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Open Eco-Innovation and Firm Performance: Sustainable Development Mediating Role Is the Solution?

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Abstract

Concern about the degradation of natural resources and the planet's environment is an issue that is gaining more interest every day from the scientific, business and government community, especially in the development and implementation of business strategies that reduce the use of natural raw materials and pollution levels. In this sense, open eco-innovation activities are gaining attention in the literature as one of the business strategies that allow organizations to reduce environmental degradation and the use of raw materials. However, despite the growth in interest in the analysis of this topic, there are relatively few studies that have provided empirical evidence of its importance, in addition to the fact that little is known about the effects of eco-innovation activities. Open in the practices of sustainable development and at the level of business performance. Therefore, this research has as its main objective to fill this existing gap in the literature and provide robust empirical evidence, through an extensive review of the literature. Likewise, a self-administered questionnaire was distributed to a sample of 300 manufacturing companies from the five most important sectors in Mexico, analyzing the data set through confirmatory factor analysis and structural equation models using partial least squares (PLS-SEM). The results obtained suggest that open eco-innovation practices have a significant positive influence on both sustainable development practices and business performance of manufacturing companies, and, in turn, sustainable development practices substantially improve the effects of innovation. open eco-innovation in business performance when it is used as a mediating variable between both constructs.

Keywords

Open Eco-Innovation, Sustainable Development, Firm Performance,

Manufacturing Industry

1. Introduction

Researchers and academics in the field of innovation are increasingly interested in the potential use of open innovation in eco-innovation practices, which is reflected in the gradual increase in the number of articles published in the literature (Pereira et al., 2020). The importance of relating both concepts has increased notably from the middle of the second decade of the current century, with the appearance of the term open eco-innovation (Ghisetti et al., 2015; González-Moreno et al., 2019), which practically refers to the openness that manufacturing companies have to environmental innovation (Russo-Spena & Di Paola, 2020), sustainable development innovation (Bogers et al., 2020), and interorganizational collaboration in the development of eco-innovation practices (Melander et al., 2017; Pereira et al., 2020), which improves business performance (Sanni & Verdolini, 2022).

Recently, the publication of theoretical and empirical studies has focused, particularly, on providing theoretical evidence of the importance of open eco-innovation in achieving the economic, environmental, and social objectives of companies (Chistov et al., 2021), thus contributing to the transition of sustainable development of society (Russo-Spena & Di Paola, 2020; Kiefer et al., 2021). However, despite the growing interest in the academic and professional literature in the analysis of open eco-innovation in the sustainability activities of manufacturing companies (Chistov et al., 2021), academic research on open eco-innovation it is currently in an initial stage, since the definition of the concept is still not clear in the literature (González-Moreno et al., 2019), for which this line of research requires a greater theoretical analysis and the contribution of evidence empirical evidence of this existing relationship (Chistov et al., 2021; Naruetharadhol et al., 2021).

In this sense, the objective of this study is the analysis and discussion of the relationship between open eco-innovation, sustainable development, and business performance, as well as how sustainable development acts as a mediating role between open eco-innovation and the level of business performance of manufacturing companies. To achieve this objective, an empirical study was carried out in the manufacturing companies of Mexico, using a sample of 460 observations, and estimating the research model through the use of Partial Least Squares Structural Equation Modeling (PLS-SEM), with the support of SmartPLS software (Ringle et al., 2015). The manufacturing industry in Mexico is essential for two basic reasons, firstly, because it is the industry that is most incompatible with caring for the environment and sustainability (Scur et al., 2019) and, secondly, it is the industry that generates the greater contribution to the national GDP (INEGI, 2020).

The results obtained in this research provide robust empirical evidence that shows that open eco-innovation has a significant positive effect on sustainable de-

velopment and business performance. This last relationship is partially mediated by sustainable development, since when this variable mediates between open eco-innovation and business performance, the level of business performance is more significant. In addition, this study contributes to the literature in two aspects, on the one hand, the limited number of studies published in the current literature that analyze open eco-innovation (González-Moreno et al., 2019; Chistov et al., 2021; Sanni & Verdolini, 2022) and, on the other hand, to the generation of knowledge of the way in which open eco-innovation affects business performance, through the mediating role of sustainable development (Naruetharadhol et al., 2021).

2. Literature Review

2.1. Open Eco-Innovation and Firm Performance

Several studies have attempted to formally define the concept of open eco-innovation (Chistov et al., 2021). In recent research, this concept has been described, for example, "*as the search for external knowledge through information gathering, R&D acquisition, and exchange strategies*" (Mothe & Nguyen, 2017: p. 2), or "*as the possibility of complementing internal investment in green resources with knowledge and skills from partners in collaborative networks*" (Russo-Spena & Di Paola, 2020: p. 3). However, one of the most widely accepted definitions in the literature is the one proposed by Ghisetti et al. (2015: p. 1081), who define open eco-innovation as "*environmentally responsible modes of knowledge acquisition and absorption, accompanied by relationships with environmentally committed partners and integration into sustainability-oriented innovation systems*".

Furthermore, Ghisetti et al. (2015) argue that openness to external knowledge can help manufacturing firms overcome internal obstacles in the adoption and development of eco-innovations, while improving their business performance. Recently, the academic and professional community have explored the importance of the concept of open eco-innovation, in the context of both its potential to solve the main problems that afflict global society, and the substantial improvement firm performance (Bogers et al., 2020), particularly in the access to external knowledge that manufacturing companies may have that can help eliminate the classic barrier to eco-innovation, such as the lack of resources and capabilities (Ben Amara & Chen, 2020). This business strategy receives various names in the literature, such as sustainable open innovation (Bogers et al., 2020), environmental open innovation (De Marchi, 2012a, 2012b; Russo-Spena & Di Paola, 2020), open eco-innovation mode (Ghisetti et al., 2015; Fabrizi et al., 2018), open ecological corporation (Störmer, 2008), collaborative entrepreneurial corporation for the circular economy (Veleva & Bodkin, 2018), among other different names, terms and definitions presented in the study conducted by Chistov et al. (2021).

However, despite the rapid growth in the publication of studies on open eco-innovation, both knowledge of this concept and its theoretical structure are still in an embryonic stage (González-Moreno et al., 2019; Chistov et al., 2021), for

which the contribution of empirical evidence of the relationship between open eco-innovation and firm performance is required (Sanni & Verdolini, 2022). In order to remedy this problem, some bibliometric analysis studies began to be published in the literature that try to explain and define the concept of open eco-innovation (Fernández, 2019; Chistov et al., 2021), which analyze interorganizational cooperation in open eco-innovation practices (Pereira et al., 2020), cooperation in sustainable open eco-innovation practices (Fernández, 2019), collaboration in eco-innovation of green products (Melander, 2017), clarification of the sustainability of the concept of open eco-innovation (Rauter et al., 2017), and, particularly, its relationship with the level of firm performance of specific sectors of the economy (Sáez-Martínez et al., 2016; Avellaneda-Rivera et al., 2019).

Additionally, the adoption and implementation of open eco-innovation as a business strategy can help manufacturing companies to substantially improve firm performance in various ways, such as increased sales, entry into new markets, growth in its level of competitiveness, increase in financial performance, competitive advantages growth, differentiation of its products with respect to its main competitors, the growth of its corporate image and the improvement of environmental performance (Doran & Ryan, 2016; Rossi et al., 2019). Furthermore, open eco-innovation considered as a new sustainable business model is important for all manufacturing companies in any industry because the integration of environmental and economic elements is emerging as a new way of doing business (Franceschelli et al., 2018). Thus, considering the information presented above, it is possible to propose the following research hypothesis.

H1: *The higher level of open eco-innovation*, *the higher level of firm performance*.

2.2. Open Eco-Innovation and Sustainable Development

Recently, the concept of open eco-innovation has been recognized in the literature as an essential mechanism for the sustainable development of manufacturing companies, as well as a robust element that generates social, environmental, and economic benefits for companies (Srisathan et al., 2020), through the innovative solution of sustainability problems (Naruetharadhol et al., 2020). In addition, in recent years, the economic performance sought by manufacturing companies is closely linked to environmental and social performance (Naruetharadhol et al., 2021), precisely because open eco-innovation practices are related to the proper use of natural resources of the countries, to produce goods and services that allow a significant decrease in the levels of industrial waste and environmental pollution (Naruetharadhol et al., 2021).

In this sense, open eco-innovation and sustainability need to be analyzed from a holistic point of view, in such a way that it allows an adequate analysis of the implementation of eco-innovation policies aimed at improving the sustainable development of companies (Naruetharadhol et al., 2020). Few studies published in the literature have tried to carry out this analysis (e.g. Ghisetti et al., 2015; Tri-

guero et al., 2018; Yang & Roh, 2019). Thus, Ghisetti et al. (2015) considered the non-linear impact of the absorptive capacity of external knowledge resources on the adoption and implementation of open eco-innovation in manufacturing companies in Europe, finding that sustainability is important for the growth of manufacturing open eco-innovation practices, since these authors focused on measuring open eco-innovation as the number of environmental innovations introduced and adopted in companies (Ghisetti et al., 2015).

Triguero et al. (2018) found similar results in the relationship between open eco-innovation and sustainability (innovation in the efficiency of materials, innovation in energy efficiency, and environmental responsibility), in food and beverage companies in Spain. Yang and Roh (2019) found that the collaboration of open eco-innovation with large manufacturing firms generates better results than with small companies, for which they suggested that small companies should consider other small firms to collaborate in open eco-innovation activities. However, companies (small and large) that have an environmental management and sustainable development system tend to achieve better results in the adoption and implementation of open eco-innovation, for which it is possible to establish that this type of firms need to work more on open eco-innovation activities so that they are able to achieve an increase in their environmental performance and sustainable development (Khan et al., 2019).

Furthermore, Perl-Vorbach et al. (2014) and Rauter et al. (2017) carried out a bibliometric review in the context of open eco-innovation and sustainability, finding several published studies that related both concepts, while Melander (2017) focused his study on the relationship between open eco-innovation and sustainability in a context of collaboration between companies, finding a positive relationship. Fernández (2019) included in his study open eco-innovation related to environmental innovation in a context of collaboration between firms, finding positive results. In a more recent study, Pereira et al. (2020) focused their search on the relationship of open eco-innovation and sustainability, finding studies that relate both constructs. These contributions play an essential role in understanding and mapping the concept of open eco-innovation and the sustainability of manufacturing companies (Chistov et al., 2021). Therefore, considering the information presented above, it is possible to propose the following research hypothesis.

H2: *The higher level of open eco-innovation*, *the higher level of sustainable development.*

3. Sustainable Development as a Mediating Variable

Sustainable Development and Firm Performance

In the last two decades, sustainable development practices are essential not only for government authorities, but also for companies and society in general (García et al., 2017), since sustainable development practices, including natural resource management and risk management, have a strong influence on decision-making and the level of firm performance of organizations (Rahi et al., 2022). In addition,

manufacturing companies that have implemented sustainable development practices have commonly improved efficiency, customer loyalty, business reputation, access to capital, capacity for innovation, and firm performance (Ferrero-Ferrero et al., 2016; Arrive et al., 2019). However, the relationship between sustainable development and firm performance is highly controversial, and it is a topic that is considered in the current literature as inconclusive that needs to be further investigated (Nasrallah & El Khoury, 2021).

In this sense, various studies published in the literature have provided empirical evidence that demonstrates that sustainable development practices increase firm performance (Tarmuji et al., 2016; Alareeni & Hamdan, 2020), with several of these studies focusing on the analysis of one or the three dimensions of sustainable development (social, environmental, and economic), and its relationship with firm performance (Yusof et al., 2016). However, despite the existence of various studies that have found a positive relationship between sustainable development and firm performance, in the literature these results are considered ambiguous and inconclusive (Rowley & Berman, 2000; Van Beurden & Gössling, 2008; Revelli & Viviani, 2015), since other studies have found a negative relationship, and others that found no relationship between sustainable development and firm performance (Orlitzky et al., 2003; Alareeni & Hamdan, 2020).

In addition, studies published in the literature that have considered sustainable development as a business strategy, have found a significant increase in the utility levels of companies (Albuquerque et al., 2012), and when it has been considered as an indicator of corporate social responsibility and corporate reputation, have also found increased financial and firm performance (Steyn, 2014; Buallay, 2019; Alsayegh et al., 2020). Therefore, it is possible to establish that the adoption of sustainable development practices helps manufacturing companies to improve their competitive advantages (Lourenço et al., 2012), increase the level of productivity (Albuquerque et al., 2019), reduce environmental risks (Hoepner et al., 2019), reduce risks in sustainable investments (Buallay, 2019), reduce operating and financial costs (Eliwa et al., 2019), and, particularly, increase the level of firm performance (Broadstock et al., 2020).

Additionally, there are studies published in the literature that analyze the relationship between each of the three dimensions of sustainable development and firm performance, finding different results (Rahi et al., 2022). Some studies identified a positive relationship between environmental and economic sustainability with firm performance, but not with social sustainability (Salama, 2005; Friede et al., 2015), in contrast, other studies found a negative relationship between these constructs (Fauzi et al., 2007; Arvidsson, 2014). Still other studies found a positive relationship between social sustainability and firm performance (Shahzad & Sgarfman, 2017), but other studies found a negative relationship between these two constructs (Smith & Sims, 1985; Peng & Yang, 2014), and others studies found no relationship between both constructs (Fauzi et al., 2007; Weston & Nnadi, 2021). In conclusion, published studies show ambiguous and inconclusive results be-

tween sustainable development practices and firm performance, which is why it is necessary to delve further into their study (Rahi et al., 2022). Thus, considering the information presented above, it is possible to propose the following research hypothesis.

H3: *The higher level of sustainable development, the higher level of firm performance.*

On the other hand, sustainable development practices are considered in the literature as a social, environmental, economic, and strategic potential that can increase in firm performance in manufacturing companies, through financial benefits (Escoubés, 1996). However, the adoption and implementation of open eco-innovation can contribute to substantially improve business results, since it is commonly considered as an innovative business model that contributes to improving environmental regulations, as well as reducing fines, lawsuits, and threats for non-compliance with environmental regulations (Guo et al., 2017). Thus, sustainable development refers to processes management and methods by which companies reduce the effects of their activities on environmental aspects (Lun et al., 2016), but open eco-innovation activities can further increase firm performance, not only producing environmentally friendly products, but also with the development of sustainability activities (Katsikeas et al., 2016).

In this sense, manufacturing companies have greater opportunities to improve firm performance, if they generate eco-products with the standards and quality demanded by the market (Guo et al., 2017), if they consider sustainable development within their strategy. In this order of ideas, Molina-Azorín et al. (2015) that environmental and sustainability management systems play a fundamental role in the definition and communication of the policies and objectives of manufacturing companies, since consumers increase their purchases of those products that are friendly to the environment, increasing thereby firm performance of companies. Lee and Min (2015), suggested that those companies that are more proactive in sustainable development, substantially improve their financial results and firm performance, through the implementation of open eco-innovation activities.

Hamdoun et al. (2018) concluded that environmental management through certification of ISO 14,001 standard, is one of the best ways to improve sustainable development in manufacturing companies, which not only serves as a vehicle to increase the level of firm performance of organizations, but also to enhance open eco-innovation. Additionally, Hamdoun et al. (2018) suggested that the adoption of particular activities of sustainable development (e.g. management policies for green activities, adoption of the 3 Rs, development of products that generate little pollution, selection of suppliers with green activities), represent innovations that generate and transfer knowledge among the participating companies. This is an argument that is generally used in the literature to establish the relationship between open eco-innovation and firm performance, since the implementation of sustainable development plays a mediating role between these two variables (Nauetharadhol et al., 2021).

In this context, it is possible to establish that the implementation of sustainable development in manufacturing companies plays a role of mediation rather than moderation between open eco-innovation and firm performance (Khan et al., 2019), particularly in those manufacturing firms of green industries. However, in companies that belong to non-green industries, sustainable development can also be considered as a mediating variable, if firms increase their environmental activities through the intervention of open eco-innovation, thereby improving firm performance (Calza et al., 2017). Therefore, it is possible to conclude that improving environmental practices can significantly contribute to improving the relationship between open eco-innovation and firm performance (Naruetharadhol et al., 2021). Thus, considering the information presented above, it is possible to propose the following research hypotheses.

H4: *Sustainable development has a mediating effect between open eco-innovation and firm performance.*

In the research model (**Figure 1**), which is presented below, the four research hypotheses planted in this study can be observed in more detail.

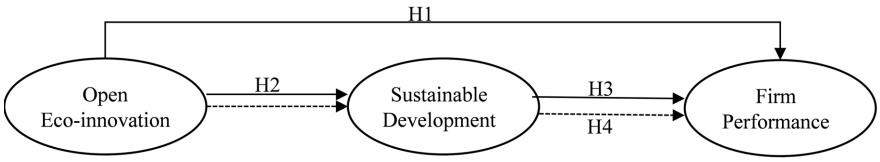

Figure 1. Research model.

4. Methodology

To respond to the hypotheses raised in the research model, an empirical study was carried out in manufacturing firms of metalworking, automotive, chemical, aerospace and textile industries in Mexico, which together represented around 5000 companies. In addition, it is important to point out that the companies surveyed belong to different organizations and business chambers, for which the study was not focused on a particular business association group. Additionally, a survey was designed to collect information, which was applied to a sample of 300 manufacturing firms selected by simple random sampling with an error of ±5 and a reliability level of 95%, applying the survey during April to September 2020 in eight states of the country, where most of the manufacturing firms in this industry are concentrated.

Measurement Development

As a preliminary step to the reliability and validity analysis of the measurement scales used in this study, the measurement scales for open eco-innovation, sustainable development, and firm performance were defined. Thus, for the measurement of open eco-innovation, an adaptation was made to the scale proposed by Chiou et al. (2011), and García-Granero et al. (2018), measuring products open eco-innovation through 2 items, processes open eco-innovation through 2 items,

and management open eco-innovation through 2 items. In addition, to measure sustainable development, an adaptation was made to the scale developed by Adger and Jordan (2009), and Goswami (2014), who measured it through social sustainability with 6 items, environmental sustainability with 6 items, and economic sustainability with 6 items. Finally, for the measurement of firm performance, an adaptation was made to the scale proposed by Bag (2014), being measured by means of 6 items. Table 1 shows the items of the measurement scales used for the three constructs.

Table 1. Measurement model assessment.

Indicators	Constructs	Factor loads	Q^2
Open Eco-innovation (OEI)			
Cronbach's Alpha: 0.942; Dijkstra-Henseler's rho (ρA): 0.947; CRI (ρc): 0.954; AVE: 0.776			
OPE1	Developing new products/services with low environmental impacts	0.887	
OPE2	Reducing the use of raw materials	0.889	
ORE1	Reusing the components and reducing chemical waste	0.906	
ORE2	Using the innovative, environmental-friendly technologies to save energy	0.885	
OME1	Cooperating with customers and/or clients for green innovation management	0.875	
OME2	Cooperating with stakeholders to support strategic eco-innovation development	0.841	
Social Development (SSD)			
Cronbach's alpha: 0.934; Dijkstra-Henseler's rho (ρA): 0.935; CRI (ρc): 0.948; AVE: 0.753; Q^2: 0.533			
SSD1	Contribuye a la reducción y/o erradicación del nivel de pobreza de la sociedad donde se localiza la empresa.	0.843	0.489
SSD2	Contribuye a la mejora de la calidad de la educación, la seguridad social, vivienda y otros aspectos del bienestar de la comunidad donde se localiza la empresa.	0.853	0.486
SSD3	Contribuye a la mejora de la calidad de la interacción, el compromiso y la capacitación de la sociedad de la comunidad donde localiza la empresa.	0.843	0.526
SSD4	Tiene una política de igualdad de oportunidades para todos los géneros de su personal	0.860	0.555
SDD5	Tiene una política de desarrollo intelectual y de habilidades de su personal	0.916	0.582
SSD6	Tiene una política de diálogo social con todo su personal	0.887	0.561
Environmental Development (MSD)			
Cronbach's Alpha: 0.900; Dijkstra-Henseler's rho (ρA): 0.902; CRI (ρc): 0.923; AVE: 0.667; Q^2: 0.499			
MSD1	Contribuye en la reducción del nivel de contaminación que afecta el medioambiente	0.802	0.499
MSD2	Contribuye en la reducción de los efectos de la industrialización y la actividad humana	0.755	0.429
MSD3	Contribuye en el uso adecuado de los recursos para preservarlos a futuras generaciones	0.801	0.470
MSD4	Tiene una política de eficiencia y uso adecuado de la energía, y de energías renovables	0.828	0.478
MSD5	Tiene una política de gestión de las emisiones y desechos generados en la empresa	0.861	0.560
MSD6	Tiene una política de reducción de las emisiones de su transporte	0.850	0.559
Economic Development (ESD)			
Cronbach's Alpha: 0.909; Dijkstra-Henseler's rho (ρA): 0.912; CRI (ρc): 0.930; AVE: 0.690; Q^2: 0.516			
ESD1	Contribuye a la reducción y/o erradicación de los ingresos de pobreza de su personal	0.808	0.533

Continued

ESD2	Contribuye en el incremento del bienestar económico de su personal	0.752	0.409
ESD3	Tiene una política inversión y remuneración para su personal	0.828	0.494
ESD4	Tiene una política de desarrollo de su personal	0.853	0.527
ESD5	Tiene una política de gestión de la calidad y eficiencia de vida de su personal	0.864	0.551
ESD6	Tiene una política de anticorrupción de todo se personal	0.872	0.581
Firm Performance (FPE)			
Cronbach's Alpha: 0.900; Dijkstra-Henseler's rho (ρA): 0.901; CRI (ρc): 0.923; AVE: 0.666; Q^2: 0.120			
FPE1	Ha reducido significativamente los accidentes medioambientales	0.791	0.123
FPE2	Ha reducido significativamente los costos del consumo de energía	0.794	0.147
FPE3	Ha disminuido significativamente el tratamiento de residuos	0.822	0.109
FPE4	Ha disminuido significativamente las multas por accidentes medioambientales	0.850	0.122
FPE5	Participa activamente en la mejora del bienestar de la comunidad	0.815	0.106
FPE6	Participa activamente en la protección de los derechos humanos y de sus trabajadores	0.825	0.111

Notes: CRI: Composite Reliability Index; AVE: Averaged Variance Extracted.

The value of the factor loads of each of the items, Cronbach's Alpha, Dijkstra-Henseler rho, and CRI are higher than the value of 0.7, as well as the values of AVE are higher than the value of 0.5 recommended by Hair et al. (2019), which indicates that the items are measuring each of their constructs. Further, we assessed the predictive ability by using the blindfolding procedure in SmartPLS in order to check that cross-validated communalities and redundancies Q^2 are superior to 0 (Tenenhaus et al., 2005).

5. Results

In order to answer each of the four questions posed in this study, a structural equation model was applied through partial least squares (PLS-SEM) with the use of SmartPLS 3.3 software (Ringle et al., 2015), since PLS-SEM is commonly used in a variety of knowledge disciplines (Hair et al., 2012; Ringle et al., 2012; Sarstedt et al., 2014; do Valle & Assaker, 2015; Richter et al., 2015), as well as in theories that are poorly developed (Hair et al., 2019). Additionally, the use of PLS-SEM is essential when the objective sought in the application of the structural equation model is the prediction and explanation of the key constructs of the research model (Rigdon, 2012). In addition, the use of compounds in PLS-SEM, as a weighted combination of their indicators, facilitates the explanation of the measurement error of the constructs, which allows this method to be more powerful than multiple regression (Hair et al., 2019).

5.1. Reliability and Validity of the Measurement Model

The evaluation of the reliability and validity of the measurement scales of open eco-innovation, sustainable development, and firm performance, was carried out through Cronbach's Alpha, Composite Reliability Index (CRI), Dijkstra-Henseler

rho, and Average Variance Extracted (AVE) (Hair et al., 2019). Additionally, the discriminant validity of the three measurement scales was evaluated through Fornell and Larcker Criterion and Heterotrait-Monotrait (HTMT) ratio (Henseler et al., 2015; Hair et al., 2019). The results obtained from PLS-SEM are shown in **Table 2**, and indicate that Cronbach's Alpha has values ranging between 0.900 and 0.942, CRI has values ranging between 0.923 and 0.954, Dijkstra-Henseler rho has values ranging between 0.901 and 0.947, which indicates that they are good values and are above the 0.7 value recommended by Bagozzi and Yi (1988), and Hair et al. (2019), while AVE has values that range between 0.666 and 0.776, which are above the 0.5 value recommended by Fornell and Larcker (1981), and Bagozzi and Yi (1988).

Table 2. Measurement model. Reliability, validity and discriminant validity.

PANEL A. Reliability and Validity						
Variables	Cronbach's Alpha		CRI	Dijkstra-Henseler rho		EVI
Open Eco-innovation	0.942		0.954	0.947		0.776
Sustainable Development	0.914		0.933	0.916		0.703
Firm Performance	0.900		0.923	0.901		0.666
PANEL B. Fornell-Larcker Criterio				**Heterotrait-Monotrait ratio (HTMT)**		
Variables	1	2	3	1	2	3
1. Open Eco-innovation						
2. Sustainable Development	**0.868**					
3. Firm Performance	0.393	**0.408**		0.230	0.429	

Notes: OEI: Open Eco-innovation; SDE: Sustainable Development; FPE: Firm Performance. 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.

Regarding discriminant validity, the results obtained from PLS-SEM are presented in **Table 2** and indicate that Fornell and Larcker Criterion is significant, since the values of AVE are greater than the square of the correlations between each pair of constructs. For its part, HTMT is an estimator of the correlation between each pair of factors if it were measured perfectly, which should have a value greater than 0.08 to be significant (Henseler et al., 2015). The results obtained in this study show that the values obtained from HTMT range between 0.175 and 0.812, which are higher than the recommended value of 0.08, thus indicating the existence of discriminant validity of open eco-innovation measurement, sustainable development, and firm performance scales.

5.2. Structural Model

The estimation of the research model was carried out through the application of

PLS-SEM, whose results show acceptable statistical levels by obtaining an R^2 greater than 0.1, a VIF value less than 3.0, and positive Q^2 values (Reinartz et al., 2009; Hair et al., 2011; Henseler et al., 2014; Hair et al., 2019). Additionally, the results obtained indicate that the value of SRMR (0.036) is below the value of 0.08 recommended by Hu and Bentler (1998), the values of geodetic discrepancy (dG) and unweighted least squares discrepancy (dULS) (0.245 and 1.489, respectively), are lower than HI99 values, which allows verifying the significance of the research model (Dijkstra & Henseler, 2015). In general terms, the results obtained from PLS-SEM allow us to establish that open eco-innovation (0.145; *p*-value 0.006), has significant positive effects on firm performance of manufacturing companies.

These results obtained provide robust empirical evidence in favor of hypothesis H1, which allows establishing that the adoption and implementation of open eco-innovation practices generates a higher level of firm performance in manufacturing companies, and are consistent with the results obtained by Doran and Ryan (2016), Franceschelli et al. (2018), Avellaneda-Rivera et al. (2019), and Rossi et al. (2019), who found a significant positive relationship between open eco-innovation practices and firm performance. **Table 3**, presented below, shows the results obtained in greater detail.

Table 3. Structural model.

Paths	Path (*t*-value; *p*-value)	95% Confidence Interval	f^2	Support
OEI → FPE (H1)	0.145 (2.731; 0.006)	[0.040 - 0.247]	0.029	Yes
OEI → SDE (H2)	0.196 (3.077; 0.002)	[0.071 - 0.317]	0.045	Yes
SDE → FPE (H3)	0.384 (6.536; 0.000)	[0.256 -0.485]	0.183	Yes
Indirect Effects				
OEI → SDE → FPE (H4)	0.170 (3.018; 0.003)	[0.061 - 0.280]	0.032	Yes

Endogenous variable	Adjusted R^2	Model Fit	Value	HI99
		SRMR	0.036	0.043
SDE	0.115	dULS	1.489	2.205
FPE	0.134	dG	0.245	0.301
		NFI	0.879	
		rms Theta	0.169	

Note: PEI: Open Eco-innovation; PRE: SPE: Sustainable Development; FPE: Firm Performance. One-tailed t-values and *p*-values in parentheses; bootstrapping 95% confidence intervals (based on n = 5000 subsamples) SRMR: standardized root mean squared residual; dULS: unweighted least squares discrepancy; dG: geodesic discrepancy; NFI: normal fit index; HI99: bootstrap-based 99% percentiles.

Additionally, the results obtained and presented in **Table 3** also allow us to verify that open eco-innovation (0.196; *p*-value 0.002), has significant positive effects on sustainable development practices, which provides robust empirical evidence

in favor of hypothesis H2, thus allowing to establish that open eco-innovation generates an increase in sustainable development practices of manufacturing firms, these results being consistent with those obtained by Ghisetti et al. (2015), Triguero et al. (2018), Khan et al. (2019), Yang and Roh (2019), and Naruetharadhol et al. (2020), who found that open eco-innovation has a significant positive relationship with sustainable development.

In addition, the results obtained verify that sustainable development practices (0.384; *p*-value 0.000), have a significant positive effect on firm performance of manufacturing firms, thereby providing robust empirical evidence in favor of hypothesis H3, these results being consistent with those found by Tarmuji et al. (2016), Yusof et al. (2016), Ferrero-Ferrero et al. (2016), and Arrive et al. (2019), who suggested that sustainable development practices have a significant positive effect on the level of firm performance of manufacturing companies. Finally, regarding the mediation effects exerted by sustainable development practices between open eco-innovation and firm performance, the results obtained establish a positive indirect effect that generates a mediating influence of the effects exerted by open eco-innovation in the level of firm performance of manufacturing companies.

In **Table 3**, it can be seen that the mediating effects generated by sustainable development practices (0.170; *p*-value 0.003), are significant in the relationship between eco-innovation and firm performance, which provides empirical evidence robust in favor of hypothesis H4, these results being consistent with those obtained by Calza et al. (2017), Hamdoun et al. (2018), Khan et al. (2019), Arrive et al. (2019), and Naruetharadhol et al. (2021), who found that an important part of open eco-innovation practices is transferred to the firm performance of manufacturing companies, through the essential role that sustainable development practices have, which allows concluding that sustainable development can be considered as an explanatory variable of the relationship between open eco-innovation and firm performance of manufacturing companies.

6. Conclusions, Discussion, Limitations and Future Research

6.1. Conclusions

The results obtained in this study allow us to conclude on three fundamental aspects. First conclusion being that the research model used, on the one hand, shows high internal consistency by having a significant positive correlation between open eco-innovation practices, sustainable development practices, and firm performance, which allowed the acceptance of four established hypotheses and, on the other hand, offers a holistic view of the main types of open eco-innovation, of the essential indicators of sustainable development practices and of the most cited firm performance in the literature. Additionally, most of the studies published in the literature that analyze the relationship between open eco-innovation, sustainable development, and firm performance have been oriented towards a bibliometric review, which from our point of view do not have an empirical contribu-

tion substantial, for which this study provides robust empirical evidence and new knowledge in favor of the relationship between these important constructs.

Second conclusion is that the results obtained in this empirical study demonstrate the existence of a strong relationship between open eco-innovation, sustainable development practices, and firm performance of manufacturing companies. Therefore, it is possible to establish that open eco-innovation not only substantially improve sustainable development practices of manufacturing companies, but also their level of firm performance, these results being consistent with those obtained in studies published with earlier in the innovation literature, particularly with those that relate open eco-innovation with sustainable development practices (Fernández, 2019; Pereira et al., 2020; Chistov et al., 2021), and in studies that relate open eco-innovation and firm performance (González-Moreno et al., 2019; Chistov et al., 2021; Sanni & Verdolini, 2022).

Third conclusion derived from the results obtained in this study is the contribution of robust empirical evidence and new knowledge, which demonstrates that sustainable development practices can be considered as a mediating role in the relationship between open eco-innovation and firm performance. Therefore, it is possible to establish that sustainable development practices help manufacturing companies to obtain a higher level of firm performance, when they act as a mediation role between open eco-innovation and firm performance, than when they are directly related open eco-innovation and firm performance. These results are consistent with previously published empirical studies (e.g. Ghisetti et al., 2015; López et al., 2021; Triguero et al., 2018; Yang & Roh, 2019), who established the lack of empirical evidence of sustainable development practices when it intervenes as a mediating variable in the relationship between open eco-innovation and firm performance, in the sense of substantially reducing negative impacts on the environment.

6.2. Practical Implications

The results obtained in this empirical study have different implications, both for managers of manufacturing companies and for government authorities, which are important to consider. First of all, it was found that open eco-innovation is a relatively recent concept in the eco-innovation literature, which has experienced rapid growth in the number of articles published since 2010. However, the few empirical studies previously published studies do not offer a holistic view of open eco-innovation practices (Chistov et al., 2021), which is why this study, by incorporating a research model that considers the three most cited types of open eco-innovation in literature (products eco-innovation, processes eco-innovation, management eco-innovation), as well as the three most cited practices in the literature on sustainable development (social sustainability, environmental sustainability, economic sustainability), and their relationship with firm performance level, provides a holistic point of view that explains the interrelationship between open eco-innovation, sustainable development, and firm performance.

In this context, open eco-innovation is a concept that is open to discussion in the innovation literature, in which more and more researchers and academics are contributing to its exploration and conceptualization. Therefore, even though the number of scientific studies published in the innovation literature has increased, there are relatively few studies that have provided empirical evidence of the importance and benefits generated by eco-innovation in manufacturing firms globally, hence the importance of this empirical study. The results obtained in this empirical study are consistent with those found by Melander (2017), Fernández (2019), Pereira et al. (2021), and Naruetharadhol et al. (2021), and expand the existing knowledge in the literature, providing empirical evidence in favor of a positive and significant relationship between open eco-innovation activities, sustainable development practices and the level of firm performance of manufacturing companies.

Additionally, despite the scant literature, open eco-innovation has great potential as a new research topic, which obviously requires both researchers and academics to focus their future studies on the development of research models that provide theoretical evidence and empirical of the benefits and changes that it entails. However, it is considered that this empirical study provides robust empirical evidence that can help the scientific and academic community to differentiate between the different manifestations and perspectives existing in the literature of open eco-innovation activities, all of which are part of the same concept, and we believe that this empirical study can inspire other authors to guide their efforts in the analysis and discussion of open eco-innovation and its relationship with others or the same constructs, and in various sectors or industries of the activity. economy, mainly in emerging economy countries.

Secondly, empirical evidence has been provided in the literature showing that open eco-innovation substantially increases firm performance, but there are also other published studies that have found a negative relationship, and other studies that have not found any relationship (Chistov et al., 2021). Therefore, Naruetharadhol et al. (2021) considered that it is necessary to provide more theoretical and empirical evidence of the relationship between both constructs, for which open eco-innovation is in an embryonic phase. In this sense, the results provided by the studies previously published in the innovation literature can be considered as inconclusive and open to discussion, for which researchers and academics will have to guide their future studies in the contribution of empirical evidence and an implementation practice, of the effects exerted by open eco-innovation activities in manufacturing companies.

Third, the relationship between open eco-innovation and sustainable development practices suggests that open eco-innovation activities do not necessarily have to equally affect social, environmental, and economic sustainability (the three practices of sustainable development most studied in the literature), since manufacturing companies are generally considered to have different environmental goals and objectives. Therefore, future research will need to focus on identify-

ing the main determinants of open eco-innovation in each of the three sustainable development practices, both separately and together, and how these open eco-innovation activities affect the adoption and implementation of sustainable development practices, not only in manufacturing companies in a particular sector or industry, but in any company in any sector and industry globally.

Fourth, empirical evidence has also been provided in the innovation literature showing that two of the three most cited sustainable development practices (social sustainability and environmental sustainability), are the ones that have a significant positive influence on firm performance of manufacturing companies. However, the results obtained in this study show that the three practices of sustainable development (social, environmental, and economic sustainability), can stimulate the level of firm performance when they act together and not separately, which is why it is established in the literature that sustainability practices can be considered as a phenomenon that helps companies increase firm performance (Velte, 2016; Bodhanwala & Bodhanwala, 2018; Alsayegh et al., 2020), for which it has to be analyzed in future studies (Miralles-Queirós et al., 2019).

Finally, in fifth place, there are studies published in the current literature on innovation that have essentially focused on a bibliometric review of the construct of open eco-innovation, leaving aside the contribution of empirical evidence of the effects between the activities of open eco-innovation and sustainable development practices and firm performance level. Therefore, this empirical study enriches the innovation literature by providing robust empirical evidence, which shows that the adoption and implementation of open eco-innovation (eco-innovation of products, processes, and management), is not only important for manufacturing companies to improve both sustainable development practices and firm performance, but also the fundamental role played by the three practices of sustainable development (social, environmental, and economic), as a mediating role that substantially improves the level of firm performance of manufacturing firms.

6.3. 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 is the use of the measurement scales of open eco-innovation, sustainable development practices, and firm performance, since these three important variables were measured only with subjective indicators obtained through surveys (subjective data) in manufacturing companies. Therefore, in future studies it will be essential to incorporate objective data from manufacturing companies (e.g. number of eco-products developed, percentage of materials reused in the production of eco-products, percentage of industrial waste reused, financial and accounting statements, investments in R&D), in order to verify if the results obtained are similar to those of this study.

A second limitation of this study is that the relationship between the three es-

sential activities of open eco-innovation (eco-innovation in products, processes and management), and the level of firm performance of manufacturing companies, possibly generates better results if instead of considering the individual practices of sustainable development (social, environmental, and economic sustainability), other variables that moderate the effects are considered, such as the particular characteristics of the companies (e.g. size, age, sector of economic activity, location of the company, technological development). Therefore, in future studies it would be pertinent to use some other variables that moderate the effects of open eco-innovation on firm performance of manufacturing companies, with the intention of corroborating whether the results obtained differ or not from those obtained in this studio. A third limitation of this study is that only the three types of open eco-innovation practices most cited in the innovation literature were considered (product eco-innovation, process eco-innovation, and management eco-innovation), the three most cited sustainable development practices in the literature (environmental sustainability, social sustainability, and economic sustainability). Therefore, in future studies it would be pertinent to consider other types of open eco-innovation activities (e.g. marketing, technology, systems), and other sustainable development practices (e.g. green strategies, environmental management, ISO 14,000 certifications), with the purpose of corroborating whether the results obtained are similar or not to those obtained in this work.

A fourth limitation is that this research focuses on the factors most used by the academic community, leaving out factors such as: 1) Combination of market knowledge sources; 2) Collaboration with universities and research centers; 3) Ethical factors and sustainability; 4) Frugal innovation. These factors are part of open eco-innovation but have not been thoroughly investigated by the academic community.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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