ISSN: 1900-7205 (En línea) | ISSN: 0120-3592 (Impreso)

Artículos

Integrating Lean and Green Production in Sustainable Performance in an Emerging Economy*

La integración de la producción *lean* y la producción verde en el rendimiento sustentable de una economía emergente
Integrando produção enxuta e verde no desempenho sustentável em uma economia emergente

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DOI: https://doi.org/10.11144/Javeriana.cao37.ilgpsp

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Received: 30 may 2023
Accepted: 09 may 2024
Published: 15 october 2024

Abstract:

Lean production and green production are two concepts that are generally discussed separately in the literature. However, the relationship between both concepts is open to debate in the scientific and academy community, just like the role it plays green production as a mediating role between lean production and sustainable performance. Thus, the objective of this study is to analyze the relationship between lean production and green production in sustainable performance, through an explanatory research model. The results obtained show that lean production positively influences both green production and sustainable performance, and that green production acts as a mediating role between both variables.
Keywords: Lean production, green production, lean-green production, sustainable performance, emerging economy, M11.

Resumen:

La producción *lean* y la producción verde son dos conceptos que generalmente se analizan por separado en la literatura. Sin embargo, la relación entre ambos conceptos es objeto de debate en la comunidad científica y académica, al igual que el papel que desempeña la producción verde como mediador entre la producción *lean* y el rendimiento sostenible. Así, el objetivo de este estudio es analizar la relación entre la producción lean y la producción verde en el rendimiento sostenible, a través de un modelo de investigación explicativo. Los resultados obtenidos muestran que la producción *lean* influye positivamente tanto en la producción verde como en el rendimiento sostenible, y que la producción verde actúa como un mediador entre ambas variables.
Palabras clave: producción lean, producción esbelta, producción verde, producción lean-verde, rendimiento sustentable, economía emergente.

Resumo:

Produção enxuta e produção verde são dois conceitos que geralmente são discutidos separadamente na literatura. No entanto, a relação entre ambos os conceitos está aberta ao debate na comunidade científica e acadêmica, assim como o papel que a produção verde desempenha como mediadora entre a produção enxuta e o desempenho sustentável. Deste modo, o objetivo deste estudo é analisar a relação entre produção enxuta e produção verde no desempenho sustentável, por meio de um modelo de pesquisa explicativo. Os resultados obtidos mostram que a produção enxuta influencia positivamente tanto a produção verde quanto o desempenho sustentável, e que a produção verde atua como mediadora entre ambas as variáveis.
Palavras-chave: Produção enxuta, produção verde, produção enxuta-verde, desempenho sustentável, economia emergente.

Introduction

The concepts of lean production (LP) and green production (GP) have generally been analyzed and discussed in the literature separately, when they have been oriented to the solution of production process problems in manufacturing firms (Singh & Singh, 2024), which allows establishing that the relationship between these two constructs is inconclusive and is open to debate (Saetta & Caldarelli, 2020). However, theoretical, and empirical evidence has been provided that the integration of LP and GP is necessary to obtain more

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sustainable production processes in economic, environmental, and social terms (Saetta & Caldarelli, 2020). Additionally, the joint analysis of LP and GP also generates a higher productivity in manufacturing firms, which allows a significant increase in sustainable performance (SP) (Pathmalatha, 2021).

To improve SP, manufacturing firms have applied different methodologies, including LP and GP (Pathmalatha, 2021), but the separate adoption of both concepts between different departments in companies, has reduced the increase in SP (Wiese et al., 2015). As an alternative solution to this problem, researchers and academics have focused their studies in the last two decades on the simultaneous analysis of the synergy between LP and GP (Cabral et al., 2012; Dües et al., 2013; Galeazzo et al., 2014; Hallam & Contreras, 2016), lean-green and organizational performance (Thanki & Thakkar, 2016; Farias et al., 2019), and so called lean-green production (Machingura et al., 2023), and can make manufacturing firms competitive and increase profits and better SP (Fercoq et al., 2016; Bhattacharya et al., 2019; Thekkoote, 2022).

However, in the case of studies focused on synergy between LP, GP, and SP, these have been oriented from the perspective of the supply chain and focus on manufacturing firms has been left aside (Govindan et al., 2015; Garza-Reyes, 2015). Furthermore, Khalili et al. (2016) considered it pertinent that both researchers and academics, must guide their studies in providing empirical evidence of the effects of LP and GP in SP with an orientation in manufacturing firms, for which it is possible to consider that the relationship between LP–GP–SP analyzed together, can be considered as open to debate.

In this context, the objective of this study is the joint analysis and discussion of the integration of LP, and GP in SP in manufacturing industry. To achieve this objective, an empirical study was carried out in manufacturing firms in Mexico, using a sample of 304 observations and estimating the research model through Partial Least Squares Structural Equation Modeling (PLS-SEM), with the use of SmartPLS 4 software (Ringle et al., 2022). In addition, it is important to establish that the manufacturing industry is interesting, on one hand, because most manufacturing firms are a greater contribution to the growth and economic development of Mexico, and, on other hand, because manufacturing firms allocated the highest expenditures on environmental protection in 2021 in Mexico –environment and climate protection (37.2%), wastewater management (18.6%), and waste management (12.9%) (INEGI, 2022).

Additionally, this study contributes to LP literature, essentially, in the inconsistency in the results of empirical studies previously published, which confirm that LP and GP generates a higher SP in manufacturing firms (Pathmalatha, 2021). The rest of the paper is structured as follows: literature review and hypotheses, research methodology, analysis and interpretation of results, and derived conclusions, limitations and future research directions.

Literature Review

Lean Production and Sustainable Performance

The concept of LP is generally considered in the literature as a set of principles, methods, and techniques that generate a substantial improvement in the production processes of manufacturing firms, through the maximization of their value and the costs reduction (Caldarelli et al., 2022). In addition, the strong social pressure that manufacturing firms have in prevention of pollution and reduction of industrial waste, as essential measures for the improvement of SP, is allowing more not only organizations that they are adopting and implementing it as a measure to obtain a better SP (Battini et al., 2018; Longo, 2019; Bottani & Murino, 2021), but also that researchers and academics are considering LP as a relevant concept in the literature in industrial engineering field (Ante et al., 2018; Behr et al., 2018; Longo et al., 2019).

Also, the increase in the adoption and implementation of aspects of sustainable development by manufacturing firms, suggest a substantial change in the techniques used in production systems, to reduce the costs of companies and improve SP (Francis & Thomas, 2020), which is why more companies are adopting LP as a new technique to achieve these objectives (Innella et al., 2019; Xing et al., 2021). Thus, LP is becoming one of the most used and effective business strategies in the last decade, especially when combined with the adoption and implementation of GP in companies in the manufacturing industry (Leong et al., 2020), particularly because today one of the most effective ways for manufacturing firms to survive in a globalized and highly competitive market, is precisely by implementing LP in their production processes (Caldarelli et al., 2022).

In this sense, LP can not only significantly reduce the negative impacts on the environment generated by manufacturing firms, through the reduction of industrial waste and the increase in the efficiency of production processes, but it can also substantially increase productivity, growth, and SP (Caldarelli et al., 2022). However, the positive effects of LP on SP are highly debatable in the literature (Dieste et al., 2019; Francis & Thomas, 2020). Therefore, to provide theoretical and empirical evidence that would counteract these criticisms, various researchers, academics, and industry professionals focused their studies on the analysis and discussion of the effects of LP on SP, finding results that allow establish a connection between the two concepts.

In this context, Yadegaridehkordi et al. (2020) analyzed the relationship between LP and SP in the construction industry, finding a positive relationship. Roy et al. (2020) analyzed the integration of LP and GP to improve SP in companies in the textile industry, finding a positive relationship between LP and SP. Kaswan and Rathi (2020), using the lean six sigma technique to evaluate the improvement of products, processes, and SP of firms, found a positive relationship between LP and SP, while Prasad et al. (2020), as a result of a case study carried out in a textile company in South India, where the initial and final diagrams of LP and SP were analyzed, they found that these methods improved SP in manufacturing firms.

Baumer-Cardoso et al. (2020) evaluated LP in manufacturing firms in Brazil, using a discrete event simulation model in relation to water, energy, and raw materials in each operating unit, including SP. The results found show that the correlation between LP and SP generated a positive impact. Heravi et al. (2020) analyzed LP and SP in the construction industry, finding that LP can be used to improve production processes and SP. Finally, Saetta and Caldarelli (2020) analyzed how technological innovation and LP improve SP, finding that LP not only reduces the costs of companies, but also improves firms SP. Thus, considering the information presented above, it is possible to propose the research hypothesis H1.

H1: The greater implementation of lean production, the greater sustainable performance.

Lean Production and Green Production

LP and GP are two concepts that manufacturing firms have adopted and promoted during the last two decades (Hallam & Contreras, 2016), with the purpose of generating greater value through products and services quality (Shah & Ward, 2003; Deif, 2011), and, particularly, the connection and disposal of environmental waste (Dües et al., 2013; Martínez-Jurado & Moyano-Fuentes, 2014). Thus, LP has commonly focused both on the continuous identification of industrial waste that generates a negative impact on the environment, as well as on the redesign of production processes in order to eliminate waste as much as possible (Stone, 2012; Gupta & Jain, 2013; Stentoft-Arlbjorn & Vagn-Freytag, 2013), generating with this type of actions a positive impact on GP of manufacturing firms (Hallam & Contreras, 2016).

The focus on reduction of industrial waste by LP suggests a very close and positive relationship with GP (Dües et al., 2013; Galeazzo et al., 2014), since the existing interdependence between LP and GP require not only proper management of production tools within manufacturing firms, but also management of strategies that capitalize on the results of this interaction and help companies simultaneously improve their financial and SP (Yang et al., 2011). Therefore, the adoption of LP in manufacturing firms requires the generation of a win-win scenario, in which organizations not only have a better GP with the investment made in LP activities, but also a higher level of economic performance (Iwata & Okada, 2011; Albertini, 2013).

Additionally, the integration of LP–GP, so called lean-green production, has gained popularity in both industry and academy community, due their synergistic effect and the improvement of SP (Ramos et al., 2018; Leme et al., 2018), particularly, because lean-green production may be complementary in three aspects: Waste minimization, process centeredness, and a high degree of people involvement (Fercoq et al., 2016). Although LP and GP may have different approaches and origins, they both aim at cost reduction through efficient resource utilization (Bhattacharya et al., 2019), essentially because the integration of two concepts is necessary to obtain sustainable production processes economically, environmentally, and socially (Rishi et al., 2018).

In this sense, in the literature it is generally considered that LP initiatives are compatible with GP, mainly because both concepts focus on the reduction of environmental waste, resource efficiency, and emphasize the satisfaction of needs of consumers, through the production of products with the lowest possible cost and friendly to the environment (Duarte & Cruz-Machado, 2013). Therefore, it is possible to establish that LP have a positive impact on GP, in terms of the reduction of industrial waste and inefficiency of production processes (Yang et al., 2011), since an essential aspect of the relationship between LP and GP, is precisely that LP can increase the profits of manufacturing firms by preventing pollution levels (Hallam & Contreras, 2016).

Finally, LP are closely related to GP, since both concepts not only share the same goal of increasing firm performance (Hallam & Contreras, 2016), but also improve quality and time of production of the products, as well as the reduction of the production costs of the organizations through the generation of a greater value (Deif, 2011; Gupta & Jain, 2013). Thus, according to Deif (2011), the implementation of LP in manufacturing firms reduces material waste and energy consumption, which allows a reduction in production costs and improves lead time production of the products, as well as the improvement of the quality of both production processes and products, thereby generating a higher GP (Gupta & Jain, 2013). Therefore, considering the information presented above, it is possible to propose the research hypothesis H2.

H2: The greater implementation of lean production, the higher level of green production.

Green Production and Sustainable Performance

It is common to find in the literature that GP exponentially reduces the negative impacts on the environment, generated by the production processes of manufacturing firms and the consumption of goods and services (Galeazzo et al., 2014; Verrier et al., 2014), which allows to increase SP (Azevedo et al., 2016). However, the relationship between GP and SP is not very clear in the literature, so this relationship is debatable (Dieste et al., 2019; Francis & Thomas, 2020). To provide theoretical evidence that would counteract this criticism, Abreu et al. (2017) considered that the basic purpose of GP is to increase production systems efficiency, which allows manufacturing firms to reduce negative impacts on environment and, therefore, an increase SP.

Fu et al. (2017) proposed an operational strategy that can be implemented through GP, based on a theoretical and practical perspective, finding that manufacturing firms in developed countries where the study was applied, obtained not only greater benefits such as the creation of advantages but also a higher SP. In another study published in the literature, D'Antonio et al. (2017) proposed a method that would help researchers, academics, and industry professionals to integrate production systems with GP, applying this work in a case study in the aerospace industry to validate the model, finding GP generated a increase in SP of manufacturing firms.

In this context, Marimin et al. (2018) analyzed the implementation of GP and the evaluation of sustainability, in a case study of a motorcycle tire production company, with the purpose of generating a scenario for the potential improvement of the productivity level, evaluating at the same time the firm SP, finding that the implementation of GP significantly improved both productivity and SP. Similar results were found by Dieste et al. (2019), who carried out an extensive review of the literature to determine the number of companies that had used GP in their production processes, had substantially improved their environmental practices, finding that most of the organizations that had implemented GP increased their SP.

Additionally, Siegel and Antony (2019) implemented GP in small and medium-sized companies, finding that most companies where GP was applied improved their SP. Finally, in a more recent study Annamalai et al. (2020) evaluated the effectiveness of the adoption and implementation of GP in companies in the export industry, which generates the greatest impact on the economy of most countries. The results obtained in this study show that GP are an essential factor in business success that must be considered by the managers of organizations, since they improved both efficiency of companies, satisfaction of employees, and SP. Thus, considering the information presented in the previous paragraphs, it is possible to propose the research hypothesis H3.

H3: The greater implementation of green production, the higher level of sustainable performance.

Whilst some aspects between LP and GP may be contradictory, empirical evidence has been provided in the literature that establishes that GP usually present opportunities to improve LP and SP (Machingura et al., 2023), therefore manufacturing firms that adopt and apply GP may attain better results in SP than those that don't (Fercoq et al., 2016; Cherrafi et al., 2018). Also, whilst implementing LP and GP separately by many manufacturing firms has helped to improve their operations and SP (Machingura et al., 2023), but when LP and GP is combined can performance results in SP than alone (Baumer-Cardoso et al., 2020), particularly when GP acts a moderator role in the relationship between LP and SP (Kosalish et al., 2023).

In this sense, the previous studies published not only claims a positive correlation between LP, GP, and SP (e.g. Duarte & Cruz-Machado, 2013; Fercoq et al., 2016; Abreu et al., 2017), but also that manufacturing firms improved their SP when GP acts a moderating roll. In this context, Thekkoote (2022) found that SP improves substantially when GP acts as a mediating role in the relationship between LP and SP, while Kosasih et al. (2023) found similar results. Furthermore, Yadav et al. (2023) found that the use of GP is growing continuously and has positive impact on all aspects of sustainability, especially in the relationship between LP and SP. Similar results were obtained in the studies of Aftab et al. (2023) and Elemure et al. (2023).

In this context, the integration of GP with LP allows manufacturing firms to obtain, not only environmentally, economically, and socially sustainable production processes, but also to significantly improve their level of productivity, economic benefits, and SP (Rishi et al., 2018). For this reason, GP are commonly considered in the literature as an effective technique that identifies and controls the damage caused by environmental pollution generated by industrial activity (Sullivan et al., 2017), which allows improving the existing relationship between LP and SP in manufacturing firms (Vahabi et al., 2022), since the goals and objectives of LP are the same as those of GP.

Finally, the synergy between GP and LP has recently been analyzed in the literature, and the results confirm a higher efficiency both in LP and in SP, when acting GP as a mediating variable between these two concepts (Vahabi et al., 2022). Particularly, because the production processes cause serious environmental pollution problems, and the identification of the practices that generate this problem is essential to achieve a better SP (Roy et al., 2020). Thus, GP are the essential area to which more attention should be paid (Giovanni & Cariola, 2020), since the implementation of GP it will allow manufacturing firms to improve both LP and SP (Vahabi et al., 2022). Therefore, considering the information presented in the previous paragraphs, it is possible to propose the research hypothesis H4.

H4: Green production has a mediating role in the relationship between lean production and sustainable performance.

Figure 1 shows the approach of the four hypotheses in the research model.

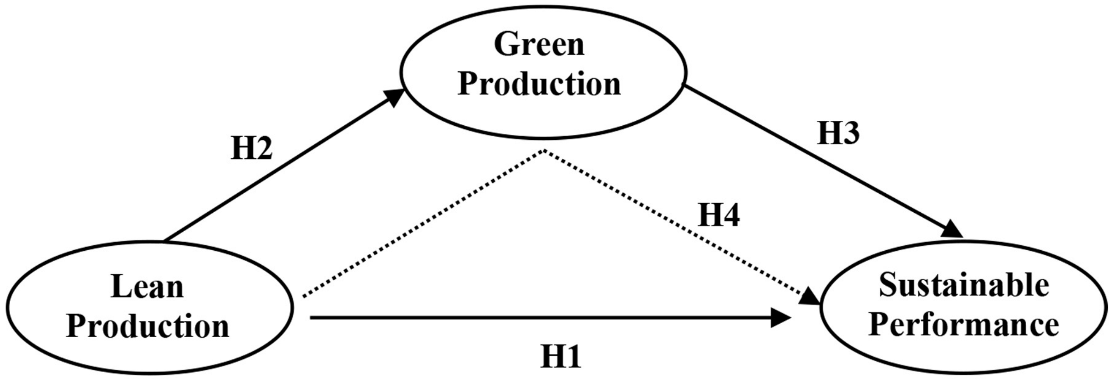

FIGURE 1.
Research Model
Source: own elaboration.

Methodology

This study has basically focused on analysis and discussion of the integration of LP and GP in SP, for which PLS-SEM has been used. Thus, this study was carried out in manufacturing firms in Mexico, which had a record of 38,950 companies as of January 30, 2020, which are registered in various national and international business organizations, for which the study it did not focus on a particular business group or association. Primary data was collected from the companies using a structured questionnaire which was applied to each of the managers of a sample of 304 manufacturing firms selected through a simple random sampling, with a maximum error of ±5% and a reliability level of 95%, applying the survey during the months of April to September 2020. Table 1 presents the main characteristics of the sample used in this study.

TABLE 1.
Sample Characteristics

Variable	Frequency	Percentage
Business size		
Small Business	20	6.6
Medium Business	138	45.4
Large Business	146	48.0
Total	**304**	**100%**
Firm's Age		
Young Companies (0-10 years)	110	36.2
Mature Companies (> 10 years)	194	63.8
Total	**304**	**100%**
Type of Ownership		
Family Business	189	62.2
Non-Family Business	115	37.8
Total	**304**	**100%**

Source: own elaboration.

Additionally, for the measurement of LP, an adaptation to the proposed scale was made by Farias et al. (2019), who measured this concept through 6 items; GP was measured by adapting to the scales proposed by Wu et al. (2015), Kovilage (2021), and Farias et al. (2019), which was measured through 5 items; and SP an adaptation was made to the scales proposed by Wu et al. (2015), Kovilage (2021), and Farias et al. (2019), which was measured through 9 items. All the items on the scales were measured using a five-point Likert-type scale, with 1 = total disagreement to 5 = total agreement, as limits. A five-point Likert-type scale was chosen to strike a balance between complexity for respondents and accuracy for analysis (Forza, 2016; Hair et al., 2016). Table 2 shows the items used to measure LP, GP, and SP, as well as the values of their factor loadings.

TABLE 2.
Measurement Model Assessment

Indicators	**Constructs**	**Factor Loads (p-value)**	**Q^2**
Lean Production (LP) Cronbach's Alpha: 0.957; Dijkstra–Henseler's rho (ρA): 0.959; CRI (ρc): 0.966; AVE: 0.852			
LP1	Produce only what the customer wants, just when the customer wants it, so production systems are flexible enough to adapt to changes in demand immediately.	0.755; 0.000	
LP2	Produce the batch size of the quantity of an item ordered for delivery on a specific date and/or manufacture it in a single production run.	0.788; 0.000	
LP3	Continuously improve the activities of all functions that involve employees from the CEO to the operational workers.	0.825; 0.000	
LP4	Improve the preventive maintenance that is performed periodically on equipment to reduce the probability of its failure.	0.818; 0.000	
LP5	The direct participation of employees to help the company achieve its mission and objectives by applying their ideas, experience and efforts towards problem solving and decision making.	0.878; 0.000	
LP6	Improve the production cycle time of a product, which is the amount of time necessary to produce a product or service.	0.855; 0.000	
Green Production (GP) Cronbach's Alpha: 0.903; Dijkstra–Henseler's rho (ρA): 0.905; CRI (ρc): 0.925; AVE: 0.674			
GP1	Make efforts to reduce water consumption in industrial operations	0.911; 0.000	0.085
GP2	Reduce pollution of water bodies as a result of industrial operations	0.916; 0.000	0.095
GP3	Reduce energy use to carry out the same operations in the company by eliminating waste.	0.919; 0.000	0.075
GP4	Reduce the use of material resources to carry out the same operations in the company, by eliminating waste.	0.937; 0.000	0.087
GP5	Reduce the amount of greenhouse gases released into the atmosphere through industrial operations.	0.931; 0.000	0.115
Sustainable Performance (SP) Cronbach's Alpha: 0.933; Dijkstra–Henseler's rho (ρA): 0.942; CRI (ρc): 0.947; AVE: 0.670			
SP1	Reduce inventory of items kept in stock for processing or resale, as having a high level of inventory adds cost to the business such as inventory management, retention, obsolescence, etc.	0.842; 0.000	0.105
SP2	Increase sustainable activities that produce financial gains for the organization.	0.832; 0.000	0.123
SP3	Reduce the total amount of waste generated through all the company's production processes.	0.857; 0.000	0.134
SP4	Comply with the standards of environmental regulations in accordance with the provisions of the regulations.	0.870; 0.000	0.121
SP5	Reduce the amount of money used to produce a product or provide a service that is no longer available on the market.	0.876; 0.000	0.122
SP6	Improving the working conditions of employees so that they are happy	0.881; 0.000	0.136
SP7	The improvement of products and services provided by the company so that they meet or exceed customer expectations.	0.870; 0.000	0.124
SP8	Reduce the time elapsed between receipt of the order by customers and its delivery.	0.818; 0.000	0.104
SP9	Reduce the amount of material, energy and water used for operations in the company.	0.812; 0.000	0.052

Notes CRI: Composite Reliability Index; AVE: Averaged Extracted Variance. All the items on the scales were measured using a five-point Likert-type scale, with 1 = total disagreement to 5 = total agreement, as limits
Source: own elaboration.

Table 2 shows the 20 items used in measuring LP, GR, and SP. In addition, in the same Table 2 it is observed that the factor loads of all the items are greater than 0.6 (p-value = 0.000), and the Q. values are greater than 0, which indicates the existence of reliability of the scales used in the research model (Hair et al., 2019).

Method of Data Analysis

Empirical study data was generated through a survey and analyzed using SmartPLS 4 software (Ringle et al., 2022). Additionally, the statistical analysis in terms of the SEM, the PLS was used to measure the effects that LP has both GP and SP of manufacturing firms in Mexico. Likewise, the evaluation of the reliability and validity of LP, GP, and SP scales was carried out using Cronbach's Alpha, Composite Reliability Index (CRI), Dijkstra-Henseler rho, and Extracted Variance Index (AVE) (Hair et al., 2019), while discriminant validity was evaluated through the three most cited elements in the literature: Fornell and Larcker Criterion, and Heterotrait-Monotrait ratio (HTMT) (Henseler et al., 2015; Hair et al., 2019).

The results obtained from PLS-SEM (Table 3), show that both Cronbach's Alpha, CRI, and Dijkstra-Henseler rho have values that range between 0.903-0.957; 0.925-0.966; 0.905-0.959, respectively, which indicates that they are excellent data and are above the values recommended by Bagozzi and Yi (1988), and Hair et al. (2019), AVE has values that range between 0.670-0.852, which are above the values recommended by Fornell and Larcker (1981), and Bagozzi and Yi (1988), while Fornell and Larcker criterion is significant because AVE values are higher than the square of the correlations between each pair of constructs, HTMT has values that range between 0.305-0.425, which are higher than recommended value of 0.08 (Henseler et al., 2015), which indicate the existence of discriminant validity of the three measurement scales used.

TABLE 3.
Measurement Model. Reliability, Validity and Discriminant Validity

PANEL A. Reliability and Validity				
Variables	Cronbach's Alpha	CRI	Dijkstra-Henseler rho	AVE
Lean Production	0.957	0.966	0.959	0.852
Green Production	0.903	0.925	0.905	0.674
Sustainable Performance	0.933	0.947	0.942	0.670

PANEL B. Fornell-Larcker Criteria				**Heterotrait–Monotrait ratio (HTMT)**		
Variables	1	2	3	1	2	3
1. Lean Production	**0.923**					
2. Green Production	0.383	**0.821**		0.408		
3. Sustainable Performance	0.285	0.390	**0.819**	0.305	0.425	

Note Panel B: Fornell-Larcker Criterion: Diagonal elements (bold) are the square root of the variance shared between the constructs and their measures (AVE). For discriminant validity, diagonal elements should be larger than off-diagonal elements.
Source: own elaboration.

Results

To respond the four hypotheses raised in research model, use of PLS-SEM through SmartPLS 4 software (Ringle et al., 2022) was considered pertinent, which is commonly used both in those theories that have not been widely developed in the literature (Hair et al., 2019), from different disciplines of knowledge, including business sciences (Hair et al., 2012; Ringle et al., 2012; Sarstedt et al., 2014; do Valle & Assaker, 2015; Richter et al., 2016), as well as when the essential objective of using PLS-SEM statistical technique in data analysis is the prediction and explanation of the constructs of the research model (Rigdon, 2012), which substantially facilitates both the explanation of the measurement error and the multiple regression of the sum of scores of the relationship between the three constructs (Hair et al., 2021).

The data obtained in this study show estimated data with acceptable statistical levels by obtaining an adjusted R^2 higher than recommended value of 0.10 (Reinartz et al., 2009; Hair et al., 2011; Henseler et al., 2014; Hair et al., 2019). SRMR has a value lower than recommended value of 0.08 (0.033) (Hu & Bentler, 1998), as well as values of geodetic discrepancy (dG) 0.131 and unweighted least squares discrepancy (dULS) 0.230, higher than the values of HI99 (0.168 and 0.332, respectively), which allows verifying the significance of the research model used (Dijkstra & Henseler, 2015). In conclusion, the estimated statistical data verify that LP has positive effects, both at SP (0.162; p-value 0.000) and GP (0.385; p-value 0.000), and GP also have positive effects on SP (0.333; p-value 0.000).

Finally, the size of the effects of the independent variables (f^2) on the values of R^2 of the independent variable, suggests small variations (values between 0.02-0.14), medium (values between 0.15-0.34) and large (values equal to and/or or greater than 0.35) (Hair et al., 2017). Table 4 shows in greater detail the estimated data obtained.

TABLE 4.
Structural Model

Paths	Path (*t-value; p-value*)	95% Confidence Interval	f^2	Support
LP → SP (H1)	0.162 (2.968; 0.004)	[0.047 – 0.265]	0.031	Yes
LP → GP (H2)	0.385 (8.347; 0.000)	[0.284 – 0.465]	0.179	Yes
GP → SP (H3)	0.333 (5.612; 0.000)	[0.211 – 0.437]	0.121	Yes
Indirect Effects				
LP → GP → SP	0.228 (5.543; 0.000)	[0.127 – 0.285]	0.132	Yes
Endogenous Variable	**Adjusted R^2**	**Model Fit**	**Value**	**HI99**
		SRMR	0.033	0.040
GP	0.144	dULS	0.230	0.332
SP	0.170	dG	0.131	0.168

Note LP: Lean Production; GP: Green Production; SP: Sustainable Performance. One-tailed t-values and p-values in parentheses; bootstrapping 95% confidence intervals (based on n = 5,000 subsamples) SRMR: standardized root mean squared residual; dULS: unweighted least squares discrepancy; dG: geodesic discrepancy; HI99: bootstrap-based 99% percentiles.
Source: own elaboration.

Discussion

Estimated data provide robust empirical evidence in favor of hypothesis H1, which allows establishing that the integration of LP generates an increase in SP of manufacturing firms (0.162; p-value 0.004), being in line to the results obtained by Battini et al. (2018), Longo (2019), and Bottani & Murino (2021). The main reason that could explain this positive effect is the flexibility of the production processes of manufacturing firms, particularly because they are adapting to customers' needs and production is personalized with increasingly smaller production batches, which it allows a significant reduction in production times, as well as waste generated during the productive process. Therefore, it is possible to establish that the costs associated with the adoption of LP in manufacturing firms are lower than the benefits obtained.

In addition, these results also verify that LP has positive effects on GP (0.385; p-value 0.000), providing evidence in favor of hypothesis H2 and are consistent with the results obtained by Gupta and Jain (2013), Duarte and Cruz-Machado (2013), and Hallam and Contreras (2016). The essential reason that could explain the positive effect of LP on GP is that the managers of manufacturing firms have prioritized the implementation of these two methods to improve deliveries efficiency and products quality, which allows for a substantial improvement in performance. lean-green of manufacturing firms. Therefore, company managers must apply LP and GP at the same time in production processes, which leads to more efficient use of resources, reduction of industrial waste, and a higher level of customer satisfaction.

Likewise, the estimated data also allows us to verify that GP have a positive impact on SP of manufacturing firms (0.333; p-value 0.000), thus providing robust empirical evidence in favor of hypothesis H3 and being consistent with the results obtained by Dieste et al. (2019), Siegel and Antony (2019), and Annamalai et al. (2020). The main reason that could explain this positive effect is that GP not only facilitate internal coordination and collaboration with the stakeholders, such as consumers and suppliers of green products, but also improve the efficiency of production processes, significantly saving the costs of use energy and water, reduction of production times and the use of raw materials, which allows to significantly improve its SP.

Finally, regarding the mediation effects that GP exert on the relationship between LP and SP, the estimated data obtained show a positive indirect effect generated by GP (0.228; p-value 0.000), in the relationship between LP and SP of manufacturing firms. The essential reason that could explain that GP can have a mediating role between LP and GP is the strong pressure that manufacturing firms increasingly have, both from public administration and their stakeholders, to improve environmental sustainability, therefore which managers have to adopt and implement the best lean, green, and sustainable production methods, and periodically evaluate their efficiency in the results of economic, social, and environmental performance, as well as in the reduction of solid waste, CO. emission and other gases polluting the environment.

Practical implications

The data estimated in this paper have various implications for managers and manufacturing firms, among which the following stand out. On one hand, the integration of LP and GP to improve SP of manufacturing firms. However, in the literature there are few empirical studies that have analyzed these two concepts comprehensively, they have commonly been analyzed separately (Hallam & Contreras, 2016; Saetta & Caldarelli, 2020). Thus, this study incorporates a research model that simultaneously analyzes LP and GP, and its relationship on SP, which provides a holistic point of view that generates a comprehensive explanation of the relationship between LP, GP, and SP in a context of manufacturing firms (Pathmalatha, 2021).

Additionally, the inconsistency in the results obtained, coupled with the existing research gap in studies published in the literature, which have analyzed and discussed LP and GP, allows this study to provide robust empirical evidence to fill that gap that is considered. Therefore, the analysis of the relationship between LP, GP, and SP is gaining more attention from researchers, academics, and industry professionals, who try to provide evidence of the relationship between these three concepts (Pathmalatha, 2021). Thus, this study using a quantitative methodology and a research model that jointly analyzes LP and GP and SP, which have been scarcely analyzed in the literature, provides robust empirical evidence that demonstrates that manufacturing firms that have implemented LP and GP simultaneously, have achieved better SP (Pathmalatha, 2021).

On other hand, studies recently published in the literature have provided empirical evidence showing that LP have positive effect on SP of manufacturing firms (e.g., Saetta and Caldarelli, 2020; Heravi et al., 2020; Baumer-Cardoso et al., 2020). However, these results are not considered conclusive and are highly debatable in the literature (Dieste et al., 2019; Francis & Thomas, 2020), so researchers, academics, and industry professionals not only have to guide their studies in the analysis of LP and GP together, but also to provide robust empirical evidence that shows that the adoption and implementation of both concepts simultaneously in manufacturing firms can generate a higher SP than if they are implemented separately.

Finally, a third implication of the results obtained is that, from the research perspective, it has been shown that LP improves GP when they are analyzed and implemented together, even when there is little empirical evidence of the improvement results in manufacturing firms (Hallam & Contreras, 2016). Likewise, while LP has been analyzed and discussed in various production and manufacturing disciplines, through the implementation of different continuous improvement tools, GP has been analyzed as tools to improve environmental regulation, which has generated confusion among managers of manufacturing firms about the benefits of their adoption and implementation (Hallam & Contreras, 2016).

Conclusions

The data obtained in this empirical study allow three main conclusions to be established, one of them referring to the research model used, since it not only has an adequate internal correlation by generating a significant positive correlation between LP, GP, and SP, which allowed the acceptance of the four hypotheses established in the research model, but also offers a more holistic view by incorporating the most cited indicators in the literature for the measurement of both LP, GP, and SP. In addition, the comprehensive analysis and discussion of LP and GP is scarce in the literature, and the relationship of both concepts with SP has received little attention from researchers and academics, compared to those studies that have guided the analysis of its conceptualization (Pathmalatha, 2021).

A second conclusion is that, even though there are several studies published in the literature that have analyzed LP and GP in manufacturing firms, only a small part of these studies has analyzed the two concepts together and only a few studies have analyzed the relationship of these two concepts with SP. Therefore, as suggested by Hallan and Contreras (2016), Pathmalatha (2021), and Caldarelli et al. (2022), manufacturing firms that have jointly adopted LP and GP are more likely to achieve not only an increase in their SP, but also a substantial reduction in the levels of environmental pollution and the generation of smaller amounts of industrial solid waste.

A third and final conclusion is that the results obtained in this study contribute to the generation of knowledge, both of the studies previously published in the literature that have focused on the analysis of the relationship between LP and SP (e.g. Battini et al., 2018; Longo, 2019; Bottani & Murino, 2021), as well as those studies that have analyzed the relationship between LP and GP (e.g. Iwata & Okada, 2011; Albertini, 2013; Sezen & Cankaya, 2013), by incorporating a theoretical model in which these two concepts are simultaneously analyzed and discussed with SP, through the most cited indicators in the literature, which allows us to conclude in general terms that the adoption of LP and GP simultaneously, generates better results for manufacturing firms than when they are analyzed separately.

This study has several limitations that are important consider when performing the interpretation and implications of the results obtained. On one hand, a limitation is that referring to the use of measurement scales of LP and GP, as well as SP, since these three concepts were measured only with subjective indicators obtained through the application of a survey (subjective data) to manufacturing firms. Therefore, in future studies it will be necessary to use objective data from manufacturing firms (e.g., improvement time of production processes; reduction of production costs), to verify if the results obtained are like the results obtained in this empirical study.

On other hand, the integration of LP and GP with SP of manufacturing firms, possibly generate better results if variables related to the managers of the organizations are considered (e.g., leadership, experience, academic training), some variables related to companies (e.g., size; age; location), or other measurement scales of LP and GP. Therefore, in future studies it will be pertinent to consider other variables or measurement scales of the three concepts, to verify whether the results differ from those obtained in this study.

Ethical considerations

No approval from a Scientific Ethics Committee was necessary for this study.

Authors' contributions statement

Raymundo Juárez-Del Toro contributed to the planning of the research, provided methodological recommendations, and provided guidelines for the analysis and interpretation of data against theory. Gonzalo Maldonado-Guzmán contributed to the development of the article, the compilation of information, and the preparation of responses to reviewers.

Financing

This article was not supported by any specific grant or funding.

Interest conflicts

The authors declare that no conflicts of interest exist.

Declaration of use of artificial intelligence (AI)

No AI tools were used in the preparation of this article. Furthermore, we declare that the principles of respect for dignity and human rights, as well as accuracy and verification of facts, were complied with.

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Notes

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