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Beyond lean manufacturing and sustainable performance: are the circular economy practices worth pursuing?

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Abstract

Purpose – The need to improve sustainability in manufacturing firms, which would allow them to reduce the emission of pollutants and the generation of industrial waste, has stimulated the adoption of circular economy (CE) alongside lean manufacturing (LM) practices to significantly improve the sustainable performance of organizations. However, empirical evidence provided in previous studies and that has related the practices of LM, CE and sustainable performance do not allow establishing an interconnection between these three concepts. Therefore, this paper fills this gap in the literature by exploring the relationship between these three concepts.
Design/methodology/approach – A quantitative study in which data were collected from 460 managers working in the automotive industry in Mexico was conducted. The data allowed the testing and validation of four hypotheses through the use of partial least squares structural equation modeling (PLS SEM).
Findings – The results obtained suggest that LM practices have a significant positive influence both on sustainable performance and CE. In turn, the results also demonstrate the existence of a significant positive relationship between CE and the sustainable performance of manufacturing firms in the automotive industry as well as that CE has a positive role in mediating the interconnection between LM practices and sustainable performance.
Practical implications – The results obtained from the present study will allow entrepreneurs in the automotive industry and industry professionals as well as government authorities to formulate more effective policies and strategies to support the improvement of environmental sustainability performance in the manufacturing sector.
Originality/value – This is one of the first studies that have investigated the relationship between LM, CE and sustainable performance, particularly, in the automotive sector.

Keywords Lean manufacturing, Sustainable performance, Circular economy, Automotive industry
Paper type Research paper

1. Introduction

Lean manufacturing (LM) is considered one of the most successful business strategies, and its application has spread around the world, particularly in manufacturing companies that seek to reduce the negative impacts of hyper-competence and global competitiveness (Ghobadian *et al.*, 2020). In addition, LM emphasizes both the generation of zero defects and zero waste (Agyabeng-Mensah *et al.*, 2021), which generates not only an increase in sustainable performance (Zokaei *et al.*, 2017; Abreu *et al.*, 2017) but also circularity (Schmitt *et al.*, 2021). However, even when LM includes aspects of sustainability, like circular economy (CE) (Cherrafi *et al.*, 2021), there are relatively few studies published in the literature that relate both concepts (Lim *et al.*, 2022), and there are even fewer studies that consider CE as a mediating variable between LM and sustainable performance (Agyabeng-Mensah *et al.*, 2021).

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CE is a relatively recent concept in the literature that has generally been implemented in manufacturing companies not only to improve sustainability (Chen, 2019) but also as a new business model that improves production systems, through the reduction of waste (Konietzko *et al.*, 2020). Caldera *et al.* (2018) established the need to guide studies in the analysis of the integration of LM and CE and their relationship with sustainable performance (Kristoffersen *et al.*, 2020). In this same line, Kurdve and Bellgran (2021) suggested undertaking studies that analyze the effects of LM on CE in manufacturing firms to provide empirical evidence that demonstrates their relationship as well as their effects on sustainable performance.

Additionally, evidence in the literature suggests that the automotive industry is interested in exploring the relationship between LM, CE and sustainability performance due to two main reasons. On the one hand, the production of vehicles by a high percentage of manufacturing firms in the automotive industry, particularly in Mexico, is commonly incompatible with environmental sustainability (Scur *et al.*, 2019) and generates a high level of environmental pollution (Farkavcova *et al.*, 2018). On the other hand, this sector is interesting because not only contributes to more than 50% of the Mexican economy's gross domestic product (GDP) and employs more than 30% of the workers, but it is also the backbone of the Mexican economy by positioning this country as the fourth largest exporter of vehicles in the world (INEGI, 2019). For these reasons, it is possible to establish that the relationship between LM, CE and sustainable performance can be considered inconclusive and still open to debate (Caldera *et al.*, 2018; Duarte and Cruz-Machado, 2019). Therefore, to complement and expand the limited body of knowledge in this field, this paper addresses the following research question:

RQ. What is the relationship between LM, CE and sustainable performance in the automotive industry?

The present study makes a significant contribution to the academic literature by providing empirical evidence that demonstrates that LM has a significant positive effect both on CE and sustainable performance. This relationship is partially mediated by CE. Since this variable plays a mediating role between LM and sustainable performance, sustainable performance is more significant. Thus, this study contributes to LM literature in two fundamental aspects. First, it addresses the inconsistencies in the results of previous studies since some authors have found a positive relationship between LM and CE (e.g. González-Chávez *et al.*, 2019; Pascual *et al.*, 2020) and between LM and sustainable performance (Pinto and Mendes, 2017; Dieste *et al.*, 2019), whereas other studies have found a negative relationship between LM and CE (Niccolini *et al.*, 2019; Yadav *et al.*, 2020) and between LM and sustainable performance (Marodin *et al.*, 2018; Belhadi *et al.*, 2020).

Second, it contributes to the generation of knowledge concerning the effects and conditions in which LM positively affect CE and the sustainability performance of manufacturing firms (Lim *et al.*, 2022), especially when CE acts as a mediating variable between LM and sustainable performance (Agyabeng-Mensah *et al.*, 2021). Finally, the results obtained from the present research have important implications for both entrepreneurs in the automotive industry and industry professionals, as well as for government authorities as it will allow them to formulate more effective policies and strategies to support the improvement of environmental sustainability performance in the manufacturing sector.

2. Literature review and formulation of hypotheses

2.1 Lean manufacturing and sustainable performance

LM is considered, in the literature, as a philosophy of work whose essential objective is the reduction of waste, which allows manufacturing companies not only to improve the quality of their products but also to reduce production costs (Pascal, 2007). Therefore, according to Ohno (1997, p. 10), LM is defined as "*a system for eliminating waste and unnecessary activities with the objective of reducing costs, with the idea of producing only what is necessary for the* *shortest possible time and with the same level of required quality*". In addition, LM also allows manufacturing firms to reduce environmental waste (Dieste *et al.*, 2019), as well as improve efficiency in the use of available resources (Caldera *et al.*, 2017), contributing to the achievement of environmental objectives and improvement of firm sustainable performance (Martínez-Jurado and Moyano-Fuentes, 2014; Caldera *et al.*, 2019).

Additionally, sustainable income is generally conceptualized in the literature on how companies have to design their activities for the benefit of society, the economy and the environment (Singh *et al.*, 2022). These are activities that focus on the design of eco-friendly products with the environment, in full compliance with the protection of the environment (Walker *et al.*, 2014). Thus, the activities of any manufacturing company can be environmentally sustainable only when (a) using resources at a rate that should not exceed the rate of their regeneration and; (b) they contaminate at levels that do not exceed the assimilation capacity of the environment (Toffel, 2014). Under this context, the World Commission on Environment and Development defines sustainable income as "meeting the needs of the present without compromising the ability of future generations to meet their own needs".

While some authors have shown that LM has significant positive effects on sustainable performance in manufacturing firms (Vinodh *et al.*, 2011; Pinto and Mendes, 2017; Dieste and Panizzolo, 2018; Dieste *et al.*, 2019), other authors have severely criticized that LM has not yet proven the integration of total sustainability (Peto, 2012; Dieste and Panizzolo, 2018). Furthermore, other authors have found negative and insignificant results between LM and sustainable performance, using various practices such as variability reduction, elimination of industrial waste and problem-solving models that engage all employees in continuous improvement (Khalfallah and Lakhal, 2020; Belhadi *et al.*, 2020). These inconsistencies obtained in some studies possibly have their origin in the use of different items to measure LM and sustainable performance (Agyabeng-Mensah *et al.*, 2021).

Thus, to provide empirical evidence in favor of the relationship between LM and sustainable performance and counteract the criticisms made by various authors, studies recently published in the literature have shown the existence of a positive relationship between both constructs (Agyabeng-Mensah *et al.*, 2021). For instance, using a sample of 115 manufacturing firms, Kamble *et al.* (2020) found that LM generates a significant increase in sustainable performance, while de Souza and Dekkers (2019) concluded that LM eliminates activities that do not generate value, which allows manufacturing firms to increase the level of sustainable performance. Moreover, Burawat (2019) found that various LM practices are positively associated with the level of sustainable performance of manufacturing firms.

Similar results were obtained by Buer *et al.* (2020), who found that LM has a positive direct effect on both operational performance and sustainable performance, whereas Chavez *et al.* (2020) found not only an indirect positive influence between internal LM and operational performance but also an indirect positive influence of internal practices of LM in sustainable performance. In this same line of results, Afum *et al.* (2020) established that LM can substantially reduce water consumption, energy use, generation of industrial solid waste and reduction of environmental pollution, which could generate an increase in sustainable performance in manufacturing firms. Similar results were also found by Garza-Reyes *et al.* (2018). Additionally, Agyabeng-Mensah *et al.* (2020), using data generated from a survey of 201 manufacturing firms in Ghana, concluded that LM has significant positive effects on sustainable performance. Therefore, considering the debate in the literature presented above, it is necessary to formulate the first research hypothesis.

H1. The greater the implementation of LM, the better the sustainable performance

2.2 Lean manufacturing and circular economy

While LM has been analyzed in a large number of studies, few studies have analyzed the relationship between LM and CE (Kurdve and Bellgran, 2021). For example, an extensive review of the literature identified 500 studies of LM that they feel should be further explored in how the CE can be related to LM and found that only 9 of the 500 studies used the word CE in the keywords, title or abstract (Kurdve and Bellgran, 2021). From these, 5 studies established a positive relationship between LM and CE (Romero and Rossi, 2017; Caldera *et al.*, 2019; Piyathanavong *et al.*, 2019; Shahbazi *et al.*, 2019a; Wang *et al.*, 2019), while in the remaining 4 studies, the authors established a negative relationship between both constructs (Garza-Reyes *et al.*, 2018; Nascimento *et al.*, 2019; Niccolini *et al.*, 2019; Yadav *et al.*, 2020).

In order to demonstrate the connection between LM and CE, various researchers and academics have focused their studies on providing evidence in favor of this interconnection. Thus, González-Chávez *et al.* (2019) presented a model for the integration of LM and CE, finding a positive interconnection between both constructs, while Piyathanavong *et al.* (2019) found a positive relationship between LM and CE, which allows for improving operational efficiency. Similar results were obtained by Caldera *et al.* (2019), who identified nine characteristics of LM practices and proposed that the implementation of LM contributes to improving CE in firms. Additionally, Shahbazi *et al.* (2019b) analyzed LM tools through 4 case studies in Australian firms and found that the implementation of LM improves the efficiency and circularity of a company's economy.

Pascual *et al.* (2020) analyzed the relationship between LM and CE through gamification, the combination of production and recycling in firms, finding a positive relationship between both constructs. Hedlund *et al.* (2020) analyzed how LM can be used to identify and reduce industrial waste and improve value creation, from the point of view of CE, finding a positive relationship between both constructs. Kurdve and Bellgran (2021) proposed the implementation of LM and CE at a descriptive level, finding the existence of a positive relationship between both constructs, but considering that the interconnection between both constructs should go beyond a simple description and provide empirical evidence that demonstrates the interconnection. However, despite the evidence suggesting a positive relationship between LM and CE, Kalemkerian *et al.* (2022) found, through the analysis of case studies identified following the systematic literature review method, that the contribution of LM to the implementation of CE practices is limited. Thus, considering the discussion elaborated above, it is possible to propose a second research hypothesis.

H2. The greater the implementation of LM, the better the CE

2.3 Circular economy as a mediating variable–circular economy and sustainable performance

Even when most of the definitions of CE have been influenced by the studies carried out by Stahel and Reday (1976) and the term has been attributed to several authors such as Pearce and Turner (1989), Andersen (2007), Su *et al.* (2013) and Ghisellini *et al.* (2016), there are several definitions of CE in the literature, and among all of them, the one proposed by the Ellen MacArthur Foundation (2013, p. 34) stands out. It defines CE as "*an industrial economy that is reconstituted or regenerated by intention and design*", while Geng and Doberstein (2008, p. 231) affirm that CE "is the realization of a closed circle in the flow of materials in the totality of the economic system". For his part, Webster (2015, p. 16) considers that CE "is an element that can be reconstituted through design, to maintain the products, components and materials with a high utility and value throughout the time". In general terms, it is possible to state that the majority of CE definitions in the literature incorporate a value retention process through diverse mechanisms, such as reuse, repair, remodeling, recycling and remanufacturing (Nasr *et al.*, 2018).

CE is generally considered in the literature as an industrial economy that is oriented toward sustainability (Ghisellini *et al.*, 2016), which, when adopted by manufacturing firms, including the automotive industry, significantly improves economic and sustainable performance (Kalmykova *et al.*, 2018). For this reason, more manufacturing firms are implementing CE practices to try to improve the level of industrial productivity, industrial ecosystem, generation of economies of scale and sustainable performance (Walker *et al.*, 2022). In essence, CE improves the sustainability of industrial development not only of organizations but also of countries by combining sustainable aspects in production systems and in combination with different business strategies (EPCEU, 2019).

However, despite the growing importance that CE has for the scientific, academic and business community, the relationship that the CE has with sustainability is not yet very clear (Geissdoerfer *et al.*, 2017), particularly because CE does not always generate a positive contribution to sustainable income (Geissdoerfer *et al.*, 2017; Corvellec *et al.*, 2021). In addition, the literature has questioned at what point the reuse of components in the manufacture of products (secondary production) shifts to the production of finished products (primary production) and/or increases the demand for products friendly to the environment (Zink and Geyer, 2017), since CE initiatives could, in many cases, stimulate an increase in consumption due to easier access to goods and services (Zink and Geyer, 2017; Ottelin *et al.*, 2020).

Several studies published in the literature have demonstrated that the introduction of new systems to increase the performance of companies inevitably generates negative consequences or rebound effects (Zink and Geyer, 2017). However, empirical evidence that demonstrates the opposite, for example in the studies carried out by Angelis-Dimakis *et al.* (2016) and Jia *et al.* (2020), has also demonstrated that the reuse of industrial waste for its reincorporation in new products production could increase sustainable performance. At the same time, the reuse of industrial waste can increase the abilities of manufacturing firms to reduce redundant production activities (Hertwich, 2008), which could consequently reduce defects in production processes and increase sustainable performance (Ciliberto *et al.*, 2021). In this order of ideas, Geissdoerfer *et al.* (2017) concluded that the main beneficiaries of the adoption and implementation of CE practices are all the economic actors that participate in the supply chain of manufacturing firms.

Additionally, when a part of the social dimension is excluded, the economic and environmental benefits are emphasized. In this line, CE can lead to the generation of positive compensations for the sustainability of companies (Geissdoerfer *et al.*, 2017; Jarre *et al.*, 2020), particularly because CE is distinguished from other business strategies because it incorporates a production system based on take-make-regenerate. This system is different from the rest of the linear strategies, whose goal is take-make-throw away, since the system of CE is a combination of the generation of economic benefits and the protection of the environment (Lieder and Rashid, 2016; Murray *et al.*, 2017). CE focuses on the reuse, remanufacturing, remodeling, repair, renovation and improvement of the cycle of product life. This reduces pollutant emissions and the demand for resources (Korhonen *et al.*, 2018) and increases the sustainable performance of manufacturing firms (Nadeem *et al.*, 2019; Pascual *et al.*, 2020; Hedlund *et al.*, 2020; Kurdve and Bellgran, 2021). Thus, considering the information presented in the previous discussion, it is possible to propose a third research hypothesis.

H3. The greater implementation of CE, the greater the sustainability performance

Additionally, in the last decade, the publication of studies that analyze the concept of CE has increased (Donati *et al.*, 2020), because CE is considered in the current literature not only as one of the best strategies that propose alternative solutions to current environmental problems (Johansson and Heriksson, 2020) but also because it increases the efficiency of resources and sustainable performance of manufacturing firms (Kirchherr *et al.*, 2017). Therefore, CE generates a reduction in the consumption of available resources in organizations through the reuse and recycling of materials (Geissdoerfer *et al.*, 2017), as well as a decrease in the emission of greenhouse gases (Aguilar *et al.*, 2021), which can increase sustainability performance in manufacturing firms (Korhonen *et al.*, 2018). In this context, sustainable performance can increase considerably if it is related to production strategies such as LM (Kurdve and Bellgran, 2021).

However, despite the fact that both CE and LM consider sustainability aspects (Cherrafi *et al.*, 2021), only a few studies have related both concepts, and even more so those studies that analyze CE as a variable that mediates the relationship between LM and sustainable performance (Lim *et al.*, 2022). For this reason, Caldera *et al.* (2018) considered the need to jointly analyze the practices of LM and CE, with the integration of other fundamental practical concepts, because both concepts have similar goals (Lim *et al.*, 2022). Thus, both LM and CE are strongly associated with the concepts of, for example, sustainable performance (Kristoffersen *et al.*, 2020), eco-efficiency (Ma *et al.*, 2015), waste reduction (Ren *et al.*, 2017) and recycling of materials (Wu *et al.*, 2014; Bartolacci *et al.*, 2018).

In this context, Yadav *et al.* (2020) developed a model that related LM and CE and found that the incorporation of CE significantly increased sustainable performance. Similar results were found by Sartal *et al.* (2020), who concluded that the combination of LM and CE reduced water use and increased labor productivity and sustainable performance. In this same line, Ciliberto *et al.* (2021) concluded that the combination of LM and CE can help manufacturing firms solve problems associated with the environment and sustainability, while Gupta *et al.* (2021) proposed a model that integrates both LM and CE, concluding that manufacturing firms that incorporated CE into LM practices increased sustainable performance more. Thus, considering the discussion and debate presented in the previous paragraphs, it is possible to propose a fourth research hypothesis.

H4. CE has a mediating effect between LM and sustainable performance

2.4 Research model

Figure 1 presents the theoretical research model, including the proposed hypotheses. In general, the model illustrates the hypothesized antecedents and consequences of the mediating effect of CE and the occurrence between LM and sustainable performance. Thereby, the theoretical research model presented in Figure 1 constitutes the foundation for the present empirical study.

3. Research methods

3.1 Data collection and sample size

The research work was focused on manufacturing firms that make up the automotive industry in Mexico, which had a record of 950 companies as of January 30, 2020. Likewise, it is important

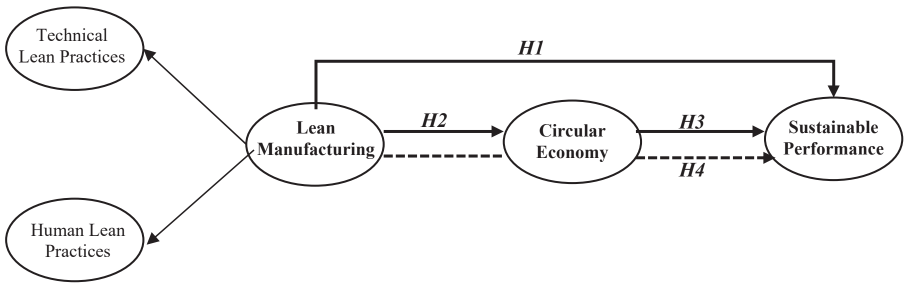

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Figure 1. Theoretical research model

to note that manufacturing firms in the automotive industry belong to different local, regional, national and international organizations and are affiliated with various business chambers in Mexico. Thus, this empirical study did not focus on a particular business group or chamber. On the other hand, it was considered essential to analyze and discuss the automotive industry, which is practically located in the center and north of the country, not only because it is one of the industries that contribute with a high percentage of the gross domestic product and employs a considerable number of workers but also because it contributes with a significant portion of the growth and development of both the economy and society in Mexico and other nations.

Additionally, secondary data were collected from manufacturing firms that were registered with the Mexican Association of the Automotive Industry (AMIA) as of January 30, 2020. For this, a structured questionnaire was designed and distributed through personal interviews with managers of manufacturing firms from a sample of 460 companies that were selected by simple random sampling with a maximum error of ±4% and a significance level of 95%. In addition, the structured questionnaire was distributed during the months of April to September 2020 to the selected manufacturing firms in the automotive industry, collecting 100% of the applied surveys.

3.2 Measuring variables

Generally, LM has been identified and measured in the literature through different perspectives but the most cited include measuring LM as a philosophy, practices, production systems, manufacturing paradigms, performance capabilities or socio-technical systems (Womack *et al.*, 1990; MacDuffie, 1995; Shah and Ward, 2003, 2007; Hopp and Spearman, 2004; Li *et al.*, 2005; Treville and Antonakis, 2006; Hong *et al.*, 2014). Of all these perspectives, socio-technical systems have received the least attention from researchers, even though they offer a totally holistic view of LM, precisely because LM is, by nature, a set of focused techniques based on the analysis and improvement of machinery and equipment work, production systems and equipment maintenance (Hyer *et al.*, 1999), as well as human elements oriented towards the analysis of employee empowerment, teamwork culture and supplier relationships (Likert, 2004).

In this sense, for the measurement of LM, an adaptation was made to the scale proposed by Möldner *et al.* (2020), who considered that LM can be measured through two dimensions, namely: *technical and human lean practices.* Technical lean practices are defined as an extension of the implementation of the technical aspects of continuous improvement programs of manufacturing firms, which commonly include computerized systems, product tracking devices and data management systems (Hong *et al.*, 2014). This dimension was measured through five items (see Table 1 indicators TPL1 to TPL5). On the other hand, human lean practices are defined as the implementation of socio-behavioral aspects of continuous improvement programs of manufacturing firms, which generally include the empowerment of workers and continuous improvement through systematic initiatives. This dimension was measured through 5 items, see Table 1 indicators HLP1 to HLP5.

In addition, for the measurement of CE, an adaptation was made to the scale proposed by Zhu *et al.* (2010), who considered that CE practices can be measured through eight items (see Table 1 indicators CEC1 to CEC8). Finally, for the measurement of sustainable performance, an adaptation was made to the scale proposed by Gadenne *et al.* (2012), for which this dimension was measured through five items (see Table 1 indicators SPE1 to SPE5). 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).

3.3 Data analysis

The present empirical study data were generated through the design and application of an information collection instrument and analyzed using the SmartPLS 3.3 software. In addition,

Indicators	Constructs	Factor loads (p-value)
Technical lean practices (TLP)		
Cronbach's Alpha: 0.957; Dijkstra – Henseler's rho (ρA): 0.957; CRI (ρc): 0.966; AVE: 0.852		
TLP1	It has a Just-in-Time system	(0.915; 0.000)
TLP2	It has a program of total productive maintenance (TPM)	(0.916; 0.000)
TLP3	It has equipment and automation technology	(0.917; 0.000)
TLP4	It has a value stream mapping (VSM)	(0.936: 0.000)
TLP5	It has a continuous improvement program (CI)	(0.930; 0.000)
Human lean practices (HLP)		
Cronbach's Alpha: 0.943; Dijkstra–Henseler's rho: 0.942; CRI: 0.956; AVE: 0.815		
HLP1	Has a skills development program	(0.823; 0.000)
HLP2	It has a teamwork and collaboration program	(0.928; 0.000)
HLP3	Has a behavior and commitment program	(0.917; 0.000)
HLP4	It has a management and leadership program	(0.923: 0.000)
HLP5	It has a structure and organization program	(0.917; 0.000)
Circular economy (CEC)		
Cronbach's Alpha: 0.949; Dijkstra–Henseler's rho (ρA): 0.950; CRI (ρc): 0.958; AVE: 0.739		
CEC1	There is an environmental commitment by senior management	(0.854; 0.000)
CEC2	There is support for environmental management from middle managers	(0.845; 0.000)
CEC3	There is cooperation between the different departments or functional areas to improve the environmental practices of the organization	(0.864; 0.000)
CEC4	There is a training program for employees and workers of the organization on environmental issues	(0.871; 0.000)
CEC5	There is a total environmental quality management program	(0.876; 0.000)
CEC6	There are permanent audit programs for the organization's environment, such as ISO 14000	(0.879; 0.000)
CEC7	Eco-labels are used in most of the products generated by the organization	(0.870; 0.000)
CEC8	There is a pollution prevention program for waste generated by the organization, such as clean production	(0.815; 0.000)
Sustainable performance (SPE)		
Cronbach's Alpha: 0.940; Dijkstra–Henseler's rho (ρA): 0.940; CRI (ρc): 0.954; AVE: 0.807		
SPE1	It has among its objectives the care of the environment	(0.901; 0.000)
SPE2	Makes great efforts to promote environmental care	(0.878; 0.000)
SPE3	It has a great commitment to invest in projects that protect the environment	(0.905; 0.000)
SPE4	Frequently discusses the results of environmental care performance within the organization	(0.907; 0.000)
SPE5	They have an excellent performance in protecting the environment compared to other companies in the same industry or sector	(0.899; 0.000)

Note(s): CRI: Composite reliability index; AVE: Averaged extracted variance
Source(s): Created by authors

Table 1. Measurement model assessment

a statistical analysis was conducted based on the structural equation model focused on the use of Partial Least Squares (PLS-SEM), which allowed the measurement of the existing effects in the interconnection between LM practices, CE and sustainable performance. Additionally, the evaluation of the reliability of the measurement scales of LM, CE and sustainable performance was carried out using Cronbach's Alpha, Composite Reliability Index (CRI), Dijkstra–Henseler rho and Average Variance Extracted (AVE) (Hair *et al.*, 2019), whereas discriminant validity was evaluated through three fundamental elements, i.e. Fornell and Larcker Criterion, Crossed Loadings and Heterotrait-Monotrait (HTMT) ratio (Henseler *et al.*, 2015; Hair *et al.*, 2019). See Table 1.

The results obtained from the application of PLS-SEM, see Table 2, showed that Cronbach's Alpha, CRI and Dijkstra-Henseler rho had values that ranged between 0.940 and

Table 2.
Measurement model

PANEL A. Reliability and validity Variables	Cronbach's alpha	CRI	Dijkstra-Henseler rho	AVE
Technical Lean Practices	0.957	0.966	0.957	0.852
Human Lean Practices	0.943	0.956	0.942	0.815
Circular Economy	0.949	0.958	0.950	0.739
Sustainable Performance	0.940	0.954	0.940	0.808

PANEL B. Fornell-Larcker Criterio					Heterotrait–Monotrait ratio (HTMT)			
Variables	1	2	3	4	1	2	3	4
1. Technical lean practices	*0.923*							
2. Human lean practices	0.543	*0.903*			0.568			
3. Circular economy	0.274	0.308	*0.859*		0.286	0.324		
4. Sustainable performance	0.398	0.464	0.292	*0.898*	0.419	0.492	0.307	

Note(s): TLP: Technical Lean Practices; HLP: Human Lean Practices. CEC: Circular Economy; SPE: Sustainable Performance. **PANEL B:** Fornell-Larcker Criterion: Diagonal elements (italic) 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
Reliability, validity and discriminant validity
Source(s): Created by authors

0.957; 0.954–0.966; and 0.940–0.957, respectively, which indicated that they were excellent data as all were above the values recommended by Bagozzi and Yi (1988) and Hair *et al.* (2019). In addition, AVE had values that range between 0.739 and 0.852, which were higher than the values recommended by Fornell and Larcker (1981) and Bagozzi and Yi (1988), whereas the Fornell and Larcker Criterion was significant because the values of AVE were greater than the square of the correlations between each pair of constructs. In the case of HTMT, it had values that ranged between 0.286 and 0.568, which were lower than the recommended value of 0.85 (Henseler *et al.*, 2015). These three criteria indicated the existence of discriminant validity in the three measurement scales used.

Additionally, given that the data were collected using the same instrument applied to the same informant (company manager), biases that could alter the responses could lead to Type I (false positive) or Type II (false negative) errors. To address this issue, the evaluation of common method variance (CMV) was employed following the recommendations of Podsakoff *et al.* (2012).

Traditionally, the method most used by researchers to verify the possible effect of CMV is Harman's one-factor test (Podsakoff *et al.*, 2003), which consists of subjecting practically all the items of the scales to exploratory factorial analysis (EFA), forcing the extraction of a single factor (Andersson and Bateman, 1997; Mossholder *et al.*, 1998; Iverson and Maguire, 2000; Aulakh and Gencturk, 2000). Thus, to verify the suitability of data and the possible effect of CMV, an EFA was applied, through the principal components method and with varimax rotation, calculating the Kaiser–Meyer–Olkin coefficients (KMO) and Bartlett's sphericity test. The results obtained supported the use of EFA with data from this sample, with a KMO value = 0.865 and Bartlett test statistically significant [X^2 (276) = 8,972.77, $p < 0.000$]. If there was a CMV problem, the common factor extracted should have a value greater than 50% of the variance (Podsakoff *et al.*, 2003), but the common factor extracted from the data was 36.12%, which is lower than the recommended value. This suggested that CMV was not a threat to the sample data of this study and did not significantly affect the relationships between the variables of the research model (Podsakoff *et al.*, 2012).

4. Results

In order to test the hypotheses formulated as part of the theoretical research model, see Figure 1, the use of Structural Equation Modeling (SEM) through partial least squares (PLS-SEM) was considered appropriate, with the use of SmartPLS software (Ringle *et al.*, 2015), since this statistical technique is the most effective when the research models or theories have not been widely developed in the literature (Hair *et al.*, 2019). SEM has been widely employed in various disciplines of scientific knowledge, particularly in social sciences (Hair *et al.*, 2012; Sarstedt *et al.*, 2014; do Valle and Assaker, 2015; Richter *et al.*, 2016), or when the fundamental objective of using PLS-SEM statistical technique is the prediction and explanation of the relationship between the constructs of a research model (Rigdon, 2012). This allows a better explanation of the measurement error and it has higher statistical power than that of multiple sum-of-scores regression (Hair *et al.*, 2021).

The results obtained from the application of PLS-SEM showed acceptable levels of the estimated data by generating an adjusted R^2 greater than 0.1 (Reinartz *et al.*, 2009; Henseler *et al.*, 2014; Hair *et al.*, 2019). Furthermore, the value of 0.052 of the standardized root mean square residual (SRMR) was lower than the value of 0.080 recommended by Hu and Bentler (1998) and higher than the value of HI99 (0.034) recommended by Dijkstra and Henseler (2015). Moreover, the values 0.335 of the geodetic discrepancy (dG) and 0.821 of the unweighted least squares discrepancy (dULS) were higher than the values of HI99 (0.215 and 0.678, respectively). In addition, the value 0.823 of the normal fit index (NFI) was higher than the 0.7 recommended by Bagozzi and Yi (1988). The value 0.116 of the root mean square residual covariance (rms Theta) was below the value of 0.12 (Henseler *et al.*, 2014), which allowed verifying the significance and adjustment of the research model used in this study (Dijkstra and Henseler, 2015). Table 3 shows, in greater detail, the results obtained from the significance and adjustment of the research model.

5. Discussion

The results obtained provide empirical evidence that supports hypothesis *H1*, which indicates that the implementation of LM practices has significant positive effects on the sustainable performance of manufacturing firms in the automotive sector (0.441; p-value 0.000). This finding

Paths	Path (*t-value; p-value*)	95% confidence interval	f^2	Support
LMP → SPE (H1)	0.441 (8.614; 0.000)	[0.336–0.537]	0.233	Yes
LMP → CEC (H2)	0.331 (6.330; 0.000)	[0.232–0.439]	0.123	Yes
CEC → SPE (H3)	0.147 (3.194; 0.001)	[0.063–0.241]	0.026	Yes
Indirect effects				
LMP → CEC → SPE (H4)	0.048 (2.540; 0.011)	[0.018–0.093]	0.019	Yes
Endogenous variable	**Adjusted R^2**	**Model fit**	**Value**	**HI99**
		SRMR	0.052	0.034
CEC	0.113	dULS	0.821	0.678
SPE	0.259	dG	0.335	0.215
		NFI	0.823	
		rms Theta	0.116	

Note(s): LMP: Lean Manufacturing Practices; TLP: Technical Lean Practices; HLP: Human Lean Practices; LM: Lean Manufacturing; SPE: Sustainable Performance; CE: Circular Economy. 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; NFI: normal fit index; HI99: bootstrap-based 99% percentiles
Source(s): Created by authors

Table 3.
Structural model

is aligned with those of Buer *et al.* (2020), Chavez *et al.* (2020), Afum *et al.* (2020) and Agyabeng-Mensah *et al.* (2020), who found a positive relationship between the implementation of LM practices and the sustainable performance of manufacturing companies. In addition, these same results also indicated the acceptance of hypothesis *H2*, by providing robust empirical evidence that established that LM practices generate significant positive effects on CE (0.331; *p*-value 0.000), when the second has been implemented by automotive companies. This finding is consistent with the results obtained by Nadeem *et al.* (2019), Hedlund *et al.* (2020), Kurdve and Bellgran (2021) and Schmitt *et al.* (2021), which suggested that the implementation of LM practices does support circularity in manufacturing companies. Nevertheless, the findings contradict, to some degree, the findings of Kalemkerian *et al.* (2022) which suggested that the contribution of Green Lean to the implementation of CE practices is limited.

Likewise, the results obtained also established that CE has significant positive effects on the sustainable performance of manufacturing firms in the automotive industry (0.147; *p*-value 0.000), hence providing robust empirical evidence in favor of hypothesis *H3*. This finding is similar to the results obtained by Angelis-Dimakis *et al.* (2016), Korhonen *et al.* (2018), Jia *et al.* (2020) and Ciliberto *et al.* (2021), who found a positive relationship between CE and sustainable performance.

Finally, regarding the effects of the mediation exerted by CE on the interconnection between LM practices and sustainable performance, the results obtained provide empirical evidence to accept hypothesis *H4*. This indicates the existence of a significant positive indirect effect generated by CE (0.048; *p*-value 0.001) between LM and sustainable performance in manufacturing firms in the automotive industry. This result shows that only a very small part of LM practices are transferred to sustainable performance through the role played by CE (0.048), which allows us to conclude that CE can be considered as an explanatory variable but at a low level of the relationship between LM practices and sustainable performance in companies in the automotive industry. However, the results also show that the adoption and implementation of LM practices by manufacturing firms in the automotive industry generates a higher sustainable performance than that obtained through the mediation of CE, for which the results can be greater if these two variables are directly related.

5.1 Theoretical and practical implications

The results obtained in this study have various implications for the theory of lean, CE and sustainability performance as well as for managers of manufacturing firms in the automotive industry, manufacturing organizations and policymakers. First of all, although the significant contribution that LM practices make to the improvement of sustainability in manufacturing companies is well established in the literature, there are relatively few studies that have incorporated socio-technical practices of LM, even though these types of practices offer a holistic view of LM (Osadume and Ojovwo, 2021; Dieste *et al.*, 2021). For this reason, this study fills this gap by proposing a research model that contemplates socio-technical practices of LM to provide a holistic point of view that generates a more robust explanation of the relationship between LM and sustainable performance (Hong *et al.*, 2014). In this sense, the results obtained in this study reveal that socio-technical practices of LM have a significant positive influence on sustainable performance and CE of manufacturing firms in the automotive industry. This is consistent with the findings of Wong *et al.* (2018) and Wong *et al.* (2020). Thus, socio-technical practices of LM improve the capabilities of manufacturing firms to design and remanufacture eco-products, not only incorporating reused and recycled materials but also reducing the generation of industrial solid waste, minimizing the use of non-renewable energy and consumption of natural resources, which could generate a more sustainable production by reducing the levels of pollution to the environment and the consumption of virgin raw materials (Agyabeng-Mensah *et al.*, 2020; Afum *et al.*, 2021; Agyabeng-Mensah *et al.*, 2021).

Second, regarding CE, the results obtained in this study reveal that LM practices and sustainable performance are positively related to CE activities adopted and implemented by manufacturing firms in the automotive industry. These results are particularly supported by the few studies published in the literature, which indicate that CE contributes positively to the improvement of sustainable performance (Korhonen *et al.*, 2018; Jia *et al.*, 2020; Ciliberto *et al.*, 2021). Furthermore, Bai *et al.* (2020) found that the flexibility of LM practices has a positive influence on CE, which is particularly consistent with the results found in this study. Particularly, this study's results suggest that zero waste practices implemented by manufacturing firms, as part of LM practices, positively impact CE activities.

Additionally, the results obtained in this study reveal that, if companies want to improve their level of sustainable performance, they must adopt and implement CE activities inside and outside the organization, both in the short and long term, if manufacturing firms implement practices like reuse and recycling of materials, they can stimulate the manufacturing and development of eco-products (Tseng *et al.*, 2020). Therefore, it is possible to establish that manufacturing firms in the automotive industry that implement CE practices will have better opportunities to develop new eco-products and production processes that promote the use of renewable energies, reduction of solid waste in industrial plants, consumption of drinking water and the use of natural resources in the production of remanufactured eco-products that are friendlier to the environment and improve sustainable performance (Tseng *et al.*, 2020).

Third, despite the increase in environmental regulations in most countries around the world, there is still a significant number of manufacturing firms that continue to generate serious environmental and sustainability problems. Gupta *et al.* (2021) argue that the combination of LM practices and CE can substantially increase the eco-innovation of products, which could contribute to sustainable development and the improvement of the sustainable performance of organizations. However, just a handful of studies have analyzed the combination of these two important approaches and the few studies that have done so have not considered CE in situations related to sustainability. In contrast, LM practices have been oriented in the context of improving production operations, hence the importance of this study, which is supported by the findings of Kirchherr *et al.* (2017).

In this context, this study contributes to the literature on lean production through the analysis of the relationship between LM practices, sustainable performance and CE. On the one hand, this study enriches the understanding of the effects of LM practices, both on sustainable performance and on CE of manufacturing firms in the automotive industry, since the results obtained promote LM practices of zero industrial waste and recycling of materials. This indicates that the use of the model of socio-technical practices of LM can not only generate new knowledge that can be transformed to facilitate the adoption and implementation of LM practices and CE (Dieste *et al.*, 2021) but also for the implementation of zero waste practices and material recycling (Agyabeng-Mensah *et al.*, 2021).

6. Conclusions

The results obtained in this study allow three main conclusions to be drawn, the first of which is related to the use of the research model since, on the one hand, it generates a high internal correlation between socio-technical practices of LM, sustainability performance and CE, which allowed the acceptance of the four proposed research hypotheses. On the other hand, this study offers a holistic vision by using indicators that have been scarcely analyzed in the lean production literature. In addition, the publication of empirical studies that have used technical lean practices and human lean practices for the measurement of LM as well as the existing relationship with sustainable performance and CE, have received little attention from researchers, academics and industry professionals, compared to those studies that have focused on its conceptualization (Agyabeng-Mensah *et al.*, 2021; Lim *et al.*, 2022).

The second conclusion is that considering the sustainability requirements, most manufacturing firms, including those that make up the automotive industry, have only focused on activating technology that allows them to exploit competitive advantages in LM practices or clean production. However, managers must understand that not only should these types of practices be considered to improve sustainable performance but they should also incorporate CE. This will facilitate not only improving sustainable performance but also substantially reducing CO_2 and greenhouse gas emissions into the atmosphere, industrial solid waste, drinking water consumption and material recycling through zero industrial waste practices, which are integrated into both LM and CE.

The third conclusion is that the results obtained from the combination of LM and CE indicate that these two concepts are fully compatible since the results obtained show the existence of a positive influence of both concepts on sustainable performance. Therefore, it is possible to conclude that the method of technical lean practices and human lean practices, as ways of measuring LM, is an innovative way to implement CE in production operations as well as in sustainable performance management of manufacturing firms in the automotive industry. In general terms, it is possible to conclude that LM practices are considered in the lean production literature as an excellent option for organizations to explain both successes and failures in generating more sustainable performance and improving CE (Agyabeng-Mensah *et al.*, 2021; Lim *et al.*, 2022).

6.1 Research limitations and future research

This empirical study has several limitations that are important to consider when performing the interpretation and implications of the results obtained. The first limitation refers to the scales used to measure LM practices, sustainable performance and circular CE as they were measured with subjective indicators obtained through surveys (subjective data). Therefore, in future studies, it will be convenient to incorporate objective data from manufacturing firms (e.g. percentage in the reduction of time in production processes; percentage in the reduction of production costs, financial statements, number of sustainable projects with financing, etc.), in order to verify whether or not the results obtained are similar to those obtained in this study.

A second limitation of this study is that the relationship between LM practices, sustainable performance and CE may have more significant positive results if a more specific combination of LM practices is used across a more holistic research model that generates the discrimination of the multifaceted concept of LM. Therefore, in future studies, LM practices with all their dimensions should be considered to determine if the effects it has both on sustainable performance and CE of manufacturing firms differ or not from the results obtained in this study.

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