EVALUATING THE IMPACT OF LEAN PRACTICES ON ENVIRONMENTAL PERFORMANCE: EVIDENCES FROM FIVE MANUFACTURING COMPANIES

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Abstract

Previous evidence suggests that both lean and green production paradigms are focused on waste reduction and that lean practices help organizations to enhance sustainability objectives, and particularly environmental performance. However, the impact of lean practices on the environment is still unclear. This study therefore aims to analyse the relationship between lean and environmental performance in manufacturing with a strong empirical focus. This research was conducted in two main stages: first, an extensive review of the relevant literature was carried out, followed by a multiple case study analysis conducted in five manufacturing companies. Onsite data were collected from the firms during a five years' time span of research and developing semi-structured interviews. Furthermore, a cross-case analysis was carried out to map the results. Findings indicate that the environmental performance of the companies analysed is generally enhanced in the long-term after the implementation of lean. Moreover, the results from the multiple case study suggest that the environmental performance of the firms under analysis is mainly improved by using JIT and TQM practices in a lean transformation context. The research findings provide further results remarking the possible negative impact of practices such as Kanban deliveries, 5S and TPM on various environmental performance indicators.

Keywords: Lean production, Green production, Environmental performance, Practices, Measures

1. Introduction

The Lean production system (Womack and Jones 1996) is the most currently widespread production paradigm with its practices and methods initiated by Toyota (Forrester et al. 2010). This philosophy is based on the concept of "doing more with less" and it is settled in five principles: define value, map the value stream, create flow, establish pull and seek perfection. Moreover, due to the currently intense pressure to utilize the resources optimally, lean pursues the reduction of non-value-added activities in firms and sets up seven categories of waste, also known as muda (Ohno 1988).

Simultaneously, 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, these are: social, economic and environmental. Delimiting the sustainability concept to an environmental performance view, arises the Green manufacturing paradigm which "employs various green strategies (objectives and principles) and techniques (technology and innovations) to become more eco-efficient, this includes creating products/systems that consume less material and energy, substituting input materials (e.g. non-toxic for toxic, renewable for non-renewable), reducing unwanted outputs and recycling" (Deif 2011). In brief, firms have to be socially responsible and be aware of their implications for the environment.

In fact, the lean manufacturing system may be helpful for firms in the achievement of environmental objectives (Shashi et al. 2019; Carvalho et al. 2017; Piercy and Rich 2015) 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 (Sanchez Rodrigues and Kumar 2019; Sartal, Martinez-Senra, and Cruz-Machado 2018; Dües, Tan, and Lim 2013; Franchetti et al. 2009).

Nevertheless, the great majority of the empirical studies already developed are anecdotal (Shashi et al. 2019; Cherrafi et al. 2018), framed in the integration of lean-green joint models (Cherrafi et al. 2019; Cherrafi et al. 2017; Verrier, Rose, and Caillaud 2016), surveys (Huo, Gu, and Wang 2019; Garza-Reyes et al. 2018) or describing punctual application examples (Vinodh, Arvind, and Somanaathan 2011; EPA 2007), anyway, are not focused on a long-term or longitudinal analysis (Sartal, Martinez-Senra, and Cruz-Machado 2018).

Hence, during the study of these relationships in literature, first was identified the necessity for a clear identification of the effects of lean practices on environmental measures, which is an issue that requires further investigation as only a few empirical researches have addressed this topic (Dieste et al. 2019; Garza-Reyes et al. 2018).

Secondly, the studies of the relationships between lean and environmental performance do not usually take into consideration that the lean transformation process requires a medium-long term horizon to show its effects on firms' performances. This means that empirical research must analyse the relationships on an extended period (Dieste et al. 2019; Sartal, Martinez-Senra, and Cruz-Machado 2018).

Therefore, the originality of this paper lies in the examination of the links between lean practices and environmental measures found in five case studies during an extended time span. The study of these relationships is of great relevance to scholars in the operations and sustainability areas; as well as to managers and practitioners designing lean and environmentally responsible strategies. Moreover, the paper provides valuable information to enhance companies' image since firm's environmental impact is a problem progressively concerning customers, which are requesting cleaner products and reduced environmental damage in general.

Thus, the main research objective of this paper is to empirically analyse the relationship between lean and environmental performance. More specifically, the aim of this paper is threefold. First, it discusses whether firms which have applied lean principles and methods have improved or not their environmental measures. Second, the study intends to highlight which are the most improved environmental measures in firms that have started a lean transformation process. Third, which are the shared lean practices which better support environmental performance improvements.

As a starting point, Section 2 collects a brief review of previous published research on the relationship between lean manufacturing and environmental performance and presents the research objectives. Section 3 provides a description of the research approach and the methodology used, additionally, in Section 4 some descriptive data of the firms considered for the study are outlined. The empirical part of this paper starts with Section 5 providing the within-case analysis for each company and showing the empirical results emerged from the analysis of every firm. Then in Section 6, the cross-case analysis is developed. Finally, in Sections 7 and 8 the discussion of the results, conclusions and future research directions are described.

2. Literature review

Among the most relevant causes of the increasing importance of environmental performance, is the fast depletion of natural resources, climate change and environmental degradation which has forced companies to continuously improve their processes pursuing environmental efficiency strategies such as green production (Garza-Reyes et al. 2016). In fact, central to the definition of green production is the theme of waste

reduction management which is present in many approaches for reducing environmental impacts (Fercoq, Lamouri, and Carbone 2016). 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 (Verrier, Rose, and Caillaud 2016; Carvalho, Duarte, and Cruz-Machado 2011). This shared objective of waste reduction between both economic (lean) and ecologic (green-sustainable) approaches was the issue that originated this research.

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. Belhadi, Touriki, and El Fezazi (2019) sustain in their research findings that the benefits on green performance of some important lean tools such as Kanban, 5S, cellular manufacturing and set-up time reduction are widely demonstrated. Piercy and Rich (2015) analyse the sustainable benefits of lean operations beyond the environment including supply monitoring, transparency, workforce treatment and community engagement. Hajmohammad et al. (2013) confirmed the impact of lean and supply management on environmental performance, mediated by environmental practices. Franchetti et al. (2009) remark for example that reducing inventory as suggested by lean, companies will be able to improve both financial and environmental performance. Miller, Pawloski, and Standrigde (2010) and Vais et al. (2006) suggest that lean increases productivity and reduces defects, enhancing then better environmental performance at the source.

With a systematic literature review study, Chugani et al. (2017) stated that lean and six-sigma can support the conservation of resources, combat global warming and reduce energy consumption while Farias et al. (2019) with the same research approach and through a content analysis of the articles indicate that lean and green share common goals, to then identify the performance criteria and practices of lean and green and their relationships. The results obtained by Campos and Vazquez-Brust (2016) demonstrated that most of the practices within their study brought synergic results to lean and green performance and that these synergies can emerge spontaneously. The authors also noticed that, the strongest synergic results involved practices related to customers and suppliers as these actors act as bridges between the lean and green areas.

Using structural equation modelling (SEM), Shashi et al. (2019) showed a significant positive impact of both leanness and innovativeness on financial and environmental performance; while the results obtained by Cherrafi et al. (2018) using the same methodology reveal that lean practices such as Just In Time (JIT), set-up time reduction, cellular manufacturing, and waste elimination can significantly contribute to improve Green Supply Chain performance (including sustainability). Earlier, Hong, Jungbae Roh, and Rawski (2012) had already 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. Other authors such as Helleno, de Moraes, and Simon (2017) and Faulkner and Badurdeen (2014) propose the integration of sustainable indicators in the Value Stream Mapping (VSM) tool and suggest that this action led to efficient improvement actions in companies. As a final point, Yang, Hong, and Modi (2011) studied the impact of lean manufacturing and environmental management on the business and provided evidences about the importance of environmental management practices as a mediating variable to resolve the conflicts between lean manufacturing and environmental performance. In

short, the majority of literature suggests that lean techniques and tools are successful when used for reducing environmental impacts.

Conversely, other studies suggest that lean practices' implementation does not necessarily enable environmental performance in companies. Carvalho et al. (2017) developed a case study from an automotive supply chain and demonstrated that practices like "geographic concentration with suppliers" and "just-in-sequence" production may have an opposite effect on environmental performance. Sartal, Martinez-Senra, and Cruz-Machado (2018) found a major trade-off between JIT initiatives and the green goals, their study suggests that, the more the plant processes are JIT, the worse the environmental result will be. Dües, Tan, and Lim (2013) concluded after a literature review analysis that lean and green production are in some cases divergent and that CO_2 emissions in the supply chain are the major point of conflict where the two paradigms cannot be combined. In line with these results Sanchez Rodrigues and Kumar (2019) also argue that JIT objectives can conflict with environmental interests such as the reduction of CO_2 emissions. 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, Rothenberg, Pil, and Maxwell (2001) explain that goals like superior quality of products for example, may lead to greater consumptions in order to achieve the desired quality levels. Scholars such as Mollenkopf et al. (2010) also remark the benefits of understanding these "trade-offs", and their possible resolution may enhance environmental performance in the future. In summary, various important studies in literature acknowledge relevant contradictory impacts of lean practices on the environment, therefore more research is needed to study these relationships.

Regardless of the results achieved, most of the studies present in literature are rather general and focused on punctual analyses, not considering the environmental information of companies following the "lean transformation process", which usually takes a few years to show its effects. For example, Powell et al. (2017) adopted a single longitudinal field study approach at a Norwegian dairy producer over a six-month period. Furthermore, Campos and Vazquez-Brust (2016) developed a ten-month in-depth case study analysis of a Brazilian subsidiary of a large multinational company. Based on the empirical observation within five motorcycle companies, Chiarini (2014) observed and measured some relevant environmental measures before and after 6 months of the implementation of five lean tools and encouraged for the development of further research in this field. Other scholars such as Cherrafi et al. (2017) have studied the application of joint frameworks to guide companies to effectively integrate lean and green production systems, measuring before and 8 months after the implementation of the framework.

Separately, other studies carried out surveys for analysing punctual relationships within organizations. Garza-Reyes et al. (2018), investigate the impact of five essential lean methods on four measures of environmental performance. Huo, Gu, and Wang (2019) examine how lean and green processes in manufacturer-customer and manufacturer-supplier interfaces in the supply chain influence the triple bottom line (including environmental performance). Concluding, again using a survey Sartal, Martinez-Senra, and Cruz-Machado (2018) address the individual environmental impact of three pillars of lean production (i.e. JIT, Jidoka and respect for people) and determine that it would be interesting to use longitudinal case studies to analyse in depth the evolution of the factors involved in a lean-green transformation, not only to explore the "why" of the relationships proposed, but also to clarify the "how".

In addition to the previous evidences obtained from literature about the green aspects of lean production, their points in common and divergences, further investigation is needed

to know with more certainty how does lean practices affect in the firm's environmental performance (Dieste et al. 2019; Garza-Reyes et al. 2018).

3. Research methodology

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. Additionally, it permits the development of a cross-case analysis for comparing the relationship patterns emerged in each company.

Moreover, the case study methodology allows 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, Tsikriktsis, and Frohlich 2002; Yin 1994). In addition, the case study method is very appropriate 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, Tsikriktsis, and Frohlich 2002).

After having decided to employ the case study methodology, 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 improved at the same time (Voss, Tsikriktsis, and Frohlich 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).

The case studies were conducted in the same manner proposing the participants a structured questionnaire during the interviews to enable the aforementioned cross-case analysis, this was aimed to identify compatible patterns across the companies (Yin 1994; Eisenhardt 1989) and pursue internal validity of the findings (Voss, Tsikriktsis, and Frohlich 2002).

Consequently, for each company three half-day meetings were arranged in the following protocol:

- During the first meeting the research was introduced and the data about the lean implementation were collected. For this aim, 17 lean practices were selected using the well-known bundle model developed by Shah and Ward (2003): JIT-Just In Time (SMED-Single Minute of Exchange of Die, Pull/Kanban, Flow layout, Production levelling, Value Stream Mapping, Kanban deliveries), TQM-Total Quality Management (Kaizen events, Standard work, Hoshin Kanri, Visual management, Spaghetti chart, PDCA-Plan Do Check Act, 5S, Free pass), TPM-Total Preventive Maintenance and HRM-Human Resource Management (Autonomous working groups, Multifunctional workers).
- The second meeting was devised to know the environmental indicators measured by the company and their values along time. For this purpose, 10 environmental performance measures were chosen based on the recognised model proposed by the EPA (2007): Energy use, Land use, Materials use, Toxic/hazardous chemicals use, Water use, Air emissions, Water pollution, Solid waste, Hazardous waste, Environmental impact of the product throughout the entire life cycle.
- Finally, during the third meeting the collection of data about the relationships between practices and measures took place ending up with a discussion of the evidences with managers.

Once the research 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 taken were ready to be replicated with other firms.

During the data collection process, the so-called "triangulation between methods" was adopted 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, Choi, and Li 2011).

To conclude, after the interviews, the information and data gathered were processed in the university department as the subsequent data collection stage. Meanwhile, further follow-up questions were made by phone or were sent by e-mail. In all cases, the companies' request for confidentiality was fulfilled.

4. General overview of the firms under analysis

As was suggested by Eisenhardt (1989) and Barratt, Choi, and Li (2011) a range of 4-10 cases usually should be enough, also advised 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 set of five companies was chosen following some strict criteria and the whole of them respects 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 Statistical Classification of Economic Activities in the European Community (NACE), this section corresponds 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 since 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 analyse processes, practices and operational and environmental data; and that a full willingness of the company to make available their documents and historical data would exist. It was also guaranteed the availability to interview the managers.

In Table 1, various relevant and up-to-date data of the companies selected for the study are summarized.

Table 1. Main data of the companies considered

Case studies	Type of company (European NACE Code)	Size (employees)	Start of the lean transformation	Research participants interviewed
Company Pilot	Manufacture of non-domestic cooling and ventilation equipment (2825)	243 (2017)	2013	(1) Production and logistics manager (2) Chief of environment and security management
Company A	Manufacture of metal forming machinery and machine tools (2480)	58 (2017)	2013	(1) Lean manager (2) Head of the environmental and security service
Company B	Manufacture of agricultural and forestry machinery (2830)	42 (2017)	2010	(1) Kaizen promotion officer (2) Safety and environment officer
Company C	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines (2811)	373 (2017)	2013	(1) Production system coordinator (2) Prevention and security manager
Company D	Manufacture of non-domestic cooling and ventilation equipment (2825)	416 (2017)	2013	(1) Kaizen manager (2) Safety and environmental manager

5. Within-case analysis

The within-case analyses carried out in this section describe the main lean transformation activities involved, the environmental data provided by organizations and the impact of the practices on each company's environmental performance.

5.1. Case 1: Analysis of Company Pilot (2013-2017)

Lean practices in Company Pilot

In 2013, Company Pilot started 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 lean implementation process started by the establishment of the so-called kaizen promotion office. In it, 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. Over time the company has implemented practices from all the bundles under analysis excluding the TPM practices. Greater importance was given to the JIT bundle aiming to achieve a transition from batch production to one-piece flow and effectively apply production levelling.

In summary, the degree of implementation of the lean practices in Company Pilot is summarized in Figure 1, 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. In order to be recorded at level 5 of the Likert scale, the lean practices must have a formal plan of implementation and there must be specific and documented improvement workshops.

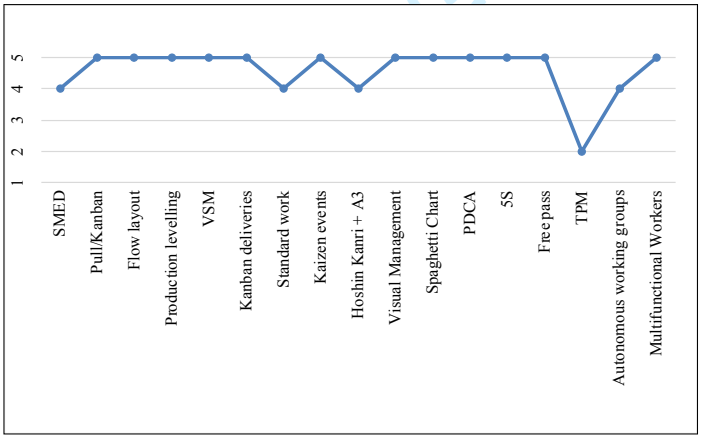

Figure 1. Lean profile of Company Pilot

Impact of lean on the environmental performance of Company Pilot

Company Pilot declared environmental benefits from the implementation of lean practices. For example, 5S was useful for the identification of damaged material and avoidance of more waste in storage areas and the Kanban "logistics train" arranged within the line helped to reduce motion and energy consumption within the plant. Practices such as VSM, 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.

However, the long-term trend of the measures is essentially constant as is outlined in Table 2. 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.

Table 2. Evolution of lean and environmental performance in Company Pilot

Company Pilot						
Time Frame	**Year 1 (2013)**	**Year 2 (2014)**	**Year 3 (2015)**	**Year 4 (2016)**	**Year 5 (2017)**	
Measure	Baseline	Percentage variation from year 1	Percentage variation from year 2	Percentage variation from year 3	Percentage variation from year 4	Overall Performance Variation (OPV) = percentage variation in the interval year 5 - year 1
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%
Lean practices implemented	• Kaizen events • VSM • SMED • Spaghetti chart • Flow layout • Production levelling	• Pull/Kanban • Kanban deliveries • Free pass • 5S • Standard work • Multifunctional workers • Autonomous working groups	• PDCA • Hoshin Kanri • Visual management			

The table 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, the environmental indicators measured by the company are listed, and for each one the performance variation year by year over the interval considered. The last column on the right outlines the overall performance variation (OPV) over the whole 5 years, calculated:

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

V_5 corresponds to the absolute value of the environmental indicator the fifth year and V_1 is the absolute 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, marked 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. Case 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 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.

During the five years period under analysis, the company concentrated mainly its efforts on the implementation of JIT and TQM practices, taking advantage of the benefits of the levelling of production and the creation of a 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.

Nonetheless, 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 the firm has done only some testing. In brief, the degree of implementation of the lean practices in Company A is summarized in Figure 2.

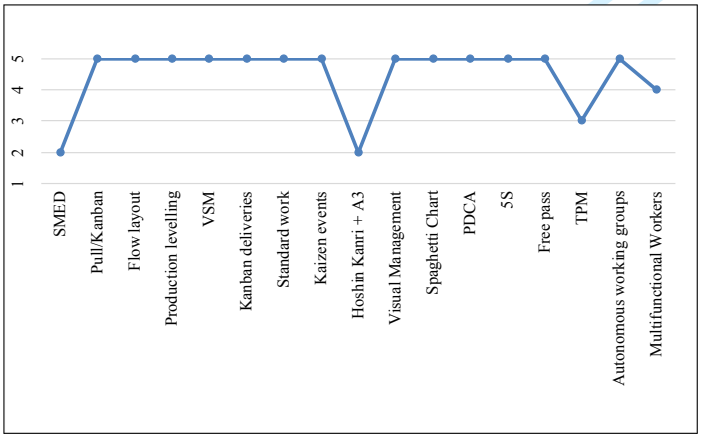

Figure 2. Lean profile of Company A

Impact of lean on the environmental performance of Company A

The same analysis as in Company Pilot was performed for Company A (see Table 3). In the case of Company A, Table 3 shows environmental benefits from the implementation of lean practices in the long-term. For example, the establishment of a continuous flow and a well-designed Kanban system permitted a correct organization of the process. These practices led to a proper organization of the subdivisions of the plant which produced outstanding reductions of the space occupied by the plant, this permitted other subsequent improvements such as energy savings for example.

On the contrary, these positive effects and in particular, those 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 same province. 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.

Table 3. Evolution of lean and environmental performance in Company A

Company A						
Time Frame	**Year 1 (2013)**	**Year 2 (2014)**	**Year 3 (2015)**	**Year 4 (2016)**	**Year 5 (2017)**	
Measure	Baseline	Percentage variation from year 1	Percentage variation from year 2	Percentage variation from year 3	Percentage variation from year 4	Overall Performance Variation (OPV) = percentage variation in the interval year 5 - year 1
A. Energy use (KWh)	0,00%	-2,39%	-5,13%	-1,84%	-0,25%	-9,33%
B. Land use (square metres 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%
Lean practices implemented	• Kaizen events • VSM • Autonomous working groups • Spaghetti chart • Flow layout • Pull/Kanban • Production levelling • Kanban deliveries	• Visual management • PDCA • Free pass • 5S • Standard work		• Multifunctional workers		

The lean implementation process and the environmental results of Company A can be summarized as follows:

- 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.

5.3. Case 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 and the advantages brought by the Kanban system were, among others, the simplification of the production processes.

It was determinant to develop a "kaizen approach" that makes it possible to progress step by step towards long-term objectives and during the kaizen events, which are developed regularly, was born the idea of implementing the 5S and PDCA rules together with weekly audits in the processes to guarantee the adequate development of the 5S; achieving continuous improvement in practice. Standardize operations was another priority for Company B, for this aim the actual times that the workers employ to perform their activities are collected and examined using time and motion methods then are modified and adapted following the 5S and kaizen directions.

In summary, the firm declared the difficulty to implement some of the practices: Company B is the one with less lean practices implemented, only 6 out of 17 were regularly used. Its lean profile is outlined in Figure 3.

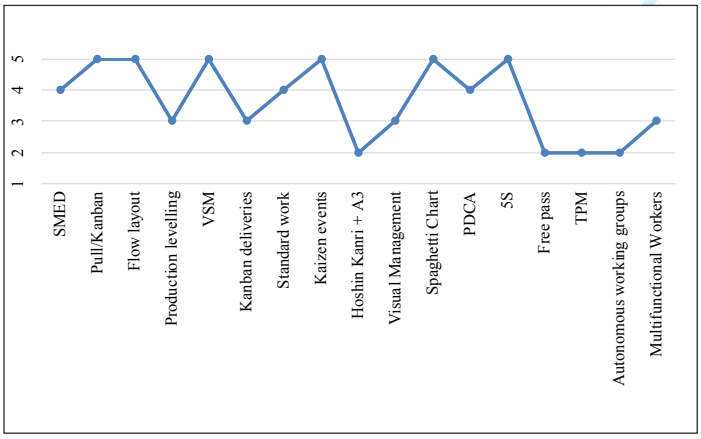

Figure 3. Lean profile of Company B

Impact of lean on the environmental performance of Company B

Among all the advantages deriving from the use of Kanban, the company observed a stock reduction of 90% and consequently a remarkable decrease in the use of packaging and energy. This was supported by a strict control of the stock and a regular use of reusable packaging like plastic pallets with standard dimensions which facilitated the movement of products within the plant.

The establishment of kaizen events, 5S and PDCA supported by weekly audits in the workplace sustain the continuous improvement approach, achieving more efficient results in the workstation and the easy identification and reduction of material waste.

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. Additional 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 more intuitive.

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. The firm is trying to find a solution to this issue making cost studies to decide whether make these pieces or buy them.

Additionally, during the period analysed various trials with Kanban deliveries were underwent. Company B noticed an increment of the movements resulting from the regular deliveries, which could represent a source of energy waste.

Table 4 shows the lean practices implemented and summarizes the evolution of the environmental measures developed with the data from Company B.

Table 4. Evolution of lean and environmental performance in Company B

Company B						
Time Frame	**Year 1 (2010)**	**Year 2 (2011)**	**Year 3 (2012)**	**Year 4 (2013)**	**Year 5 (2014)**	
Measure	Baseline	Percentage variation from year 1	Percentage variation from year 2	Percentage variation from year 3	Percentage variation from year 4	Overall Performance Variation (OPV) = percentage variation in the interval year 5 - year 1
A. Energy use (KWh)	0,00%	-7,02%	-5,78%	-3,85%	14,39%	-3,64%
C. Materials use (tonnes of materials)	0,00%	-7,02%	-2,29%	-2,92%	-23,37%	-32,42%
E. Water use (cubic metres/year)	0,00%	-31,81%	-10,14%	-5,70%	18,77%	-31,37%
H. Solid waste (tonnes of disposed materials)	0,00%	-19,42%	-11,01%	-4,77%	-16,99%	-43,31%

Lean practices implemented	• Kaizen events • VSM • SMED • Flow layout • Pull/Kanban	• 5S • Spaghetti chart • PDCA • Standard work				

From Table 4 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: in particular the use of materials, the water use 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.

5.4 Case 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.

During the five years analysed, Company C has implemented several important lean practices and the managers interviewed demonstrated their commitment towards continuous improvement and made a strong emphasis on the implementation of practices such as SMED, flow layout, 5S visual management and TPM. 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 further important practices like Kanban, production levelling and standard work. Figure 4 shows the degree of implementation of the various lean practices under study.

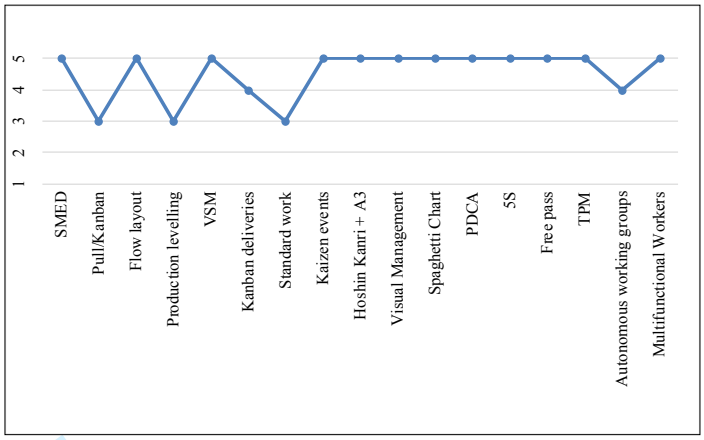

Figure 4. Lean profile of Company C

Impact of lean on the environmental performance of Company C

In Company C, following some changes in management and various kaizen events, a project to launch the lean transformation and establish a 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, which also permitted to reduce the number of product rejections and therefore, the quantity of material waste generated. Hence, the positive effects coming from the flow layout permitted the reduction of solid waste productions and energy consumption.

Through the kaizen events the firm was able to collect ideas about waste identification that enabled solid waste and energy consumption reductions. Even employees' innovative ideas were gathered to adapt the workplace and to improve efficiency.

After the implementation of the TPM, 5S and PDCA approaches, 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, after some kaizen events, it was decided to hibernate the machines between working days, saving in this way hours of energy. Moreover, in the weekends 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 by 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.

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 managers during the interview (see Table 5).

Table 5. Evolution of lean and environmental performance in Company C

Company C						
Time Frame	**Year 1 (2013)**	**Year 2 (2014)**	**Year 3 (2015)**	**Year 4 (2016)**	**Year 5 (2017)**	
Measure	Baseline	Percentage variation from year 1	Percentage variation from year 2	Percentage variation from year 3	Percentage variation from year 4	Overall Performance Variation (OPV) = percentage variation in the interval year 5 - year 1
A. Energy use (GWh/millions of euros of turnover)	0,00%	-25,93%	5,00%	-9,52%	15,79%	-18,52%
E. Water use (cubic metres/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%
Lean practices implemented	• Kaizen events • Kanban deliveries • TPM • Free pass • Spaghetti Chart • Flow Layout • 5S	• SMED • VSM • Hoshin Kanri • Visual management • Multifunctional workers • Autonomous working groups • PDCA				
*In 2016 and 2017 the firm experienced additional water consumptions due to an exceptional event						

It is worth noting that Company C improved its environmental measures by the regular use of some of the most relevant lean practices 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 achieved 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.

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.

5.5 Case 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.

With the commitment of the company managers, the transformation started with a "training phase" aimed to inform and motivate 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 and throughout the period analysed Company D has shown a high commitment with efficiency and regularly applies practices belonging to all the lean bundles (see Figure 5).

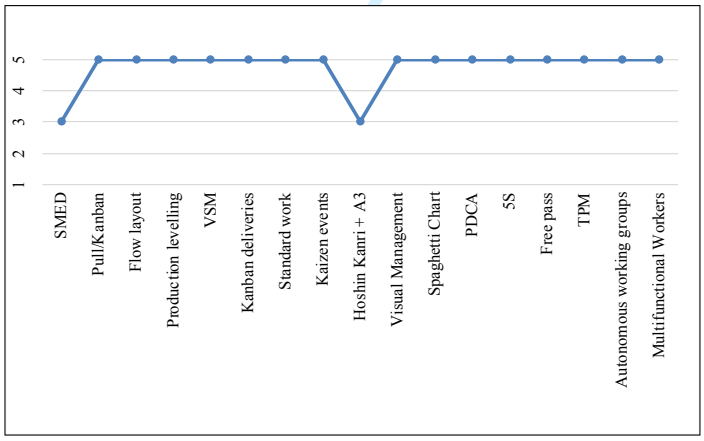

Figure 5. Lean profile of Company D

Impact of lean on the environmental performance of Company D

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. As highlighted in Table 6:

- 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.
- 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 were measured every two years in compliance with national regulations. 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.

Table 6. Evolution of lean and environmental performance in Company D

Company D						
Time Frame	**Year 1 (2013)**	**Year 2 (2014)**	**Year 3 (2015)**	**Year 4 (2016)**	**Year 5 (2017)**	
Measure	Baseline	Percentage variation from year 1	Percentage variation from year 2	Percentage variation from year 3	Percentage variation from year 4	Overall Performance Variation (OPV) = percentage variation in the interval year 5 - year 1
A. Energy use (KWh)	0,00%	1,44%	-1,27%	5,93%	-3,05%	2,85%
A. Energy use (cubic metres of methane gas)	0,00%	-14,41%	36,49%	-16,19%	-4,85%	-6,85%
F. Air emissions (mg/cubic metres of dusts)*	0,00%	-	-32,66%	-	-82,21%	-88,02%
F. Air emissions (mg/cubic metres of inorganic compounds)*	0,00%	-	79,21%	-	-76,99%	-58,77%
F. Air emissions (mg/cubic metres of solvent)*	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 of refrigerant gas)***	-	0,00%	-40,88%	-90,26%	850,00%	-45,31%
Lean practices implemented	• Kaizen events • VSM • Flow layout • Production levelling • Multifunctional workers • Autonomous working groups • Pull/Kanban • Kanban deliveries	• Free pass • Visual management • 5S • Standard work • Spaghetti chart • PDCA	• TPM			
						*Indicator measured every 2 years **Second and fifth years data not available ***First year data not available

In summary, the case of Company D is very particular and as was noted by the company, lean practices and especially 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, however Kanban, flow layout and production levelling were considered beneficial for the use of energy. Other process activities, such as the implantation of a new painting spray-based method and the change from plastic packaging to wooden packaging were also considered harmful and produced notorious increments in air emissions, wooden packaging and painting water use, but research participants confirmed that were not in direct connexion with lean practices. Nevertheless, practices such as 5S, standard work and kaizen were deemed useful for the reduction of the air emissions of the plant; 5S, standard work, free pass, flow lines and pull were responsible of the reduction of solid waste; and the hazardous waste produced in terms of oil and refrigerant gas were reduced due to the application of the quality tools provided by lean like standard work, 5S, visual management and, to a lesser extent, PDCA and kaizen events.

6. Cross-case analysis

After the within-case study analyses, the data collected from the companies were also compared through a cross-case analysis. In particular, from this analysis it is possible to identify the lean practices that these companies consider most important and their degree of implementation. This analysis also allows to evaluate the most used environmental measures in the cases. 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 7 shows, for each of the 17 lean practices investigated, the number of firms that have implemented them at level 5 (applied and used 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. The remaining practices such as SMED and Hoshin Kanri, were implemented only by one of the five companies under study.

Table 7. Practices used within the companies

Lean practice	Number of companies using regularly this practice (level 5)
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	1

Regarding the environmental measures, Table 8 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 two or more indicators and one of them has not been improved. Moreover, three categories of environmental indicators (i.e. Toxic/hazardous chemicals use, Water pollution and Environmental impact of the product throughout the entire life cycle) were not measured.

Table 8. Summary of environmental results over 5 years

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*
J. Environmental impact of the product throughout the entire life cycle	-	-	-	-	-

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

Table 9 synthetises the evidences of Table 8 and shows firstly for every environmental measure category the number of companies that have measured it. 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, air emissions, water use and hazardous waste, were used by 2 out of 5 of the companies analysed; land use was measured only by 1 of the 5 companies analysed; and finally, for the rest of categories, the firms did not make assessments during the periods examined.

Table 9. Measures used within the companies analysed

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
J. Environmental impact of the product throughout the entire life cycle	0	0

The rightmost column in Table 9 indicates for every environmental measure category the number of companies that have improved it after having implemented lean practices. 3 out of 5 of the companies that assessed their energy consumption levels, improved this measure. Moreover, 3 out of the 4 firms that measured their solid waste production improved its value. For materials use and air emissions measures, 2 out of 5 companies used these measures and both companies improved them. 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 7 and 9 it should be noted that all the lean practices selected for this study were applied in at least one firm of the five under study, while not all the environmental measures selected were used by the group of companies investigated.

After having highlighted the level of implementation of the various lean practices and the types of environmental measures used by companies, the second part of the cross-case analysis it is focused on the possible relationships between lean practices and the improvement of environmental measures. The evidences obtained from the five case studies are outlined in Table 10. The matrix crosses the lean practices and the environmental measures. In each cell are indicated only the companies that have improved the measure of the column and have implemented at level 5 the practice of the row. Please note that:

- Company Pilot was not included in Table 10, since none of its measures was improved during the period under study.

- Three categories of environmental indicators (i.e. D. Toxic/hazardous chemicals use, G. Water pollution and J. Environmental impact of the product throughout the entire life cycle) were not measured by any company and therefore are not recorded in Table 10.

Table 10. Summary of the positive relationships between practices and measures

		A. Energy use	B. Land use	C. Materials use	E. Water use	F. Air emissions	H. Solid waste	I. Hazardous waste
Number of firms which have measured this environmental category and have improved it		3	1	2	1	2	3	1
Firms that have implemented each lean practice at level 5	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 (A3)	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

In order to investigate if some lean practices better support the improvement of specific environmental measures and therefore to design a framework for building more robust patterns, the following considerations can be made by observing Table 10. Please, note that for this type of analysis only those environmental measures improved by two or more companies were considered, these have been highlighted in grey colour.

As regards the energy use measure, three firms (namely A, C and D) have measured this environmental category and have improved it. The lean practices regularly used (level 5 in the lean profile) by all these three companies are shown in Table 10 in correspondence of the cells highlighted in grey: 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.

Even for what concerns the solid waste environmental category, three firms (namely B, C and D) have measured and improved it. All these firms have implemented at level 5 the following lean practices: flow layout, VSM, kaizen events, spaghetti chart and 5S.
The first two practices belong to the JIT bundle and last three practices to the TQM bundle. 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.

Turning the attention to materials use, two firms (namely A and B) have measured this environmental category and have improved it. Both firms use regularly a set of practices from the JIT and TQM bundles, these are respectively: pull/Kanban, flow layout, VSM, kaizen events, spaghetti chart and 5S. These practices mainly reduce rejections and waste from manufacturing processes 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.

Finally, observing what have emerged with reference to the air emissions measure, two firms (namely C and D) have reduced them. The lean practices regularly used by these two companies belong to all bundles under analysis (JIT, TQM, TPM and HRM): flow layout, VSM, kaizen, visual management, spaghetti chart, PDCA, 5S, free pass, TPM and multifunctional workers. These practices generally lead to the reduction of motion, standardization and continuous improvement, and facilitate a proper management of proactive and preventive maintenance.

Summing up what has been stated so far, the lean practices comprised within the JIT and TQM bundles are more related with environmental performance improvements. Looking at the rows of Table 10, it is possible to identify a group of practices which is strongly correlated with the improvement of green indicators: these are the practices regularly used by *all* companies A, B, C and D:

- JIT bundle: Flow layout and VSM.
- TQM bundle: Kaizen events, Spaghetti chart and 5S.

This gives further consistence to the statement that these two bundles may have a stronger impact than TPM and HRM practices.

7. Discussion

The main results emerging from both within and cross-case analyses can be examined as follows.

The first research aim was to discuss whether firms which have applied lean principles and methods have improved their environmental measures. In spite of the mixed results and agreeing with previous studies (i.e. Shashi et al. 2019; Helleno, de Moraes, and Simon 2017), the general trend supports that lean improves and sustains the environmental measures in the long term. Only in one case (Company C) an environmental measure (water use) worsened. Company Pilot experienced a constant trend of environmental measures along the time span, so as Company B for one measure (Energy use). More in detail:

- Company Pilot declared environmental direct benefits from the implementation of lean practices. Nevertheless, the long-term trend of the environmental measures remained constant due to factors apparently not related to the lean practices' implementation.
- Company A declared that the energy use was incremented by the implementation of Kanban deliveries with suppliers. However, this measure still improved its value due to other positive effects enabled by other practices.
- Company B did not improve its "energy use" measure. Managers suggested that some manufacturing processes are very costly in terms of energy use. Moreover, the firm have made some testing with Kanban deliveries but similar to Company A this practice may be harmful for the environment in terms of energy consumption.
- Company C reported a negative trend with the consumption of water due to an exceptional event but also managers stressed that the adoption of 5S and TPM approaches may increase this measure due to frequent cleaning of the shop floor and machinery.
- The case of Company D was rather particular since they experienced a general positive trend but having measured several indicators for each category, some of them followed a negative or constant trend. Managers reported that the reason of this situation is linked to the use of some lean techniques such as Kanban and the contextual adoption of a new painting spray-based method.

In summary, these observations suggest that the adoption of Kanban deliveries is the most problematic practice for the achievement of environmental goals, this evidence is aligned with previous literature as JIT practices usually turn out to be the most problematic for green performance (Sartal, Martinez-Senra, and Cruz-Machado 2018; Carvalho et al. 2017). To partially overcome this situation, Company A suggested the use of the "milk run" technique in order to find the right trade-off between storage and transport costs to minimize movements, stock, energy and total cost in general.

As regards the second objective the study, 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. As was suggested, energy use is one of the most used measures by companies (Dieste and Panizzolo 2018). On one hand this depends on its "mandatory nature" as the amount of energy used must be paid to the electric companies. This makes it easy to measure the energy consumption in a simple and precise way. On the other hand, the use of energy has important economic and environmental implications for companies.

The generation of solid waste within the plant is also another important measure featuring in the sample of companies. Similar to what happens to the energy consumption, also in this case firms must pay external services to dispose these materials, therefore, it is easier

to record the annual performance. The difficulty of measure and the less relevance of some environmental measures are the main reasons why firms do not assess them.

The empirical results show that among the measured environmental indicators those which show the best performances are energy use, solid waste, materials use and air emissions.

The third goal of the study was to identify which are the shared lean practices which better support environmental performance improvements. The results show the following relations:

- Energy use reduction is enabled mainly by these lean practices: flow layout, VSM, kaizen events, visual management, spaghetti chart, PDCA, 5S and free pass.
- Solid waste lessening is enabled mainly by these lean practices: flow layout, VSM, kaizen events, spaghetti chart and 5S.
- Materials use diminution is enabled mainly by these lean practices: pull/Kanban, flow layout, VSM, kaizen events, spaghetti chart and 5S.
- Air emissions savings are enabled mainly by these lean practices: flow layout, VSM, kaizen, visual management, spaghetti chart, PDCA, 5S, free pass, TPM and multifunctional workers.

In summary, the lean practices belonging to the JIT and TQM bundles are the most regularly used and those which better support environmental performance improvements, these results are in line with preceding studies (Dieste et al. 2019). The contribution of practices within the HRM and TPM bundles seems much more limited. Previous studies such as Longoni and Cagliano (2015) with an inductive case study analysis demonstrate that cross-functional executive involvement and worker involvement positively affect the alignment of the HRM practices with environmental goals and practices. Besides, Garza-Reyes et al. (2018) with a survey study suggest that TPM and JIT may have a strong significance on environmental performance. On the other hand, Garza-Reyes et al. (2018) give less relevance to the effect of TQM practices (i.e. kaizen, jidoka) to obtain environmental results. Consequently, there may be reasons for further discussion of the analysis of the HRM and TPM bundles and their relationships with environmental performance as not many recent studies have addressed this issue.

In order to better analyse the data from the cross-case analysis (see in particular Table 10) the graph of Figure 6 was developed. 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.

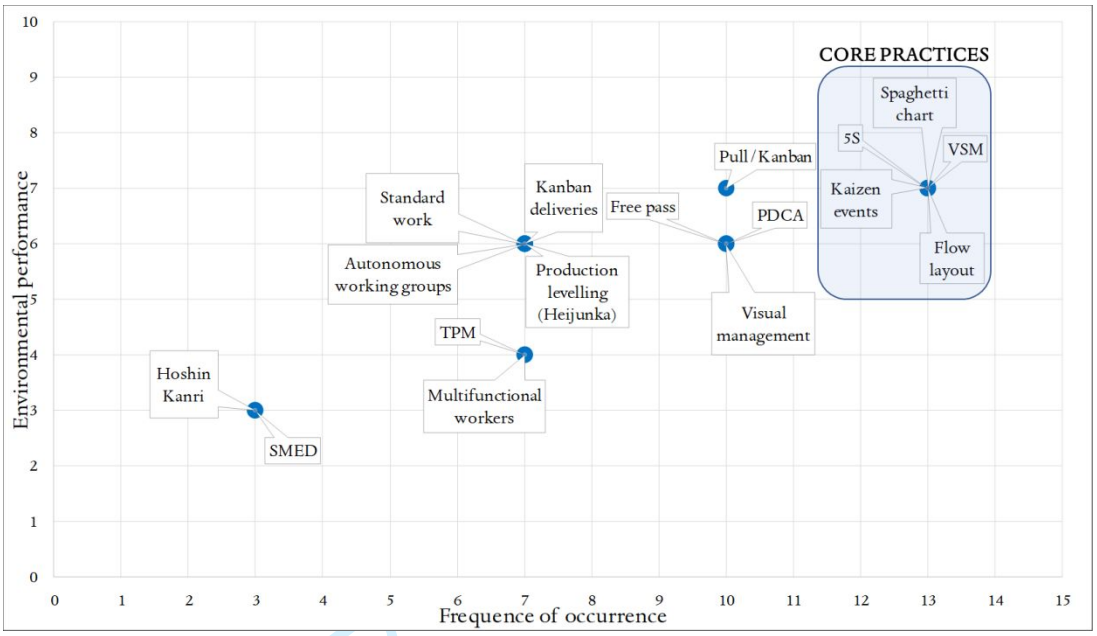

Figure 6. Relevance of lean practices for environmental performance improvements.

At the top right of Figure 6 it is possible to observe those lean practices that may have a positive impact on a high number of environmental measures and have a higher frequency of occurrence. These practices are flow layout, VSM, kaizen, spaghetti chart and 5S, and can be referred as "core practices".

8. Concluding remarks, limitations and future research

Alongside the results presented in previous sections, the research has highlighted other topics for discussion that could be the subject of future studies.

In studying the impact of lean practices on environmental performance it is important to consider a suitable time interval (Dieste et al. 2018). The effects of lean practices manifest themselves on horizons of years and not months since lean transformation represents a change of firm's strategy it usually lasts more than a year (Achanga et al. 2006).

Another point of reflection regards the mix of lean practices that better impacts on environmental performance. 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. 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. In line with this, from the data provided in this paper, a theoretical framework could be developed in order to facilitate the simultaneous implementation of lean and green strategies. Additionally, this framework could enable the transition from lean to green operations considering as a starting point the "core practices" identified in this study.

A final remark concerns the relevance of contingent factors which may affect the environmental performance of the company. For example, Company C experienced an increase in water use due to exceptional spills. Company D underwent extraordinary solid waste generation due to unexpected changes in wooden packaging. These factors can hide the real effects of lean, even if they are positive or negative. In order to grasp the

importance of these events, case study methodology should be preferred for conducting empirical research on this topic.

Besides, some limitations that constrained the extent and scope of this research were encountered in the development of this paper and must be acknowledged. First, 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. Second, 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. Third, there is not a predefined list of environmental measures, companies have developed indicators based on their characteristics and therefore, each of them used different measures.

Regardless of the limitations found, it would be challenging to repeat a similar study in companies that are about to develop a lean transformation process and are also concerned about their environmental impacts. However, this type of research could be challenging since managers and practitioners would already try to pursue environmental efficiency objectives simultaneously with the lean transformation. Moreover, the effects of JIT and TQM bundles on green performance have been deeply investigated in literature, but in this research it has also been demonstrated that there are still further research opportunities for studying the effect of the TPM and HRM bundles on environmental measures.

Additionally, during the interviews, managers recognized the possibility of gaining greater environmental benefits from the application of lean practices. Hence, this research holds important implications for manufacturing managers who can develop a richer consciousness on the effect that some of the most essential lean practices have on the environmental performance of their operations. In fact, 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 green performance enhancement. At the same time, this paper provides practical information to enhance companies' corporate image since climate change and environmental degradation are some of the major issues currently faced by humankind. This paper also provides for scholars points of discussion and further research and gives light to novel evidences about positive and negative effects of lean on the environment which can be particularly valuable for both researchers and practitioners. In fact, insights on new positive and negative environmental impacts of lean are provided and also practices which are more likely to improve specific environmental performance measures in companies are identified. Moreover, various lean practices that may have a positive impact on a high number of environmental measures and have a higher frequency of occurrence are also acknowledged from the data provided by the companies under analysis.

In conclusion, from the evidences obtained during the case study analysis, research participants declared that they were environmentally concerned and took care of the environment. However, the environmental performance must be accompanied by the economic performance. Actually, the economic results are the priority for companies and only once they are achieved the company will research environmental excellence. From the academic perspective, it is important to empirically demonstrate the effects of lean and show managers and practitioners that obtaining economic and environmental performance may be easier than expected by using the principles and practices provided by the lean philosophy.

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