

Impact of Lean Tools and Green Practices on Environmental Performance in Spanish Manufacturing Companies

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Abstract:

Purpose: This study analyses the impact of lean tools on environmental performance and examines whether combining them with green practices can generate positive synergies.

Design/methodology/approach: Using data collected in the 2022 European Manufacturing Survey of Spanish manufacturing companies, a correlation analysis between lean tools and green practices was carried out on the 86 companies surveyed. Furthermore, a Stepwise multiple linear regression was performed between the aggregated Lean and Green independent variables and the dependent variable environmental performance.

Findings: Findings of our study show that green practices, unlike lean tools, are not yet sufficiently developed in manufacturing industries to be meaningful in terms of environmental performance. In the proposed regression model, the aggregate variable Lean was found to have a significant relationship with environmental performance. The Green variable, however, was excluded from the model as it was not significant.

Research limitations/implications: Spanish companies should continue to work on the adoption of green practices in order to benefit in the future from the synergies between these practices and lean tools, as the literature has shown. Findings will be useful for managers in the manufacturing firms to make best strategic decisions. The current study is limited by the relatively small sample size.

Originality/value: To the best of the authors' knowledge, this study represents the first attempt to examine the combined impact of lean tools and green practices on environmental performance within the context of Spanish industry.

Keywords: lean tools, green practices, environmental performance, sustainability, survey, manufacturing industry

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1. Introduction

Waste is one of the primary concerns in the manufacturing sector, encompassing issues such as excessive transportation, nonessential inventory, avoidable motion or waiting times, overproduction, overprocessing and product defects (Bashar, Hasin & Adnan, 2021). Furthermore, the increase in industrial development in recent years has led to a number of negative environmental impacts such as increased greenhouse gas emissions and overuse of natural resources. This has forced companies to make their operations increasingly greener and more sustainable by adopting environmentally responsible initiatives in their production processes (Abilakimova, Bauters & Afolayan-Ogunyemi, 2024; Cherrafi, Garza-Reyes, Kumar, Mishra, Ghobadian & Elfezazi, 2018; Despeisse, Chari, González-Chávez, Monteiro, Machado & Johansson, 2022; Lartey, Yirenkyi, Adomako, Danso, Amankwah-Amoah, & Alam, 2020; Lucato, Vieira & Da-Silva-Santos, 2015; Vinodh, Ben-Ruben & Asokan, 2016; Yadav, Samadhiya, Kumar, Majumdar, Garza-Reyes & Luthra, 2023). The manufacturing sector is a major contributor and perpetrator of environmental pollution and poses a significant problem for environmental sustainability (Rathi, Kaswan, Garza-Reyes, Antony & Cross, 2022).

To counteract these effects, employing lean methodology leading to greater production efficiency (Hopp & Spearman, 2021; Mouzani & Bouami, 2019), together with the adoption of Green Practices (GPs) can help companies achieve greater economic and environmental performance (Amrina, Hidayatno & Zagloel, 2021; Garza-Reyes, 2015; Sanchez-Rodrigues & Kumar, 2019; Singh, Kumar-Mangla, Bhatia & Luthra, 2022; Udokporo, Anosike, Lim, Nadeem, Garza-Reyes & Ogbuka, 2020).

When the Kyoto Protocol came into force in 2005, it became a priority for manufacturing companies to find sustainable solutions for their production processes. The current business scenario requires systems that go beyond mere efficiency and aim to create eco-efficient systems with lower environmental impacts (Abreu, Alves & Moreira, 2017; Baysan, Kabadurmus, Cevikcan, Satoglu & Durmusoglu, 2019; Cherrafi et al., 2018; Dieste, Panizzolo, Garza-Reyes & Anosike, 2019; Orji & Liu, 2020).

This study assesses the current situation regarding the use of Lean Tools (LTs) and GPs in Spanish manufacturing companies, and examines how their relationship affects environmental performance measures such as energy, water and material efficiency. The study data was extracted from the 2022 European Manufacturing Survey (EMS).

This topic is particularly relevant as new laws fostering the circular economy, corporate social responsibility and sustainability, are forcing organizations to minimise waste that could damage the environment. Moreover, the recent rise in energy costs has meant that companies are having to resort to more cost-effective production methods. It is also worth pointing out that the manufacturing sector analysed accounts for 12% of Spain's GDP (European Commission, 2021).

The structure of the paper is as follows: Section 2 provides a review of the literature on lean tools and green practices, and introduces the research questions and theoretical. Section 3 outlines the methodology while Section 4 presents the empirical results. Section 5 offers a discussion of the findings, and Section 6 concludes the paper by highlighting the main conclusions, limitations and directions for future research.

2. Literature Review

2.1. Lean Tools

Lean management has its origins in the Toyota Production System, which was initially developed by Taiichi Ohno in the 1950s to enhance efficiency and eliminate waste in manufacturing processes (Martins, Fonseca, Ávila & Bastos, 2021; Mostafa, Dumrak & Soltan, 2013, Ar, 2025). This enables companies to gain a competitive edge over rivals (Belekoukias, Garza-Reyes & Kumar, 2014; Durakovic, Demir, Abat & Emek, 2018; Garza-Reyes, Parkar, Oraifige, Soriano-Meier & Harmanto, 2012; Jezierski & Janerka 2013; Jum'a, Zimon, Ikram & Madzik., 2022; Kumar, Vaishya & Parag, 2018; Salonitis & Tsinopoulos, 2016; Sumant & Patel, 2014; Womack & Jones, 1996).

Lean tools can be categorized as either internal or external to the organisation. Internal tools are associated with aspects such as processes and equipment, production planning and control, human resource management, and overall manufacturing management (Olhager & Prajogo, 2012). In contrast, external lean tools relate to the organisation's relationships with its suppliers and customers (Salonitis & Tsinopoulos, 2016). Internal lean tools

from the model proposed by Shah and Ward (2007) were used to carry out this study, as Losonci and Demeter (2013) point out that it is easier to manage the internal level of organisations than external factors.

Regarding the environmental dimension, some authors such as Thanki, Govindan and Thakkar (2016) or Inman and Green (2018) argue that the lean tool use is positively associated with GPs and environmental performance.

Furthermore, although Lean was not specifically developed to address sustainability issues, several authors have found that its principles and practices generate a number of environmental benefits through its intrinsic focus on waste disposal; however, there were concerns about the environmental consequences of enabling shorter inventories by providing more frequent transport trips (Abreu et al., 2017; Govindan, Azevedo, Carvalho & Cruz-Machado, 2014). Indeed, some authors argued that the positive effects of using lean practices on environmental and social dimensions have not yet been clarified (Dey, Malesios, De, Chowdhury & Abdelaziz, 2020; Dieste et al., 2019). Others mentioned that, while productivity gains were obtained as a benefit of implementing lean strategies, their use also led to efficiency problems due to increased energy consumption (Choudhary, Sangwan & Goyal, 2019; Kalemkerian, Santos, Tanco, Garza-Reyes & Viles, 2022).

Furthermore, lean tools can have positive effects on all pillars of sustainability, leading to lower production costs due to error prevention, which in turn reduces reworking and resource wastage (Iranmanesh, Zailani, Hyun, Ali & Kim, 2019; Jum'a et al., 2022; Solaimani & Sedighi, 2020; Teixeira, Sá, Silva, Ferreira, Santos & Fontoura, 2021). The first research question is thus posed.

RQ1 - Does Lean tool usage positively influence environmental performance in Spanish manufacturing companies?

2.2. Green Practices

GPs are measures and methods that lead to less environmental degradation by incorporating environmentally friendly technologies (Baum, 2021; Rathi et al., 2022; Zhu, Liang, Xiao, Xiao & Deng, 2023). Along these lines, implementation of GPs can help organisations improve their environmental performance whilst still meeting their economic goals (Azevedo, Govindan, Carvalho & Cruz-Machado, 2013; Cherrafi, Elfezazi, Chiarini, Mokhlis & Benhida, 2016; Cherrafi et al., 2018; Garza-Reyes, Villarreal, Kumar & Molina-Ruiz, 2016). Several authors note that implementing GPs bring both companies and the environment significant benefits by reducing environmental risks and impacts, while at the same time improving efficiency (Beckmann, Hielscher & Pies, 2014; Bendig, Kleine-Stegemann & Gisa, 2023; Cherrafi et al., 2018; Dubey, Gunasekaran, Papadopoulos & Childe, 2015; Govindan et al., 2014; Govindan, Azevedo, Carvalho & Cruz-Machado, 2015; Kumar et al., 2018; Lee, Ooi, Chong & Seow, 2014; Zhu, Sarkis, Cordeiro & Lai, 2008).

GPs mentioned in previous studies include “LCA” (Life Cycle Assessment), “ISO 14001” and “ISO 50001”, “3R” (Reduce, Reuse, Recycle), “Design for Environment” (DFE), “Environmental Emission Control” (EEC) and “Impact Remediation” (IR) (Banawi & Bilec, 2014; Cherrafi et al., 2018; Cheung, Leong & Vichare, 2017; Sartal, Llach, Vázquez & de Castro, 2017; Thanki et al., 2016; Zhu & Sarkis, 2004).

2.3. Lean-Green on Environmental Performance

This section examines the integration of LTs and GPs in the context of environmental performance. Through a literature review, the most relevant concepts were identified, and a literature search carried out to find relevant studies linking LTs and GPs to environmental performance. Keywords used were “lean tools”, “green practices”, “environmental performance”, “sustainability”, “survey” and “manufacturing industry”. Regarding studies similar to this paper, 16 articles were detected in the literature, and are detailed in Table 1.

Integrating GPs with LTs is an approach that may potentially encourage companies to become more proactive and sustainable, while at the same time enhancing their economic, social and environmental performance (Abreu et al., 2017; Abualfarraa, Salonitis, Al-Ashaab & Ala'raj, 2020; Bhattacharya, Nand & Castka, 2019; Inman and Green, 2018; Kalemkerian et al., 2022; Teixeira et al., 2021). This new “Lean-Green” approach focuses on avoiding using resources unnecessarily and reducing carbon emissions by delivering higher-value, less polluting products (Abreu et al., 2017; Dües, Tan & Lim, 2013; Leong, Lam, Ng, Lim, Tan & Ponnambalam, 2019; Lim, Lai, Wang & Lee, 2022). In short, the Lean-Green strategy enables companies to operate more effectively and efficiently (Kalemkerian et al.,

2022; Thanki & Thakkar, 2020). The majority of previous studies taking a Lean-Green approach point to efficient use of energy and resources and reducing waste in order to improve environmental performance (Abualfaraa et al., 2020; Bhattacharya et al., 2019; Carvalho, Azevedo & Cruz-Machado, 2010; Yang, Hong & Modi, 2011).

System	Studies	Lean Tools	
Lean	Chiarini (2014)	Kanban, VSM, 5S, Cell Manufacturing, TPM, SMED	
	Piercy and Rich (2015)	Kanban, 5S, Continuous Improvement (CI), SMED, TPM, Visual Management, Standard work	
	Powell, Lundeby, Chabada and Dreyer (2017)	VSM, SPC (Six Sigma)	
	Garza-Reyes, Kumar, Chaikittisilp and Tan (2018)	CI, VSM, TPM, Kanban, Visual Management, Takt-Time	
	Sartal, Martínez-Serna, and Cruz-Machado (2018)	Jidoka, JIT tools	
	Chen, Fortuny-Santos, Lujan and Ruiz-de-Arbulo-López (2019)	TPM	
	Baumer-Cardoso, Campos, Portela Santos and Frazzon (2020)	Kanban	
	Sartal, Ozcelik and Rodríguez (2020)	VSM, 5S	
System	Studies	Lean Tools	Green Practices
Lean-Green	Zhu and Sarkis (2004)	JIT tools	ISO 14001
	Banawi and Bilec (2014)	VSM, Six Sigma	LCA
	Thanki, Govindan and Thakkar (2016)	TPM, CI, 5S, SMED, VSM	ISO 14001, 3R, DFE, EEC, IR
	Cherrafi, Elfezazi, Govindan, Garza-Reyes, Benhida & Mokhlis (2017)	5S, CI, VSM, SMED, TPM, Kanban, Six Sigma, Vis. Manag, St. Work	ISO 14001
	Cheung, Leong and Vichare (2017)	Kanban, TPM, Cell Manufacturing, 5S	LCA
	Sartal et al. (2017)	Kanban, CI	Energy saving technologies
	Cherrafi et al. (2018)	JIT tools, SMED	LCA
	Inman and Green (2018)	Lean tools	Green practices

Table 1. Leading studies on the use of Lean and Lean-Green in relation to environmental performance

LTs are unable to quantify environmental impacts; however, GPs can bridge this gap by estimating the environmental impacts of waste generated (Cherrafi, Elfezazi, Hurley, Garza-Reyes, Kumar, Anosike et al., 2019; Rathi et al., 2022). Indeed, several authors suggest that Lean and Green are complementary when their strategy is based on waste reduction, takes a process-centred approach and has high levels of involvement and participation from the members of the organization (Dües et al., 2013; Fercoq, Lamouri & Carbone, 2016). In this regard, a series of conditioning factors for Lean-Green implementation were mentioned. These included restricted funds and the lack of involvement from senior management, as well as the lack of governmental support. Other obstacles to implementation mentioned in the literature are manufacturing employees' lack of knowledge and skills, their resistance to change and people's attitudes towards sustainable manufacturing (Cherrafi et al., 2017; Kalemkerian et al., 2022; Singh, Singh & Kumar, 2020; Singh et al., 2022; Teixeira et al., 2021; Tiwari, Sadeghi & Eseonu, 2020). Thus, the second research question is posed.

RQ2 - Does integrating lean tools and green practices generate a synergistic effect on the environmental performance of Spanish manufacturing companies?

3. Sample and Methods

3.1. Sample

The study data were extracted from the European Manufacturing Survey (EMS) on Spanish manufacturing companies during 2022. The German Fraunhofer Institute for Research and Innovation in Systems (ISI) coordinates the survey and seeks to standardize information on organizational and technological aspects of manufacturing companies in Europe. To meet the survey requirements, manufacturing companies must have a statistical classification of economic activities (NACE) code of 10-33 corresponding to the manufacturing sector and at least 20 employees on their payroll. According to the National Institute of Statistics of Spain, over 15,000 companies meet these requirements annually. Table 2 shows the distribution of data collected according to industrial sector.

Industrial Sector (Nace Code)	N (Respondents)	%
Agri-food (10-12)	17	19.77
Textile (13-15)	3	3.49
Chemical (20-21)	4	4.65
Electronics (26-28)	9	10.47
Automotive (29-30)	4	4.65
Industrial equipment (16-19, 22-25, 31-33)	40	46.51
N/S	9	1.47

Table 2. Distribution of data collected according to industrial sector

Regarding the data collection system, a structured questionnaire was distributed via email and post to the senior managers of 4,000 companies. One week after the initial distribution, follow-up phone calls were conducted to encourage participation. During the period analysed, 86 valid responses were obtained with a response rate of 2.15%.

Regarding the respondent profile, first-level executives such as manufacturing managers, operations managers and CEOs were selected due to their global perspective and access to comprehensive information on both industrial and commercial requirements. These individuals are generally considered more reliable sources of information compared to lower-level employees (Sartal et al., 2017).

3.2. Variables and Encodings

The variables selected for the study were 11 internal LTs, 8 GPs and 4 environmental performance variables related to the use of water, energy and materials.

Regarding internal LTs, the following tools from the model proposed by Shah and Ward (2007) were used: “Kanban,” “Specific lines,” “Visual management,” “SMED” (Single-Minute Exchange of Die), “5S,” “Standardized work,” “SPC” (Statistical Process Control), “Product and processes improvements,” “Quality control,” “Task integration,” and Total Productive Maintenance (“TPM”). In relation to GPs, the study by Thanki et al. (2016) was taken as a reference to analyse the use of environmental management systems such as “ISO 14001”, the 3Rs (reduce, recycle and reuse) and Environmental Management Systems (EMS) aimed at reducing environmental impact. The practices selected for the study were grouped into environmental management systems such as “ISO 14001” and energy management systems such as “ISO 50001”. In addition, practices to promote energy efficiency and circular economy such as “Kinetic energy recovery” (KIN.EN.REC.), “water recycling technology” (WAT.REC.TECH.), “waste separation technology” (WAS.SEP.TECH.), “product recycling technology” (PROD.REC.TECH.), “remanufacturing technology” (REM.TECH.) and “sustainability training” (SUS.TRAIN.) were also selected.

Lastly, the variables used for environmental performance were detailed. It is worth mentioning that studies by Zhu et al. (2008) and Inman and Green (2018) linked environmental performance to the capacity of manufacturing factories to reduce effluent and solid waste, air emissions, and to lower the use of toxic and hazardous materials. This aligns with the environmental performance metrics used in this paper. Additionally, a study by Garza-Reyes et al. (2018) related internal lean tools to variables on the efficiency of water, materials or energy. To measure environmental performance in the present study, survey questions were selected on whether the organisation used management tools to pursue efficiency in the following three areas: energy usage (Energy efficiency), water usage (Water efficiency), and materials usage (Materials efficiency). Furthermore, regarding materials reduction, a question was included about whether the organization employed technology that could significantly improve material efficiency (technological efficiency of materials).

Table 3 shows a detailed description of all variables for LTs, GPs and environmental performance.

Lean tools (LT)	Questions in the Survey (No = “0”; yes = “1”; not relevant = “-99”)
	Which of the following organisational concepts are currently used in your factory?
Standardised work	Standardised and detailed work instructions (e.g. standard operation procedures SOP, MOST)
Task integration	Planning, operation or control functions with the machine operator (task integration)
SMED	Fixed process flows to reduce set-up time or optimize change-over time (e.g. SMED, QCO)
Kanban	Production control following the Pull principle (e.g. KANBAN, Internal zero-buffer principle)
Specific lines	Customer- or product-oriented lines/cells in the factory (instead of task-/operation-structured shop floors)
5S	Method of 5S (workplace appearance and cleanliness) – 5S
SPC	Methods of operation management for mathematical production analyses (i.e. Six Sigma)
Visual management	Display boards in production to illustrate work processes and work status (e.g. Visual Management)
Quality control	Methods of assuring quality in production (e.g. Total Quality Management procedures)
Product and processes improvements	Plant employees lead product and process improvements
TPM	Methods of assuring quality in production (e.g. CIP, TQM, preventive maintenance) - TPM
Green Practices (GP)	Questions in the Survey (No = “0”; yes = “1”; not relevant = “-99”)
	Which of the following production control technologies are currently used in your factory?
ISO 14001	Certified environmental management system (as ISO 14001 or Eco-Management and Audit Scheme, EMAS)
ISO 50001	Certified energy management system (as ISO 50001)
Kinetic energy recovery	Technologies to recuperate kinetic and process energy (e.g. waste heat recovery, energy storage)
Water recycling technology	Technologies to recycle and reuse water (e.g. water recycling system)
Waste separation technology	Use of technologies to separate productive waste
Product recycling technology	End-of-life product recycling technologies (e.g. chemical or mechanical treatment)
Remanufacturing technology	Remanufacturing technologies (e.g. inspection, disassembly, cleaning, reprocessing, coating, repair with additives, etc.)
Sustainability training	Training for employees in sustainable production processes

Environmental performance (ENVPER)	Questions in the Survey (No = “0”; yes = “1”; not relevant = “-99”)
	Does your factory take any specific organizational measures to improve material, energy or water use efficiency?
Materials efficiency	Improved efficiency of material consumption
Energy efficiency	Improved efficiency of energy use
Water efficiency	Improved efficiency of water use
Technology efficiency materials	Are you using technology that significantly made more efficient use of materials when first implemented?
	Use of technology that improves efficiency of materials

Table 3. LT, GP and ENVPER variables description

It should be noted that all the variables mentioned are binary, so responses regarding their use or non-use were as expected, although another possible response was given. If companies considered that using these tools or practices made no sense within their organisation, they could choose the response “not significant” (NS).

To integrate LTs, GPs and ENVPER into a single variable that was relevant for each company, 3 new variables were created. These corresponded to the sums of the 11 LTs, the 8 GPs and the sum of the 4 company objectives favouring environmental performance, labelled “LEAN”, “GREEN” and “ENVPER”, respectively. To create the variables in all three cases, we discarded any binary variables in the calculation with the value NS, not taking it into account when calculating the company’s LTs and GPs. The equations (1), (2) and (3) below calculate the variables representing the percentage of LT, GP or ENVPER applied in each company, considering only those that were relevant to the company.

$$LT (\%) = \frac{\sum_{i=1}^{11} (Lean\ Tools_i, value \neq NS)}{Count_{i, value \neq NS}(Lean\ Tools_i)} \times 100 \quad (1)$$

$$GP (\%) = \frac{\sum_{i=1}^8 (Green\ Practices_i, value \neq NS)}{Count_{i, value \neq NS}(Green\ Practices_i)} \times 100 \quad (2)$$

$$ENVPER (\%) = \frac{\sum_{i=1}^4 (Env\ Performace_i, value \neq NS)}{Count_{i, value \neq NS}(Env\ Performance_i)} \times 100 \quad (3)$$

Through this definition of variables, the specific characteristics of each company were taken into account, considering the disparate sectors and sizes of the companies in the sample. This is one of the limiting factors of the study, as discussed below, but it is sufficient when it comes to assessing the impact of LTs and GPs on ENVPER.

3.3. Techniques Employed

Using the variables described above, firstly, a descriptive statistical analysis of the LT and GP variables was carried out, obtaining the results shown in Table 4.

To find out the relationship between LT and GP usage, a correlational study was carried out, as shown in Table 5.

This study follows on from Leksic, Stefanic and Veza (2020) research on using internal lean tools in the elimination of production waste, using the “stepwise” method to perform a multiple linear regression study, by using the same methodology relating the aggregate variables LEAN and GREEN to the aggregate variable ENVPER.

The stepwise regression method (in SPSS software) includes the selection of all available independent variables, then eliminating them one by one in line with their decreasing significance for the model proposed. This process of elimination continues to the point where eliminating a variable makes no significant improvement in the model. At

the end of this process, the resulting model contains all the significant independent variables needed to explain the dependent variable of the regression model. In this study LEAN and GREEN were taken as independent variables and ENVPER as a dependent variable.

4. Results

Before evaluating the regression model used to address the research questions (RQ1 and RQ2), the results the analysis of the LT and GP variables are taken as a reference, in which the percentage of use of the LTs “Task integration”, “Standardised work”, “Visual management”, “Quality control”, “5S” and “TPM” and the percentage of use of the GP “ISO 14001” are highlighted on one hand, and on the other hand, the percentage of use of the GP “ISO 14001”. Furthermore, the average use of LT is 55.54% compared to 34.31% for GP. These results are shown in Table 4.

Group	Variables	Use
Lean Tools	Task integration	71.05%
	Specific lines	40.28%
	Kanban	30.14%
	SMED	42.25%
	Standardised work	67.61%
	Visual management	68.06%
	Quality control	83.56%
	5S	65.38%
	SPC	22.22%
	Product and processes improvements	44.44%
	TPM	75.93%
MEAN	55.54%	
Green Practices	ISO 14001	52.86%
	ISO 50001	12.50%
	KIN.EN.REC.	25.37%
	WAT.REC.TECH.	35.82%
	WAS.SEP.TECH.	44.93%
	PROD.REC.TECH.	36.23%
	REM.TECH.	20.59%
	SUS.TRAIN.	46.15%
	MEAN	34.31%

Table 4. Results of the descriptive analysis of LT and GP usage

The two new grouped variables LEAN and GREEN show a significant correlation (see Table 5).

This relationship is also shown graphically in Figure 1.

The results of the analysis of the grouped variables LEAN and GREEN in relation to ENVPER, show that of the two independent variables LEAN and GREEN, the GREEN variable was discarded as it was not significant in explaining the model, thus leaving a model comprising the dependent variable ENVPER and the significant independent variable LEAN, which accounted for 25.6% of the variability of the ENVPER variable. Furthermore, a moderate correlation of 50.6% was observed between LEAN and ENVPER. The partial correlation of the excluded variable GREEN with ENVPER was 15.3%.

Lean-Green Correlation		Green	Lean
Green	Pearson correlation coefficient	1	0.502**
	Significance		<0.001
	N	75	75
Lean	Pearson correlation coefficient	0.502**	1
	Significance	<0.001	
	N	75	77

** Correlation is significant at the 0.01 level

Table 5. Correlation between LEAN and GREEN aggregate variables

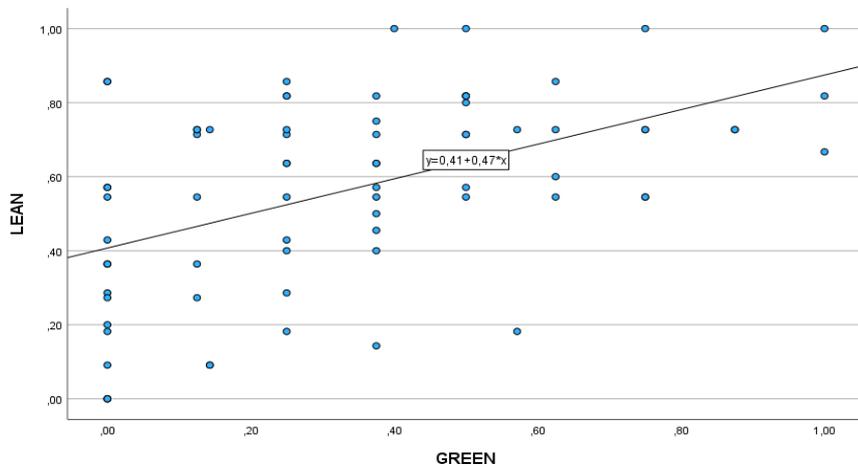


Figure 1. Correlation between LEAN and GREEN aggregate variables

Regarding the intensity of the relationship between the independent variables and the dependent variable (standardised Beta coefficient), we found that LEAN obtained 50.6% with ENVPER and 15.7% with GREEN. It is noteworthy that the relational intensity between GREEN and ENVPER was positive, although not significant, therefore the independent variable GREEN was excluded from the regression model.

The Durbin-Watson statistic gave a result of 1.924, thus ruling out any autocorrelation between the independent variables. Furthermore, the Levene test confirmed the non-significant values of both LEAN and GREEN, thus verifying the homoscedasticity of the independent variables, i.e. the equality of the variances of the errors between them.

Regarding the collinearity statistics, we observed that both the tolerance values (0.709>0.1) and the Variance Inflation Factor (VIF) (1.414<10) ruled out collinearity, thus ensuring the independence of the variables. Table 6 summarises the results of the model.

Predictor variable	R	R ² / R ² adjusted	Standardised Beta coefficient	Standard error	F	Significance	Durbin-Watson	Levene
Lean	0.506	0.256 / 0.245	0.506	0.33497	23.424	<0.001	1.924	0.168
Excluded variable	Beta	t	Partial correlation	Signification	Tolerance	VIF	-	-
Green	0.157	1.268	0.153	0.209	0.709	1.411	-	0.409

Table 6. Model of the aggregate independent variables LEAN and GREEN and the aggregate dependent variable ENVPER

This lack of collinearity ensured the independent variables stayed independent of each other. Collinearity of the variables could have biased the model and rendered it invalid. Furthermore, the fit tests performed on the proposed model, such as the coefficient of determination (R^2), Fisher's statistic (F) or the standard error and the robustness tests of the model, such as linearity, homoscedasticity, autocorrelation and collinearity, provided reliability and validity of the proposed model.

The statistical analysis of the data was carried out using the IBM SPSS Statistics v29 software.

5. Discussion

Regarding the first research question (RQ1), the results of the model (the standardised Beta coefficient, the coefficient of determination and the significance of the relationship between LEAN and ENVPER) show that LEAN positively influences ENVPER.

The model also showed that a significant relationship between the LEAN variable and the ENVPER variable prevailed over the non-significant GREEN variable.

Furthermore, the model showed that a significant relationship between the LEAN variable and the ENVPER variable prevailed over the non-significant GREEN variable. Notably, the intensity of the relationship (standardised Beta coefficient) stood out, with the LEAN variable obtaining a value over three times higher than GREEN in its relationship with ENVPER (0.506 for LEAN, to 0.157 for GREEN). With these data, the second research question (RQ2) on possible synergies between the joint use of LTs and GPs with environmental performance is answered negatively. It is worth mentioning that synergies between LEAN and GREEN with ENVPER may have been determined if the two independent variables had a positive Beta standardised coefficient and a significant relationship with the dependent variable; however, the GREEN variable did not meet the latter condition.

Findings relating to the two research questions are aligned with studies by Chiarini (2014), Piercy and Rich (2015), Powell et al. (2017), Garza-Reyes et al. (2018), Sartal et al. (2018), Chen et al. (2019), Baumer-Cardoso et al. (2020) and Sartal et al. (2020), which highlight the use of LTs in relation to environmental performance (Table 1).

Studies that have related LTs and GPs to ENVPER, but are not aligned with this paper, include Thanki et al. (2016), who found a link between the use of LTs such as TPM, 5S, SMED and continuous improvement tools with some GPs such as ISO 14001, where environmental performance is improved by reducing carbon emissions and energy used in production processes. A study by Sartal et al. (2017) linked LTs such as Kanban and Continuous Improvement with some GPs including Energy Saving Technologies where energy savings are achieved in the production processes. Cherrafi et al. (2018) suggested improvements in efficiency and sustainability by using LTs such as Kanban, Visual management or SMED together with GPs such as LCA. Inman and Green (2018) noted significantly positive correlations between LT and GP use and environmental performance.

Regarding findings, Table 4 shows that the average use of LTs is significantly higher than that of GPs, suggesting much lower progress in GPs than LTs. One example of the lack of GP implementation in Spanish manufacturing companies is ISO 50001, which is a widely recognised GP for energy management. The survey data underpinning this study shows rather poor results regarding the use of this GP: 2.51% in 2012, 6.38% in 2015, 7.59% in 2018 and 12.5% in 2022. Although usage is increasing, and there is even a correlation between LTs and GPs (see Table 6), GP implementation is still significantly lower than that of other LTs surveyed.

6. Conclusions and Future Research

LTs have been used for longer than GPs in manufacturing firms and therefore, although it might appear that higher levels of environmental performance are more closely associated with GPs than with LTs, GPs are in fact still in the initial stages of development and require time for their successful implementation in Spanish manufacturing firms. This suggests that in the context of Spanish manufacturing companies, we cannot yet consider that LT and GP generate a synergistic effect on environmental performance, as proposed in studies by Thanki and Thakkar (2020) or Kalemkerian et al. (2022).

Furthermore, the relationship between the use of LT and environmental performance is unsurprising, given that the objective of Lean is to eliminate waste. It is therefore logical that eliminating waste also improves environmental performance as decreasing machine inactivity time, for example, reduces energy consumption; or cutting back material wastage reduces purchasing costs, both of which improve production efficiency.

We therefore recommend that manufacturing managers in Spanish manufacturing companies continue to implement lean tools in their organisations, as these tools both eliminate waste and improve environmental performance. Furthermore, Spanish companies should continue to work on the adoption of GPS in order to benefit in the future from the synergies between these practices and LTs, as the literature has shown.

The current study is limited by the relatively small sample size of 86 responses. The findings show only a trend, and should be corroborated with future studies using a larger sample, in addition to analysing the situation in other countries or sectors.

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