruz-Machado	Modelling lean and green a review from business models	2013	Literature review	Journal
Duarte et al.	Exploring Lean and Green Supply Chain Performance Using Balanced Scorecard Perspective	2011	Theoretical model	Conference
Dües et al.	Green as the new Lean how to use Lean practices as a catalyst to greening your supply chain	2013	Literature review	Journal
EPA	Lean and environmental toolkit	2007	Theoretical model	Report
EPA	The Environmental Professional's Guide to Lean & Six Sigma	2013	Theoretical model	Report
EPA	Lean Manufacturing and the environment	2003	Theoretical model	Report
Faulkner and Badurdeen	Sustainable Value Stream Mapping (Sus-VSM) methodology to visualize and assess manufacturing sustainability performance	2014	Single or multiple case study	Journal

Authors	Title	Year	Method	Publication
Fercoq et al.	Lean/Green integration focused on waste reduction techniques	2016	Quantitative experimental study	Journal
Fliedner	Sustainability: a new lean principle	2008	Theoretical model	Conference
Florida	Lean and green to move to environmentally conscious manufacturing	1996	Survey	Journal
Franchetti et al.	Lean and green: Industrial engineering methods are natural stepping stones to green engineering	2009	Theoretical model	Journal
Galeazzo et al.	Lean and green in action: interdependences and performance of pollution prevention projects	2014	Single or multiple case study	Journal
Garza-Reyes	Lean and green - a systematic review of the state of the art literature	2015	Literature review	Journal
Garza-Reyes et al.	The effect of lean methods and tools on the environmental performance of manufacturing organizations	2018	Survey	Journal
Gustashaw and Hall	From Lean to Green Interface, Inc.	2008	Single or multiple case study	Journal
Hajmohammad et al.	Lean management and supply management their role in green practices	2013	Survey	Journal

Authors	Title	Year	Method	Publication
Helleno et al.	Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes: Application case studies in Brazilian industry	2017	Single or multiple case study	Journal
Ho	Integrated lean TQM model for global sustainability and competitiveness	2010	Theoretical model	Journal
Ho	Integrated TQM for sustainable development	2010	Theoretical model	Journal
Hong et al.	Benchmarking sustainability practices evidence from manufacturing firms	2012	Structural equation modelling	Journal
Ioppolo et al.	Industrial Ecology and Environmental Lean management: lights and shadows	2014	Theoretical model	Journal
Johansson and Winroth	Lean vs green manufacturing	2009	Literature review	Conference
Kainuma and Tawara	A multiple attribute utility theory approach to lean and green supply chain management	2006	Single or multiple case study	Journal
King and Lenox	Lean and green? An empirical examination of the relationship between lean production and environmental performance	2001	Empirical analysis	Journal
Klassen and Whybark	Environmental Management in Operations: the Selection of Environmental Technologies	1999	Survey	Journal

Authors	Title	Year	Method	Publication
Kleindorfer et al.	Sustainable operations management	2005	Literature review	Journal
León and Calvo-Amodio	Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective	2017	Literature review	Journal
Miller et al.	A case study of lean, sustainable manufacturing	2010	Single or multiple case study	Journal
Mollenkopf et al.	Green, lean, and global supply chains	2010	Literature review	Journal
O'Rourke	The science of sustainable supply chains	2014	Theoretical model	Journal
Pampanelli et al.	A Lean and Green Kaizen Model	2011	Single or multiple case study	Conference
Pampanelli et al.	A Lean & Green Model for a production cell	2014	Single or multiple case study	Journal
Piercy and Rich	The relationship between lean operations and sustainable operations	2015	Single or multiple case study	Journal
Porter and van der Linde	Green and Competitive: ending the stalemate	1996	Theoretical model	Journal
Powell et al.	Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer	2017	Single or multiple case study	Journal

Authors	Title	Year	Method	Publication
Qureshi et al.	Sustainability a new manufacturing paradigm	2015	Literature review	Journal
Rothenberg et al.	Lean, green and the quest for superior environmental performance	2001	Survey	Journal
Simons and Mason	Lean and green: "doing more with less"	2003	Single or multiple case study	Journal
Sobral et al.	Green benefits from adopting lean manufacturing a case study from the automotive sector	2013	Single or multiple case study	Journal
Soltero and Waldrip	Using kaizen to reduce waste and prevent pollution	2002	Theoretical model	Journal
Taubitz	Lean, green & safe Integrating safety into the lean, green and sustainability movement	2010	Single or multiple case study	Journal
Torielli et al.	Using lean methodologies for economically and environmentally sustainable foundries	2011	Theoretical models	Journal
Vais et al.	Lean and green at a Romanian secondary tissue paper and board mill - putting theory into practice	2006	Single or multiple case study	Journal
Venkat and Wakeland	Is lean necessarily green?	2006	Simulation	Conference

Authors	Title	Year	Method	Publication
Verrier et al.	Lean and green strategy: the Lean and Green House and maturity deployment model	2016	Theoretical model	Journal
Verrier et al.	Combining organizational performance with sustainable development issues: the lean and green project benchmarking repository	2014	Single or multiple case study	Journal
Vinodh et al.	Tools and techniques for enabling sustainability through lean initiatives	2011	Theoretical model	Journal
Wiese et al.	The integration of lean, green and best practice business principles	2015	Single or multiple case study	Journal
Wong and Wong	Synergizing an ecosphere of lean for sustainable operations	2014	Single or multiple case study	Journal
Yang et al.	Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms	2011	Research database	Journal
Zhu and Sarkis	Relationships Between Operational Practices and Performance Among Early Adopters of Green Supply Chain management practices in Chinese manufacturing enterprises	2004	Survey	Journal
Zokaei et al.	Creating a Lean and Green Business System: Techniques for Improving Profits and Sustainability	2013	-	Book

Annex 2 – Basic environmental measures for lean enterprises

Relevant environmental measures extracted and adapted from the "The Lean and Environment Toolkit" published by the U.S. Environmental Protection Agency (EPA) in 2007.

	Category	Definition	Unit of measure
Input measures	Energy use	Any source providing usable power or consuming electricity: transportation and non-transportation sources	Specific to energy source such as BTUs or kilowatt hours, % reduction, energy use/unit of product
	Land use	Land covered by buildings, parking lots, and other impervious surfaces. Land/habitat conservation	Square feet, acres, square meters
	Materials use	Materials used (total or specific), ex. Packaging proportion of input materials that were recovered (vs. virgin materials)	Tons/year, pounds/unit of product, % materials utilization
	Toxic/hazardous chemicals use	Use of hazardous and toxic chemicals that are regulated or are otherwise concern	Pounds/year, pounds/unit of product, % reduction
	Water use	Incoming raw water, from outside sources, e.g., from municipal water supply or wells, for operations, facility use, and grounds maintenance	Gallons/year, % reduction, % recycled pounds priority chemicals/year, % reduced, % recycled

	Category	Definition	Unit of measure
Non-Product output measures	Air emissions	The release of any of the following: Air toxics - CAA 112b HAPs Carbon Monoxide Lead Ozone and its precursors, including: VOCs (volatile organic compounds), NO_x (nitrogen oxides), Ozone-depleting substances, PM10 (particulate matter), PM2.5 (fine particulate matter), Sulfur Dioxide, Greenhouse gases including Carbon Dioxide	Pound/year, tons/year, % reduction
	Water pollution	Quantity of pollutant in wastewater that is discharged to water source. Should include any substances regulated in NPDES permit. May include: Heavy Metals - Cu, Pb Hexavalent Chromium, Cadmium, Zn, Ni, Hg, Organic Pollutants and Pesticides, Conventional pollutants, e.g., oil and grease, BOD and suspended solids, and Nutrients - N, P Pathogens Sediment from runoff Wastewater discharge volume	Pounds/year, mg/L or % reduction

	Category	Definition	Unit of measure
	Solid waste	Wastes (liquid or solid) other than RCRA hazardous wastes	Gallons or pounds/year, % reduction, % recycled
Downstream/Product measures	Product impacts	Expected lifetime energy and water use, wastes (to air, water and land) from product use and disposal or recovery	Energy—BTU, kWh, mWh Water use– gallons Wastes– pounds, tons
Other measures	Money saved	Money saved in the reduction of materials or other changes in processes	Dollars saved
	Qualitative measures	Other environmental improvements that cannot be directly or accurately quantified. For example: implementing an Environmental Management System	Savings and environmental benefits from leaning out of permits/ Design for Environment/ Clean Production/ EMS implementation/ Extended Product Responsibility

Annex 3 – Questionnaire

Research project

Lean and Green

Dear Madam/Sir,

the University of Padova initiated a research project aimed to investigate whether the adoption of management practices related to "lean thinking" model (which, as we know, eliminate the so-called "muda" or waste: inventory, scrap, etc.) permit to reduce/eliminate consumption and emissions by promoting environmental protection as a last resort. The project is located within a wider international research and for some years the link between lean production and environmental protection is being investigated since important studies conducted by the United States Environmental Protection Agency (EPA) were released. The project aims to contact a sample of Italian firms known for starting the path of lean transformation and these are prompted to answer a series of questions about the lean practices that have adopted, on environmental measures that are measured and the progress of these measures over a given time horizon.

If you are able to participate in this research, we ask you to answer the following questions. All responses will be treated in an anonymous and aggregated way.

Section 1: Demographic data

Company name:
Plant of (indicate Municipality):
Sector of belonging:
Type of products made:
The plant makes products:

on sales forecast _______% of turnover
on customer's order _______% of turnover

The products offered to the market are:

catalogue standard ______% of turnover

catalogue standard with options ______% of turnover

designed to costumer specifications ______% of turnover

The production process is:

in line flow ______% of turnover

in batches for departments ______% of turnover

in islands or fixed place______% of turnover

Section 2: Lean practices

Starting year of the Lean transformation process ______________

Place equal to X the year of start of the Lean transformation path, given this year complete the following table (if X is after 2012 complete the table only for years until 2017).

	X	X+1	X+2	X+3	X+3	X+4
Turnover (millions of euros)						
Number of employees of the plant						

Indicate the relative degree of implementation for each of the following Lean practices/tools. Please give your perception of their importance and provide details about their implementation process.

	We do not know it	We know it but we do not apply it	We only did some experimentation	It is among those less used	It is among those that we use regularly
Single Minute of Exchange of Die (SMED)					
Pull/Kanban					
Flow layout					
Production levelling (Heijunka)					
Value Stream Mapping (VSM)					
Kanban deliveries with suppliers					
Standard work in the workplace					
Kaizen events					
Hoshin Kanri – X Matrix + A3					
Visual management					
Spaghetti chart					
PDCA (Plan Do Check Act)					
5S					

	We do not know it	We know it but we do not apply it	We only did some experimentation	It is among those less used	It is among those that we use regularly
Quality at the source (free pass)					
Total Productive Maintenance (TPM)					
Autonomous working groups					
Multifunctional workers					

Section 3: Environmental measures

For the different categories of environmental measures, specify if one or more measures are used and measured in the company: if so, describe the measure used.

Categories of measures	We do not measure the following measure for this category	We measure the following indicator for this category
Input		
A. Energy use		
B. Land use		

Categories of measures	We do not measure the following measure for this category	We measure the following indicator for this category
C. Materials use		
D. Toxic/hazardous chemicals use		
E. Water use		
Output		
F. Air emissions		
G. Water pollution		
H. Solid waste		
I. Hazardous waste		
L. Environmental impact of the product throughout the entire life cycle		

Regarding the same years considered in section 2 above, indicate the value of the environmental indicators measured in the company.

	X	X+1	X+2	X+3	X+3	X+4
Input						
A. Energy use						
B. Land use						
C. Materials use						
D. Toxic/hazardous chemicals use						
E. Water use						
Output						
F. Air emissions						
G. Water pollution						
H. Solid waste						
I. Hazardous waste						
L. Environmental impact of the product throughout the entire life cycle						

Section 4: Qualitative relationships between practices and environmental measures

Fill the cells of the following table with:

- 5 if you consider that the adoption of the practice of the line impacted **positively** the environmental measure of the column.
- 1 if you consider that the adoption of the practice of the line impacted **negatively** the environmental measure of the column.
- Do not fill the cell if you consider that there is not any relationship the practice of the line and the environmental measure of the column.

Please give your perception, justify and provide details, data and/or document demonstrating your answer and explain how this relationship occurred.

	Input					Output				
	A. Energy use	**B.** Land use	**C.** Materials use	**D.** Toxic/Hazardous chemicals use	**E.** Water use	**F.** Air emissions	**G.** Water pollution	**H.** Solid waste	**I.** Hazardous waste	**L.** Environmental impact of the product throughout the entire life cycle
Single Minute of Exchange of Die (SMED)										
Pull/Kanban										
Flow layout										
Production levelling (Heijunka)										
Value Stream Mapping (VSM)										

	Input					Output				
	A. Energy use	**B.** Land use	**C.** Materials use	**D.** Toxic/Hazardous chemicals use	**E.** Water use	**F.** Air emissions	**G.** Water pollution	**H.** Solid waste	**I.** Hazardous waste	**L.** Environmental impact of the product throughout the entire life cycle
Kanban deliveries with suppliers										
Standard work in the workplace										
Kaizen events										
Hoshin Kanri – X Matrix + A3										
Visual management										
Spaghetti chart										
PDCA (Plan Do Check Act)										
5S										
Free pass with suppliers										
Total Productive Maintenance (TPM)										
Autonomous working groups										
Multifunctional workers										