Integral sustainability model for the improvement of environmental and productive processes in small and medium enterprises.

Doctoral Dissertation

Jenifer Vasquez Aguilar
Engineering Ph.D.
Management, Production and Design Ph.D.
Double Degree Program

Advisors:
Santiago Aguirre, Ph.D.
Department of Industrial Engineering

Luca Settineri, Ph.D.
Department of Management and Production Engineering

Co-tutor:
Paolo C. Priarone, Ph.D
Department of Management and Production Engineering

Bogota, Colombia 2021

Abstract

Environmental problems and the depletion of natural resources are a worldwide concern which has not yet been fully solved. These environmental problems have had a negative impact on the population and economic development of all countries, the industrial sector being one of the biggest sources of pollution.

The present doctoral dissertation focuses on small and medium sized enterprises (SMEs), which actually constitute the productive gear in emerging countries. The negative impact of a small business is so weak that it tends to be neglected, but considering that this sector accounts for 90% of an average country´s economy, its effect on the exacerbation of environmental pollution through commercial, industrial and service activities significantly contributes to overall environmental, social and economic difficulties.

Therefore, SMEs play an important role in the adoption of sustainable and respectful practices when it comes to reducing negative impacts on ecosystems. Thus, the adoption of sustainability is related to the effective application of environmental practices and tools that must be incorporated into an organization's internal strategies and objectives. This actually means considering environmental sustainability as a priority in all aspects of business activity.

However, by gathering the relevant literature related to the subject of study, it could be observed that there are multiple sustainability models designed for the industrial sector, but few research studies comprehensively evaluating and exploring the social, environmental, economic and technological aspects of SMEs. For this reason, and in order to reach a deep understanding of the adoption of sustainability by SMEs in Colombia, the present research is framed in the analysis of the current state of small businesses in face of the challenge posed by the achievement of corporate sustainability.

In this sense, this work proposes the development of an Integral Sustainability Model for SMEs (ISM-S), framed in an environmental management system aimed at improving economic indicators, minimizing negative environmental impacts and making their employees adopt more sustainable and responsible behaviors.

The ISM-S developed in this doctoral dissertation focuses on the analysis of a series of factors related to (*i*) a decision-making management system, (*ii*) sustainable tools and strategies, (*iii*) social responsibility and knowledge management, and (*iv*) technological convergence. It also includes a sustainability maturity classification model that operates through data analysis and supervised classification algorithms, and a predictive simulation model that allows examining a sequence of changing events that can be subjected to probabilistic analysis as the company goes through different scenarios to achieve sustainability. In summary, this research resorts to a conceptual framework, descriptive statistical methods, data analysis, and stochastic prediction models.

Additionally, the ISM-S model was quantitatively evaluated through its components (statistical analysis, classification of sustainable maturity states and predictive simulation) in different productive SME sectors in Colombia. In relation to the statistical analysis of the case study, the results show that SMEs have internal and external barriers that affect the adoption of practices of interest at the national level, since they lack environmental, social, economic and technological strategies.

Using the techniques Design Science Research and Design of Computational Intelligence Experiments, the classification of sustainable maturity was applied to a group of companies in Colombia. Making use of data analytics and supervised classification algorithms, the model found that the studied group of Colombian (micro,small and medium sized enterprises-MSMEs) was composed as follows: 6% of the companies were at an insufficient sustainability maturity level; 31% were at the basic one; and 45% and 18% at the developing and consolidated levels, respectively. According to the current model's simulation of the fulfillment of a set of characteristics, assumptions and constraints on the part of Colombian MSMEs from different productive sectors, they will have reached a maximum level of sustainability maturity after a two and a half-year period (on average).

The conclusions of this research reveal it is one of the first empirical studies to integrally analyze various sustainability factors in connection with the behavior of SMEs in Colombia. Therefore, the current framework can be applied to both regional development plans and the evaluation and monitoring of economic indicators in companies. This, in turn, allows them to minimize negative environmental impacts and have their employees adopt more responsible behaviors.

Thus, this doctoral dissertation constitutes a platform for future research projects wishing to improve the analysis of other factors than those studied here. This may aid researchers in comparing SMEs across different regions of Latin America, thus allowing them to determine similarities or differences in the achievement of sustainable development and framing other methodologies in future research studies.

Acknowledgements

First of all, I would like to give a special thanks to Professor Santiago Aguirre as supervisor of this dissertation, together with and all my professors at Pontificia Universidad Javeriana. Also, I would like to thank my professors at at Politecnico di Torino: Luca Settineri, Giulia Bruno and Paolo C. Priarone, as supervisors of this thesis. Thanks to everyone for your support and for sharing your knowledge in the development of this thesis.

I owe my total gratitude to God for giving me perseverance and strength during my doctoral studies. I would also like to thank my family who have always been by my side, giving me encouragement in all the projects that I have undertaken. I would like to give special thanks to my niece Gabriela Pelaez for her unconditional support. I have to really thank my husband, Edwin Puertas, for being my partner and his unconditional support in every moment of my life. I could not have carried out this thesis without his continuous care, motivation and love.

This thesis is dedicated to my sweet baby that is on the way; we did it!

Contents

List of Tables

List of Figures

Chapther 1. General Overview of the Study

1.1 Introduction

In introducing the current research study, this chapter offers an encompassing view of the context in which it was conducted. Also, the motivation and the research question are formulated, together with the general and specific objectives. Likewise, the contributions and limitations are briefed, just as the publications issued during its development and the structure of the chapters making up the document.

1.2 Motivation and problem statement

The current debate on environmental protection in social sectors has not left industry aside. In addition, it has intensified in recent decades due to the persistence of a variety of environmental, social and economic problems arising in the business sector. Environmental concerns revolve around energy consumption, resource depletion and environmental imbalance [1]. These problems have been rapidly taking a toll on people's health and the sustainable development of societies.

Research conducted by and Hachaichi and Baouni [2] on the capacity of the planet to reach an adequate resource distribution balance has identified that the current life style patterns have triggered diverse environmental crises such as climate change, loss of biodiversity, widespread contamination, water shortage, reduced food production capacity, sea level rise, and ocean acidification [2], [3]. Although urban areas only represent 2% of the earth's surface, more than half of the population of the planet actually dwell in cities. Population growth projections estimate an increase towards 9.8 thousand million people by 2050 [4].

Hence, both industrialized and emerging countries have recognized the seriousness of these environmental problems. In fact, important world forums have agreed that environmental protection is a joint responsibility of all countries [5]. One of the leading organizations seeking for environmental strategies is the *World Commission on Environment and Development,* created in 1984 by the general assembly of the *United Nations* as a leading organism and world regulator in environmental matters. This commission issued a report explaining the main causes of this environmental degradation, which allowed introducing the concept of sustainable development as that which allows "satisfying the needs of the current generation without compromising the capacity of future generations to satisfy their own needs" [6], [7].

In consequence, sustainability must bring along both progress and life quality in any country, keeping a balance among different variables which are not only economic in nature, since social and environmental aspects must also be included. For the purpose of the present research, corporate sustainability has been defined as the reduction of waste and environmental impacts produced by the internal activities of a company, making efficient use of its economic, social and environmental resources.

Diverse studies have proven several useful strategies for the implementation and advance of corporate sustainable development, which allow the business sector to significantly reduce environmental contamination, increase productivity and optimize productive processes [8], [9]. In this sense, the optimization of supplies, the reduction of waste and the use of clean technologies are synonyms of doing more with less, producing less waste.

The effective implementation of sustainable strategies in industrial sectors is still the object of debate due to the diversity of models intended for the implementation of environmental sustainability in internal and external processes [10]. Furthermore, these models reveal the scarcity of studies comprehensively tackling key elements of environmental sustainability in internal processes[7], [11], [12]. Examples of said elements are the adoption of social features of business partners, which is related to their capacity to acquire environmental knowledge and socialize it; the adoption of environmental factors in internal activities, which is related to the degree of implementation of environmental strategies and practices; and the adoption of economic aspects, which are related to the development of environmental management systems and indicators for decision-making at the management level.

On the other hand, most companies around the world correspond to the category Small and Medium Sized Businesses (SMEs), which makes significant contributions to the economy of any nation. However, only few studies have addressed the factors that allow measuring business maturity and knowledge management, or the necessary strategy implementation guidelines within a SME integrated system [13]. Furthermore, in most cases this has only been done to a limited extent. In local contexts, there is certainly a gap in the literature dealing with the business management model that businesses should adopt when it comes to sustainable actions. For this reason, the current study has set the goal to identify and analyze those factors that may integrally promote sustainability in SMEs. Hence, the following sections introduce the scheme under which such contribution has been developed.

1.3 Research question

The question raised in this study is: What is necessary for small and medium sized businesses to improve their economic indicators, minimize negative environmental impacts and have their employees adopt a more sustainable and responsible behavior?

1.4 General objectives and specific objectives

In order to answer the research question, the following objectives were proposed:

Developing an integral sustainability model for SMEs, framed in an environmental management system intended to improve economic indicators, minimize negative environmental impacts and have their employees adopt a more sustainable and responsible behavior.
Specific objectives:

- Identifying and analyzing the components of an integral sustainability model.
- Designing and evaluating an integral sustainability model for SMEs, such that it combines sustainable practices and environmental knowledge management in an environmental management system.
- Validating the model through a predictive simulation, in order to assess improvement strategies.

1.5 Main contribution

The main contributions of the present research are:

- The current one is a strategic model intended to provide guidance to an environmental and productive business system. The point is that very few SMEs in developing countries can invest large amounts of financial, technological and human resources to undertake sustainable strategy innovations. In this context, the present study contributes to the debate on the strengths and weaknesses of these companies when it comes to taking the path to corporate sustainability.

- Designing and controlling a set of key factors and indicators of economic and environmental performance. This is made possible because the proposed model provides a comprehensive view of the organization, framed in sustainable strategies. This, in turn, allows managers to develop environmental, economic and social decision-making abilities.

- The theoretical contribution of the present study is the contextual analysis of the studied factors affecting SME sustainability. This certainly broadens the framework formerly provided by empirical and practical models, for which the author resorted to data analysis techniques.

- Another contribution of this research study is its expected relevance for corporate leaders, since it indicates if the current sustainable strategies are sufficient for their intended purpose, or if adjustments are needed.

1.6 Scientific publications resulting from this thesis

It is important to mention that the present dissertation is based on several papers we published in conferences or journals. Hence, this document is the result of the development of our research.

The publications issued during the development of this research are the following:

- Vásquez, J., Aguirre, S., Fuquene-Retamoso, C. E., Bruno, G., Priarone, P. C., & Settineri, L. (2019). A conceptual framework for the eco-efficiency assessment of small-and medium-sized enterprises. Journal of Cleaner Production, 237, 117660.

- Vásquez, J., Aguirre, S., Puertas, E., Bruno, G., Priarone, P. C., & Settineri, L. (2020). A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs), based on a data analytics evaluation approach, Journal of Cleaner Production (under review).

- Vásquez, J., Aguirre, S., Settineri, L. (2020). Development of an integral model of sustainability for the improvement of the environmental and productive process in small and medium enterprises (SMEs) Second National Meeting of Doctoral Students in Engineering, ENEDI-ACOFI 2020, published in the proceedings of the event, September 18, 2020.

- Vásquez, J., Bruno, G., Settineri, L., & Aguirre, S. (2018). Conceptual Framework for Evaluating the Environmental Awareness and Eco-efficiency of SMEs. Procedia CIRP, 78, 347-352.

- Vásquez, J., Aguirre, S., Fuquene-Retamoso. "Development of eco-efficiency models in small and medium enterprises -SMEs" for the 8th International Conference on Production Research – Americas 2016 in Chile.

Appendix 1 details the relation of these publications with the development of the current thesis.

1.7 Structure of the thesis

The structure of this document is detailed below:

Chapter one provides a general view of the research study. Besides, its general purpose is defined, together with its objectives, research questions, contributions and limitations, as well as the contributions to the academic community.

Chapter two introduces the conceptual framework leading to the topics "Corporate sustainability" and "Sustainable development". Besides, it contains the literature review on theoretical and practical sustainability models as framed in the context of SMEs. Thus, the research gap is identified.

Chapter three defines the research methodology and describes the process followed in the investigation and its focus of study, together with the instruments that allowed the testing of the model.

Chapter four introduces the design and assemblage of the integral sustainability model, based on the literature review presented in Chapter 2. Additionally, the characteristics of the model, its purpose and limitations are described in detail.

Chapter five presents the quantitative analysis of the results of the investigation. Also, the most relevant findings are discussed based on the analysis of the resulting data, in order to provide an answer to the research question.

Chapter six provides the general discussion of the developed ISM-S model, general application and novel aspects in comparison to the current scientific literature.

Chapter seven provides the research conclusions and details certain recommendations for the sector in question. Just as well, a methodological proposal to implement the model through future research is presented.

Chapther 2. Literature Review

2.1 Introduction

The second chapter of the doctoral dissertation presents the theoretical background to achieve the first research objective. Thus, a series of items are addressed: Introducing the conceptualization of sustainable development and corporate sustainability; checking the state of the art of the theoretical and practical models that have dealt with sustainable management in SMEs; and identifying the progress and research gaps featuring this topic. These points are developed in the sections below.

2.2 Sustainable development and important achievements

In analyzing the cornerstones of sustainable business management, it is necessary to explore the departing points from which the topic has developed. For such purpose, it is necessary to find a clear-cut definition of sustainability, coupled to the main events in which it has gained momentum. Nonetheless, the definition of sustainability is still confusing due to the variety of attempts coming from different disciplines and perspectives operating in the political, religious, economic and scientific realms.

According to T. O. Olawumi et al. [14], the search for a definition of “sustainability and sustainable” started in the 1970’s, when environmental concerns first hit the ground in connection with human development. This overall interest was triggered by situations of population displacement, transformation of ecosystems and the relation between productive and economic systems.

As a consequence, a first convention addressing the problem was held in 1972, under the sponsorship of the United Nations (UN). The central topic in this event was on the “Human environment”, which allowed setting a series of cornerstones for the formulation of international strategic environmental policies. Later on, in 1980, the Worldwide Strategy for the Conservation of Nature and Natural Resources was formulated. In its section “Towards Sustainable Development”, the main causes of poverty and habitat destruction were identified: Demographic pressure, social inequality and unbalanced growth of industry and commerce. The identification of these causes allowed establishing a worldwide preservation agenda [15].

In analyzing the concepts of sustainability and sustainable throughout the Brundtland report, also known as Our Common Future, it can be observed that they are both used with the same meaning. This report refers to the terms sustainable and sustainability as synonyms without these terms reflecting any particular difference. This lack of differentiation between terms like sustainable development or sustainability development is reflected by the definition “the capacity to satisfy the needs of the current generation without compromising the capacity of future generations to satisfy their own needs” [14], [16].

In order to apply this definition, governments need to maintain certain balance between social, economic and environmental aspects. Along these lines, world organizations have held several gatherings and conventions to provide environmental guidelines for the governments of both developed and emerging countries [17], [18]. One of the most important gatherings highlighted by the literature on the history of the environmental movement is the one conducted in Rio de Janeiro in 1992. This event issued “Rio declaration on environment and Development” [19], which stated 27 environmental protection principles, five of which are closely related to the corporate world: No activity can take a toll on the rights of future generations; strategic objectives must be set, so that environmental protection is incorporated into any productive activity; information and report transparency are a collective right; precautionary principle; and those who pollutes pays.

After “Rio Summit”, both environmental concerns and sustainable development declaratory have been steadily increasing. From 1992 to 1999 the main gatherings of this movement - like the Protocol of Kyoto and the conformation of the Network for Sustainable Development in 1997 - focused on the definition of specific emission reduction goals for the six main greenhouse effect gases. Additionally, the formalization of the World Pact of the United Nations and the Corporate Citizenry Principle were reached in 1999 [20]. The latter addressed the contributions of a company to society through its main business activities, social investments and participation in the development of public policies.

More sustainable development agreements would come in the following years, from 2000 to 2010. This is the case of the declaration of the Millennium Development Goals (MDGs), issued by the United Nations in New York in 2000, which had the participation of 189 countries and manifested eight main goals related to human development and nature, as well as the commitment to reach them in 2015 [21]. In 2015, took place the World Conference on Sustainable Development Rio+10, known as the Johannesburg Summit, which reasserted that sustainability is the central strategy of the international endeavor against poverty and towards environmental protection.

In 2005, the Kyoto Protocol was enforced, but it was only until 2009 that the Fifteenth session of the Conference of the Parties, known as COP 15, conducted the corresponding financial negotiations and set economic penalties for concrete greenhouse gas reduction goals [22]. Despite this, several nations, including the European Union and some emerging countries, criticized China and the USA for not reaching solid carbon emission capping agreements.

During the period comprised between 2011 and 2020 took place an important convention known as RIO+20 (conducted in 2012), which dealt with the “green economy”, an important issue when it comes to solving the problems caused by business activities. Thus, green economy and sustainable development have come to show the way in which companies can treat the residues of their economic activities.

Taking into account the millennium development goals defined in previous years, the 2015 Sustainable Development Convention conducted in New York in 2015 formulated a new agenda stating 17 updated Sustainable Development Goals (SDGs). These were intended for the members of the UN to protect the planet, end up poverty and guarantee peace and prosperity by 2030 [23]. The SDGs are still the object of criticism due to the lack of strategies, investments and processes by which countries may fulfill them. In that same year, the Paris COP21 Summit on Climate Change gathered 195 countries to formulate the United Nations Framework Convention on Climate Change (UNFCCC), which set the goal to limit global warming below 2ºC.

Based on the specifics of the SDGs, the 2017 World Economic Forum designed a platform intended to support companies, governments and civil society in the study of the necessary public-private cooperation to speed up the fulfillment of the SDGs. On these grounds, the Sustainable Development Solutions Network (SDSN) prepared the Sustainable Development Report in 2019, informing on the progress of the 162 countries that had agreed on the SDGs. This is certainly a not encouraging document since, despite the remarkable progress made by the Scandinavian countries, Africa and Latin America show poor results and even deterioration [24]. This implies stronger challenges and corresponding efforts for the countries of these regions, in order to reach the SDGs.

In the current national and international context faced by the corporate sector, it is necessary to strengthen the necessary business strategy and sustainable practice effort to competitively transform the sector. Hence, the next section introduces the term “corporate sustainability” as a pivotal development of the current research study.

2.3 Corporate sustainability

As noted in the previous section, over the last few decades there have been concerns and challenges in achieving balanced sustainable development integrating political, economic, environmental and social aspects. Although said concerns have been addressed through protocols, conventions and agreements, globalization and emerging issues have been increasing due to the rapid and aggressive changes that companies have had to face. These challenges include new technologies, government regulations, economic crises and/or recessions, and capacities for the use of ecosystem services, which companies must include in their productive activities.

Thus, several factors resulting from globalization have promoted sustainability in the business sector. Due to its complexity, corporate sustainability is better known as represented by the triple bottom line (TBL). According to Elkington [25], the TBL approach could lead an organization to realize economic prosperity, environmental quality and social justice simultaneously. Figure 1 explains the integration between business activities and the environmental, economic and social dimensions of sustainable development. This balance, which results from the notion of sustainable development as meeting the needs of the current generation without sacrificing those of future generations, allows the entire system to current harmoniously in time and space by progressively

achieving partial objectives. Additionally, in the context established by the needs, requirements and challenges of globalization, this necessary balance call for five outstanding sustainability-achieving factors: Energy efficiency, emerging trade, sustainable value chains, business models and information technologies intended to support companies in their transformation toward industry 4.0, which is what is currently taking place [26].

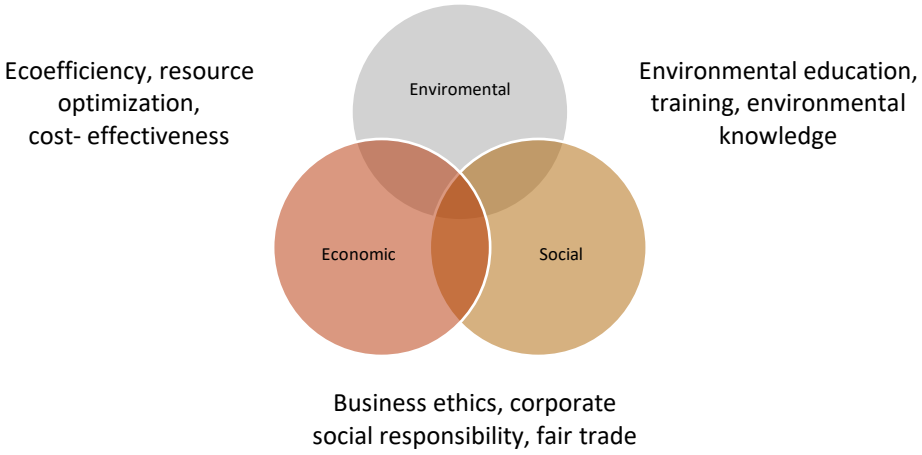


Figure 1. Sustainable Development Dimensions

In order for leaders and managers to be able to contribute to these sustainable development dimensions, the notion of "business sustainability", also named "corporate sustainability" or "corporate sustainable management", has been coined as the strategy that allows the creation of economic, environmental and social value to increase the welfare of present and future generations [27]. According to this author [28], corporate sustainability at the business level refers to the strategic systems that transform organizational management into a set of activities that contribute to sustainable development within the limits of ecosystems. That is, the capability to produce efficiently while minimizing environmental impacts and contributing to economic and social development. This intrinsic philosophy has been the main reason for companies to consider the corporate sustainability approach [29].

In addition, corporate sustainability is considered to integrate social and environmental dimensions in the process of strategic management and planning, thus highlighting the strategic position of a company with respect to sustainable development. Caldera [30] explains that corporate sustainability practices address a variety of economic, social and environmental objectives and instances framed in organizational and administrative management and integrated into the actual business processes. As such, it has constituted an aspiration for an increasing proportion of SMEs, since it likely to bring about profitability, resilience and positive social and environmental deeds.

On the other hand, corporate sustainability intends to achieve SDG No. 12, which aims at establishing sustainable production and consumption by 2030. Presently, this goal has been integrated into Industry 4.0, which intends to achieve potential benefits in the three dimensions of

sustainable development [31].In this way, corporate sustainability comes to be an opportunity to advance towards new ways of doing business, innovating and increasing competitive capacity.

In addition, as consumers observe that companies base their activities on principles of corporate sustainability, they tend to perceive them and services as environmentally friendly and supported by an ethical behavior background. This, in turn, helps companies increase their sales, improve their corporate image and increase their profits [32]. In addition, companies with a sustainable management orientation focus on meeting government requirements and regulations that respond to the progress of society.

As a result, business leaders face complex situations as they simultaneously manage activities related to the environment, the economy and society, which require specific administrative and productive perceptions for the organization to move effectively in sustainability contexts. In several countries, great efforts have been made to protect the environment through regulation proposals and financing strategies for the development of companies, so most of them are aware of the importance of sustainability. However, this endeavor requires the decision makers of internal corporate processes to integrally address activities that support strategic growth through new tools, methodologies and models which, in turn, must contribute to increasing economic prosperity and generating positive effects for the environment and their workers.

Thus, researchers from various scientific disciplines have designed sustainable management and business models based on new trends that combine data analysis, automation, e-commerce and marketing, among other new transformations. But for some companies, making these changes implies complex and difficult paths, while for other companies it is an urgent need [33].

2.4 State of the art

With the aim of identifying research works related to the topic of the current study, a bibliometric analysis was carried out in order to analyze relevant topics, authors, publications per countries, and proximity between investigations. For such purpose, a systematic review was conducted by the bibliometric method for the evaluation of scientific papers (both empirical and topic reviews), which were grouped according to research objective similarity through the following steps: Identification, selection of relevant studies, quality assessment, extraction of relevant data, and information synthesis [28], [34], [35].

Table 1 describes the search criteria employed for the systemic review of research papers related to the subject of the study.

Table 1. Scientific studies search criteria

Items and search criteria	
Items	Criteria
Period	From 2015 to 2020
Online databases	Scopus, Web of Science (WOS)
Search topics	Sustainable management models for SMEs
Category	Engineering, business and administration, decision-making sciences, interdisciplinary areas.
Type of document	Empirical reports and reviews
Employed software and programming languages	Python and VosViewer®
Language	English and Spanish

In searching the databases Scopus and Web of Science (WoS), the equation "(sustaina* AND management*) AND ((model*) OR (framework*)) AND ((smes) OR (small AND medium AND sized AND enterprises) OR (small AND business))" was applied in the search fields TiTle-ABS KEY (Scopus) and TOPIC (WoS).

The search equation above yielded 247 articles in Scopus and 262 in WoS. Therefore, it was deemed necessary to unify the list of scientific articles issued from 2015 to 2020 by comparing the following fields: Keywords, summary, authors, country, journal and affiliation information. The list of papers was systematized in CSV and HTLM files and then processed in the programming language Python, in order to standardize the keywords (i.e., synonym unification and information refinement). For example, the keywords "small business" and "SMEs" were unified as "small and medium sized enterprises". In addition, the articles were stratified according to the keyword combinations defined in the search equation. Out of the 507 articles analyzed, 226 were found to contain some words from the equation in their summary or keywords.

After exporting the information from Python, the results were displayed in a VOSviewer software package version 1.6.15, which allows the identification of the most relevant research clusters [34]. Figure 2 highlights the three major clusters of keywords associated with the subject of study, plus a cluster that is embedded in the large ones.

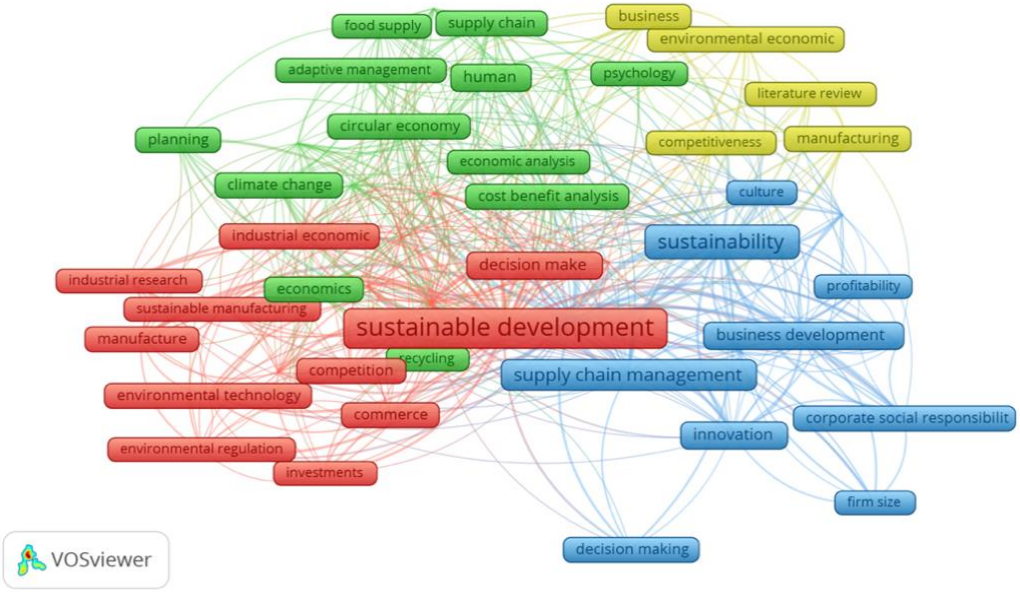


Figure 2. Key word clusters based on co-occurrence (VOSviewer 1.6.15)

For the present research, “sustainable development” is naturally the central word in the map of key topics, which are, in turn, associated with other focal topics. These key topics have been classified into three main clusters: Focusing on strategic management, Cluster 1 (red) highlights environmental regulations, technology, economy, competitiveness, industrial research, sustainable manufacturing, trade, investment and decision-making. Cluster 2 (green) focuses on sustainable tools and practices such as circular economy, recycling, cost-benefit analysis, planning, climate change and adaptive resource management and adaptive environmental management assessment. In turn, cluster 3 (blue) focuses on business development as seen from the perspective of human resources in a sustainable value chain, which includes corporate social responsibility, innovation, culture, profitability and decision-making. Although reduced in the number of key topics, the remaining cluster (yellow) focuses on business, literature review, competitiveness, manufacturing, and environmental economics, all of which are included in at least one of the three main clusters.

Figure 3 also shows the various research topics revolving around SMEs, highlighting the close ties sector holds with the three main clusters through topics like management systems, sustainable practices and social responsibility. It is noteworthy how these topics are, in turn, related to the economic, social and environmental dimensions of sustainable development.

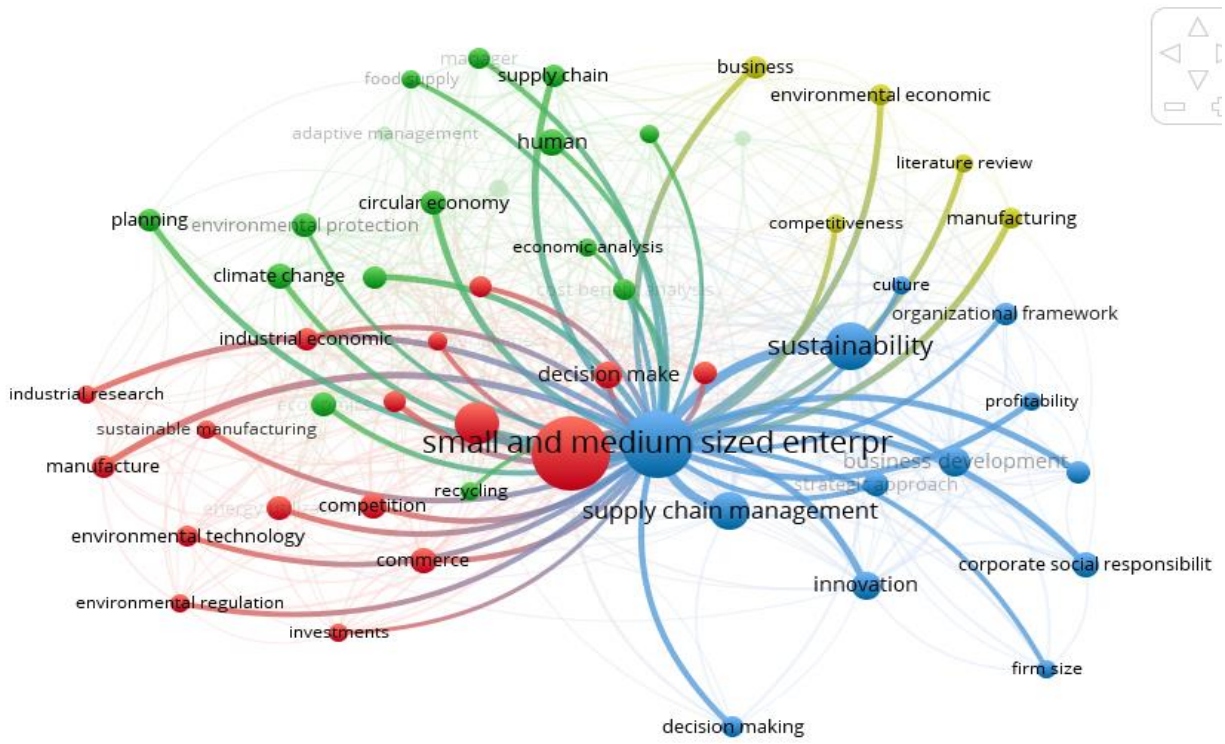


Figure 3. Focal mapping around SMEs (created in VOSviewer 1.6.15)

Based on the above, and in order to actually review the papers related to the subject of study, those with the most citations in recent years were given priority. Therefore, the selection criteria for the articles that make part of the state of the art were the following:

- Five articles with more than 15 citations were selected from each of the clusters.
- The abstract of the articles should include keywords related to the search equation.
- The articles are biased by the knowledge and interest of the researchers in the area of study.

Besides their categorization in the three mentioned clusters, the scientific papers under analysis were segmented according to their correspondence with the dimensions of sustainable development (economic, social and environmental). Table 2 shows the results obtained from the literature review.

Table 2. Cluster analysis according to sustainable development dimensions

Economic dimension of sustainable development			
Cluster 1. Management systems for sustainable decision-making			
Author/ Year	Title	No. Citations by 2020	Model type
H. S. Birkel et al., (2019) [33]	Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers	42	Theoretical
S. K. Mangla et al., (2018) [36]	Enablers to implement sustainable initiatives in agri-food supply chains	44	Theoretical – practical
T. B. Long et al., (2018) [37]	Critical success factors for the transition to business models for sustainability in the food and beverage industry in the Netherlands	31	Theoretical
C. H. Hsu et al., (2017) [38]	Identifying key performance factors for sustainability development of SMEs – integrating QFD and fuzzy MADM methods	50	Theoretical – practical
P. R. Crowe et al., (2016) [39]	Operationalizing urban resilience through a framework for adaptive co-management and design: Five experiments in urban planning practice and policy	31	Practical
Environmental dimension of sustainable development			
Cluster 2. Sustainable tools and practices			
Author/ Year	Title	No. Citations by 2020	Model type
D. D'Amato et al., (2020) [40]	Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs	21	Practical
H. T. S. Caldera et al., (2019) [30]	Evaluating the enablers and barriers for successful implementation of sustainable business practice in 'lean' SMEs	20	Theoretical – practical
M. Aboelmaged et al., (2018) [41]	The drivers of sustainable manufacturing practices in Egyptian SMEs and their impact on competitive capabilities: A PLS-SEM model,	41	Theoretical
Changwichan et al., (2018) [42]	Eco-efficiency assessment of bioplastics production systems and end-of-life options	20	Theoretical – practical
G. C. Oliveira et al., (2017) [43]	Framework to overcome barriers in the implementation of cleaner	32	Theoretical – practical

	production in small and medium-sized enterprises: Multiple case studies in Brazil		
Social dimension of sustainable development			
Cluster 3. Social responsibility and knowledge management			
Author/ Year	Title	No. Citations by 2020	Model type
W. Kucharska et al., (2019) [7]	How to achieve sustainability?— Employee's point of view on company's culture and CSR practice,	15	Theoretical
J. Batle et al., (2018) [44]	Environmental management best practices: Towards social innovation	15	Theoretical
G. C. Wu, (2017) [45]	Effects of Socially Responsible Supplier Development and Sustainability-Oriented Innovation on Sustainable Development: Empirical Evidence from SMEs	33	Practical
C. C. Nakamba et al, (2017) [35]	How does social sustainability feature in studies of supply chain management? A review and research agenda	32	Theoretical

Taking into account the dimensions of sustainable development and the three mentioned clusters, a literature review with the most significant contributions of these investigations is detailed in the lines that follow.

2.4.1 Cluster 1. Management systems for sustainable decision-making

The economic dimension of sustainable development has been related to Cluster 1: Management systems for sustainable development decision-making, wherein recent studies not only introduce the development of theoretical strategic models that allow creating value in industrial sectors, but also report on their practical application.

The studies analyzed in this cluster deal with SMEs in their search for industrial development 4.0, for which they are making use of new management systems intended to reach sustainable balance between internal and external factors. This is the case of the scientific research of H. S. Birkel et al. [33], which introduces a decision model that allows identifying the economic, ecological, social, technical, and political risks that arise during the implementation of industry 4.0. Although this scientific research integrates its results with the dimensions of sustainability, it attracts criticism by extrapolating its results to more general considerations on risk analysis, since it only evaluates 14 German companies. Just as well, it can be said to lack detail on how these risks can be adequately counteracted in different contexts.

On the other hand, S. K. Mangla et al. [36] introduces a novel approach called DEMATEL, which identifies different corporate sustainability factors and integrates them into a strategic system that contributes to decision-making. Among these factors we can count: Pressure from various government agencies, incentives and support to undertake sustainable initiatives, the understanding of customer requirements, managerial commitment, and auditing of ongoing supply chain activities. The latter has been applied to the agribusiness sector through the cause-effect diagram, which allows for the analysis of interactions between facilitators, in order to improve the long-term implementation of sustainability-focused concepts. However, the author suggests that such orientations may have a different impact on sustainable performance across different industries, depending on the integration of resources, organizational efficiency and technological innovation, which need to be addressed in a more comprehensive manner.

Likewise, a study conducted by T. B. Long et al. [37] explores and identifies critical success factors and barriers for the transition from traditional to sustainable business models by evaluating 14 SMEs in a particular sector. This author determined that the primary drivers correspond to business collaboration, a clear vision of the business, continuous innovation, a sustainable base, profitability, and fortuitous external events that emerge as critical success factors. However, due to the limited number of evaluated companies it may be necessary to confirm whether the factors in question are applicable in different contexts.

Research by C. H. Hsu et al.[46] shows that improving business management and performance as a function of sustainability constitutes a growth and development opportunity. However, it is difficult for SMEs to achieve sustainability due to economic resource availability limitations. In correspondence with that, this author shows how to effectively use the resources of SMEs and prioritize performance factors through the Balanced Scorecard (BSC). However, this research does not take into account that depending on the type of SMEs, it can develop its own sustainability criteria and appropriate performance indicators that allow it to prioritize their goals and critical indicators.

For its part, the scientific research of P. R. Crowe et al. [39] introduces different lines of collaborative management and adaptive design linking SMEs, scholars, citizens and local governments. These initiatives are aimed at reaching adequate socio-ecological resilience, thus enabling the citizenry to face the challenges that are proper of urban areas. Among the proposed management lines are: *i)* an online crowdsourcing application to map underutilized spaces, *ii)* an interactive chronology tool to identify drivers of change over time, *iii)* a guidance and signage tool to help community projects overcome resource barriers, *iv)* an epistemic network for citizens to exchange knowledge and resources related to underutilized spaces, and *v)* an online portal that provides visibility to projects or community groups and facilitates the creation of horizontal networks.

The above-mentioned study highlights the importance of generating innovative and tangible ideas aimed at efficient decision-making in the context of sustainability. Just as well, it shows how these

initiatives can be prioritized as a mechanism for collaborative change. This is particularly important when it comes to the efficient use of social spaces for knowledge exchange involving different economic sectors, which certainly allows for the advance of sustainable development along its different dimensions.

As it can be seen, the studies reviewed in this section focus on organizational and strategic management systems that allow SMEs to analyze those factors that must be taken into account when implementing sustainable practices. Among these factors are costs, barriers, investments, incentives and profitability, among others. These considerations facilitate better short- and long-term decisions for these companies, so that they can prioritize and achieve an efficient allocation and control of their resources while avoiding unnecessary costs.

2.4.2 Cluster 2. Environmentally sustainable tools and practices

The environmental dimension of sustainable development has been associated to sustainable practices and related tools developed through scientific research in SMEs. These correspond to eco-efficiency, cleaner production, eco-design, frugal innovation, measurement and control of indicators, environmental certifications and circular economy, among others [47], [48]. These have allowed small businesses to implement preventive and corrective routines in order to increase the efficiency of processes, products and services, while reducing or eliminating environmental and human risks.

In this second cluster, the scientific research of D. D'Amato et al. [40]stands out, since it focuses on a new tool associated with the practice of circular economy, known as circular bioeconomy. This new environmental practice implies the use and management of renewable biological resources in SMEs, through the principles of circular economy [49]–[51].The circular bioeconomy model suggests a series of resource transformation environmental policies, such that they promote the implementation of sustainable models. It focuses on improving not only current consumption efficiency and recycling capacity, but also the production systems, which is theoretically achieved through input reduction, eco-design, reuse, and waste recycling.

In evaluating the bioeconomic model in a group of SMEs from the forestry sector, D'Amato et al. [40] concludes that the model is oriented towards economic aspects and environmental benefits but does not refer to the social dimension of sustainable development. In addition, the selected sample of companies was certainly small and heterogeneous, which may bring about analysis unit limitations when it comes to decision-making in the sector.

In addition, the investigation conducted by M. Aboelmaged [41] examines how sustainable manufacturing practices in SMEs are influenced by technological infrastructure, technological competition, environmental pressure, environmental regulations, management support and employee engagement. The model evaluated in this study shows that environmental pressures, management support and employee engagement positively influence sustainable manufacturing practices. Contrastingly, environmental regulations, technological infrastructure and technological

competition do not significantly affect sustainable manufacturing practices in terms of cost, quality, delivery and product manufacturing flexibility.

In turn, several studies have emphasized that, due to the particular features of SMEs, they make multiple efforts to implement sustainable tools and practices, which is an arduous task for them [52]–[54]. Research carried out by H. T. S. Caldera et al.[30] on Lean and Green thinking has shed some light on this problem. Intended for continuous improvement ecological contexts, this approach addresses problems such as waste management, overproduction, waiting, transportation, defects, excessive use of ecosystem services, garbage, pollution and industrial safety deficiencies, among others. The mentioned author develops a model based on strategic facilitators for sustainable business practices, intended to guide SMEs toward the use of Lean and Green strategies. In practical terms, the model recommends internal process changes, improvement of employee attitudes and perceptions, optimization measures, financial incentives and a support network to connect industrial SMEs with environmental sustainability experts.

G. C. Oliveira Neto et al. [55] highlights that, when it comes to implementing Cleaner Production, SMEs have to face several barriers that prevent the transition to sustainability. These can be financial, economic, cultural, technological, legislative, governmental or organizational in nature. The mentioned authors proposes that companies can achieve sustainable changes if they modify their production systems and follow a route that allows them to identify the barriers and monitor their opportunities. Said allows overcoming those to barriers, prioritize and identify causes and effects, and perform economic and environmental analyses. However, taking into account that the sample analyzed in the mentioned study comprised only four metal-mechanic companies located in Brazil, this research could be strengthened by analyzing other sectors in different regions, in order to unify criteria and barrier- overcoming mechanisms.

Another sustainability initiative is ecoefficiency, which is actually a management strategy that motivates small entrepreneurs to balance their environmental and economic performance through innovation, growth and competitiveness. This results in a less harmful use of natural resources and higher financial savings for the company [56]. Thus, the life cycle analysis approach to supply chain improvement allows identifying the potential for eco-efficiency in SMEs. For such purpose, the key actors in the chain need to detect the opportunities to not only emphasize their environmental performance, but evaluate their products as well, thus recognizing the critical processes that need to be improved.

Although SMEs are classified as resource-poor companies [57] they have been placed further up in the supply chain because of the potential influence of final product processing. In the scientific research carried out by Changwichan et al. [42] the environmental and economic sustainability of a manufacturing company were evaluated through eco-efficiency. They found that the combination of economic and environmental indicators could be improved by 100% through the use of clean technologies.

Thus, in the current literature review, good management and implementation of sustainable tools and practices in SMEs are observed to optimize ecosystem services and facilitate the reduction

of the negative impacts caused by internal corporate activities. This, in turn, allows generating multiple opportunities for continuous business improvement.

2.4.3 Cluster 3. Social responsibility and knowledge management

Corporate social responsibility (CSR) and Knowledge Management (KM) have become key aspects of business performance in academic, professional and entrepreneurial sectors [46]. In this respect, “Knowledge” has been defined as the capacity to acquire information individually or in groups of people to improve effective actions in companies [58]. In turn, knowledge management – i.e., the acquisition and administration of environmental protection knowledge – is used by workers in companies to reduce the environmental impacts of production and consumption processes [59]. Currently, social responsibility and knowledge management activity in SMEs is oriented towards health, safety, employee awareness of environmental issues, transfer of environmental knowledge, and the general well-being of employees and the community [10], [60], [61]

CSR and KM relate to the social dimension of sustainable development in the third cluster of the current literature review, wherein authors like W. Kucharska et al. [7] have pointed out that people are the actual backbone of a company. Through the perception of employees about CSR and KM practices, these authors explore different factors (such as culture, reputation and sustainable social practices) that intervene in the social development of a group of companies. In this sense, Ravasi and Schultz [62] have defined organizational culture as:

"Assumptions that guide interpretation and action in organizations by defining appropriate behaviors for different situations, with employee norms, values and beliefs likely to play an important role in their CSR perception and behavior".

In this regard, it has been shown that in order to build a good corporate reputation, companies must create a long-term employee-oriented culture that allows them to observe how each business decision affects their workers [7]. Contrarily, short-term employee culture is considered to go against CSR. According to J. Batle et al. [63], one of the main environmental management factors is sustainable innovation, which corresponds to the capacity to incorporate new environmental tools and approaches such as circularity, design, knowledge and learning management, and organizational synergies conducive to both competitive social development and a more significant and sustainable impact on the environment. However, the creation of new tools and clear opportunities derive from collaborative and proactive activities among entrepreneurs and other agents of the value chain, which result in environmental awareness in the internal activities of the company.

Along these lines, G. C. Wu [45] demonstrated the importance of CSR and KM for improving environmental performance in SMEs through sustainability-oriented innovations. Yet, it is a difficult task for this type of company, since they have limited resources and experience. In this regard,

the mentioned author proposes an evaluation framework to determine the influence of sustainable innovation practices on getting socially responsible suppliers. This scientific research reveals that innovative practices can improve environmental performance in terms of competitive advantage and environmental management systems. Just as well, the researcher found that improving the relationship with suppliers can effectively help SMEs enhance their social responsibility as long as those suppliers actively cooperate to overcome the barriers imposed by limited resources and knowledge.

Likewise, the study developed by C. C. Nakamba et al. [35] examines how social sustainability is considered in supply chain management, with the aim of identifying key future research perspectives. These authors synthesize some trends and research implications in the framework of corporate social responsibility: Existing pressures on social sustainability implementation by different actors of the supply chain; the development of measurement units to assess corporate social aspects (e.g., decent working conditions, incentives, wages and satisfaction among employees and customers, among others); and the development of tools and strategies to integrate social risk management into hiring and supplier selection decisions.

Consequently, the lack of sustainable social responsibility in the internal processes of the companies have become a must when it comes to improving workers' behavioral ethics. This is supported through the acquisition of environmental, social and economic knowledge, the latter being transformed into results that contribute to the improvement and sustainable development of the company.

2.5 Conclusions

This chapter presents a detailed description of the state of the art of the topic dealt with in the present research, starting from an analysis of the evolution that has emerged around sustainable development, through to the concepts of corporate sustainability. In addition, a bibliometric analysis focused on SMEs sustainable development models provides further insight into the research so far carried out in this field. As a result of this analysis, three clusters were defined: *i) Cluster 1*. *Management systems for sustainable development decision-making*, which highlights the importance of defining the different risks, challenges, approaches, elements and characteristics involved in this type of decision in SMEs; *ii) Cluster 2. Sustainable Tools and Practices*, wherein different types of strategies and tools that have been applied to SMEs are analyzed, showing their benefits and implementation barriers; *iii) Cluster 3. Social Responsibility and Knowledge Management*, underpinning the link between corporate economic and environmental component and the social aspect of the labor force, thus guaranteeing that the systems and procedures of the operational activities comply with the social requirements of SMEs sustainability projects.

Chapther 3. Research Methodology

3.1 Introduction

The third chapter of the present dissertation introduces its research methodology, which allows the fulfillment of its objectives. Thus, the Design Science Research (DCR) methodology is described [64], [65] highlighting the purpose of each cycle and activities, the research focus and the instrument design process applied to obtain the data.

3.2 Research methodology

The scientific research technique selected for the present thesis is the descriptive analytical method [66], [67] which allows presenting a scientific problem, diagnosing it and proposing possible solutions. This is done with scientific tools that facilitate investigating the causes of the problem, analyzing their effects and finally proposing different solutions.

On these grounds, the DCR methodology [64], [65] was adapted to the descriptive analytical research method. DCR is compatible with research processes intended to improve some existing model or to propose a new one. As such, it allows developing scientific strategies to provide a useful and effective solution to a particular problem. The development of the model implies a series of activity cycles intended to diagnose the environment and, subsequently, proceed to the actual design, construction and evaluation of the model. Figure 4 shows the cycles and activities comprised in DCR.

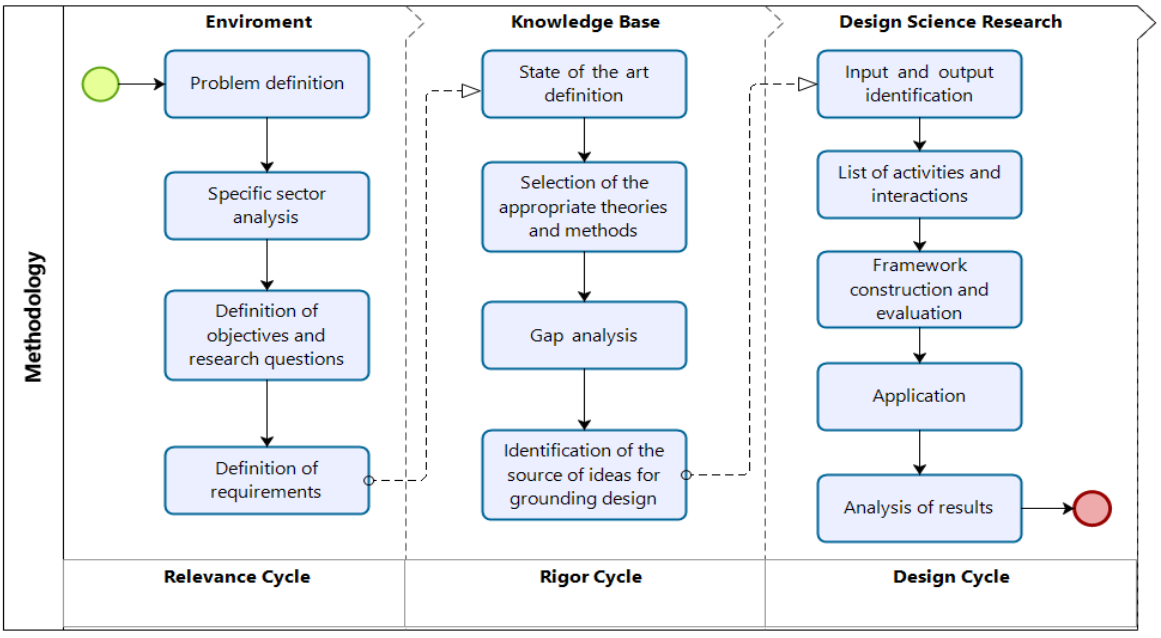


Figure 4. Steps followed in the DCR methodology: Adapted from [64], [65].

In the lines that follow, each one of the cycles making up the research methodology are described:

- **Relevance cycle:** As it deals with the analysis of the environment, this cycle not only connects the contextual environment of the research project with the activities of the "rigor" and "design" cycles but defines the research problem and justifies the value of the solution as well. The main objective at this stage is to understand the relevance of the problem and the weaknesses of the sector of interest, analyzing those investigations related to the subject of study.

  As it can be seen in Figure 4, the first activity is the "definition of the problem", which comprises a sequence of four steps: Selecting and specifying the sector to be analyzed, defining the objectives of this activity, and establishing the research question and necessary requirements for the analysis. Table 3 summarizes the activities involved in the first cycle:

Table 3. Activities of the relevance cycle (RC)

1. RC
RC Activity 1.1. Definition of the problem: The lack of strategic models integrating management systems, sustainable practices, social responsibility and environmental knowledge management for workers in accordance with the needs of Colombian SMEs.
RC Activity 1.2. Specific sector analysis: SMEs of the services, manufacture and construction services in Colombia.
RC Activity 1.3 Definition of the objectives and research question: Attaining a rigorous conceptualization of the current situation of SMEs, such that it allows answering the question: What are necessary conditions for SMEs to improve their economic efficiency indicators, minimize their negative environmental impacts and have their employees adopt a more sustainable responsible behavior?
RC Activity 1.4 Definition of requirements: Literature reviews and bibliometric analyses to provide insight into the environmental, economic and social approaches of the current SMEs environmental sustainability models.

- **Rigor cycle:** It connects the relevance cycle activities with those of the design cycle. In this cycle, the state of the art is defined, based on the bibliometric analysis carried out in the relevance cycle. As it can be seen in Figure 4, the first activity is the "definition of the state of the art", which provides the knowledge background of the process, and is followed by the selection of the models that allow analyzing the research gap. This activity is followed by a brainstorming one, in order to set the key elements that will be included in the model under development. Table 4 summarizes the activities corresponding to the second cycle.

Table 4. Activities of the rigor cycle (RCe)

2. RCe
RCe Activity 2.1. Definition of the state of the art: The literature review evidences few sustainability models integrating knowledge management strategies, environmental practices and management systems according to the needs of SMEs.
RCe Activity 2.2. Selection of the main models: The main sustainability models identified in each approach are shown in Table 2 of Chapter 2.
RCe Activity 2.3. Research gap analysis: The main research gaps as currently identified are: i) The lack of a methodology to implement simplified sustainability models that do not require long periods of time to evaluate the return on investment by SMEs; ii) The comprehensive assessment of sustainability must include social aspects such as knowledge management and environmental culture. However, this dimension is rarely considered or evaluated; iii) It is necessary to strengthen learning and communication programs to implement sustainable models among the actors of the value chain; iv) Lack of sustainable maturity models that allow establishing a gradual route for implementing environmental, social and economic strategies; v) Lack of information technology tools for managing and monitoring sustainability in SMEs; vi) Scarcity of sustainable models validated through data analysis.
RCe Activity 2.4. Identification of ideas for the design of the model: A list of concepts, components and factors is extracted from the literature review, based on which their integration into the integral sustainability model is proposed in section 4.3.

- **Design and validation cycle:** this cycle connects the previous ones in order to build the proposed model and evaluates its application. According to Figure 4, which illustrates the DVC process, the first activity of this cycle are the results of the "identification of inputs and outputs" step involved in RCe Activity 2.4. These results are employed for the particular need of the present research through an analysis of interactions, which allows defining the elements and factors that are essential for the design of the model. This results in a conceptual map, which is then visually deployed, leading to the actual construction of the model. Next, its validation and application activities are carried out, making use of specific methods which will allow the analysis of the results. Table 5 summarizes the activities corresponding to the third cycle.

Table 5. Activities of the Design and Validation Cycle (DVC)

3. Design and Validation Cycle
DVC Activity 3.1. Identification of inputs and outputs: According to activity RCe 2.2, all the components and factors that are referenced in the state of the art are taken as inputs. For their part, the outputs correspond to the most representative ones.
DVC Activity 3.2. List of components, factors and interactions: The factors and components resulting from DVC 3.1 are listed in order of importance (high, medium or low, according to the objective of each sustainability dimension) and classified by author (Tables 6,7, and 8 of Chapter 4).
DVC Activity 3.3. Construction and evaluation of the model: The design activity starts the schematization and construction of the integral sustainability model for SMEs, resulting in a first draft of it. After the first two design proposals [57], [58], the design was redefined, since more requirements and relationships between the factors were considered. Then, “definition of components” activity was re-iterated, resulting in the model shown in Chapter 4.
DVC 3.4. Activities. Application: The input of this activity was the model resulting from DVC Activity 3.3. Taking into consideration RC Activity 1.1, the model was applied, for it to be evaluated later on. This activity was based on the Case study methodologies [68] Computational intelligence experimental design [69].
DVC Activities 3.5 Analysis of results: After conducting DVC Activity 3.4, the data were statistically analyzed and corroborated against the research objectives and questions, which must be answered to assure that the proposed model fulfills its function. The results are discussed in Chapter 5 and 6. Finally, recommendations and conclusions are presented in Chapter 7.

3.3 Research focus

The research focus of the current study are Colombian SMEs. The following is a descriptive analysis of the situation of this sector in terms of some economic and environmental aspects.

3.3.1 Social and economic situation of SMEs in Colombia

Besides its great cultural, natural and geographic richness and diversity, Colombia has a key strategic position in Latin America, connecting air, land and shipping routes with North and South America. According to the report on Colombia's productive dynamics presented by the Ministry of Commerce, Industry and Tourism, the Colombian economy grew 3.3% in 2019, which is the highest rate recorded since 2014, surpassing the economic growth of Latin American and Caribbean countries during that year.

The sectors reported to have undergone higher economic dynamism in 2019 were finance (5.7%), public administration (4.9%), commerce, transportation, lodging and meals (4.9%), professional and scientific activities (3.7%) and industry, which registered significant growth (1.6%). However, the construction sector underwent a contraction of -1.3% [70] in its economic dynamics. The same report states that in 2019, consumption, exports and investments grew by 4.6%, 4.3% and 3.1% respectively, while imports increased by 9.2%.

Representing 90% of the national economy, SMEs are the main business force and the productive support and employment engine in Colombia. Thus, given the importance of improving this sector, the focus of the present study are those SMEs located in the five main cities of Colombia: Cartagena, Barranquilla, Bogota, Medellin and Cali. Figure 5 shows the geographical location of the studied SMEs. The city of Cartagena has an estimated population of 887,946 inhabitants, while Barranquilla has a population of 1,120,103 inhabitants. Bogota, the capital of the country, has a population of 7,181469 inhabitants, whereas Medellin and Cali have 2,372,330 and 1,822,869 inhabitants, respectively [71]. These figures clearly indicate that the business sector, the state and society must certainly respond to the needs of each of these regions.

Among the productive sectors, those that stand out in these cities are manufactures, services and commerce. However, and regardless of the productive sector, SMEs have shown various social, economic and environmental problems over the years. For example, lack of an integrated internal management, high influence of the country's economic environment, few technological tool, limited expansion to new markets, and the lack of innovation and associative networks. These limitations certainly restrain SMEs to strict survival in the national market, thus preventing the development of competitive and strategic alliances between suppliers and distributors in order to export their production.

Figure 5. Location of the studied SMEs in Colombia

According to the analysis of business performance carried out by the Colombian Association of Micro, Small and Medium-sized Enterprises (ACOPI) by the end of 2019 [72], production, sales and employment in service, commerce and manufacturing SMEs in Colombia showed a variation when compared to the same data in 2018 (see Figure 6).

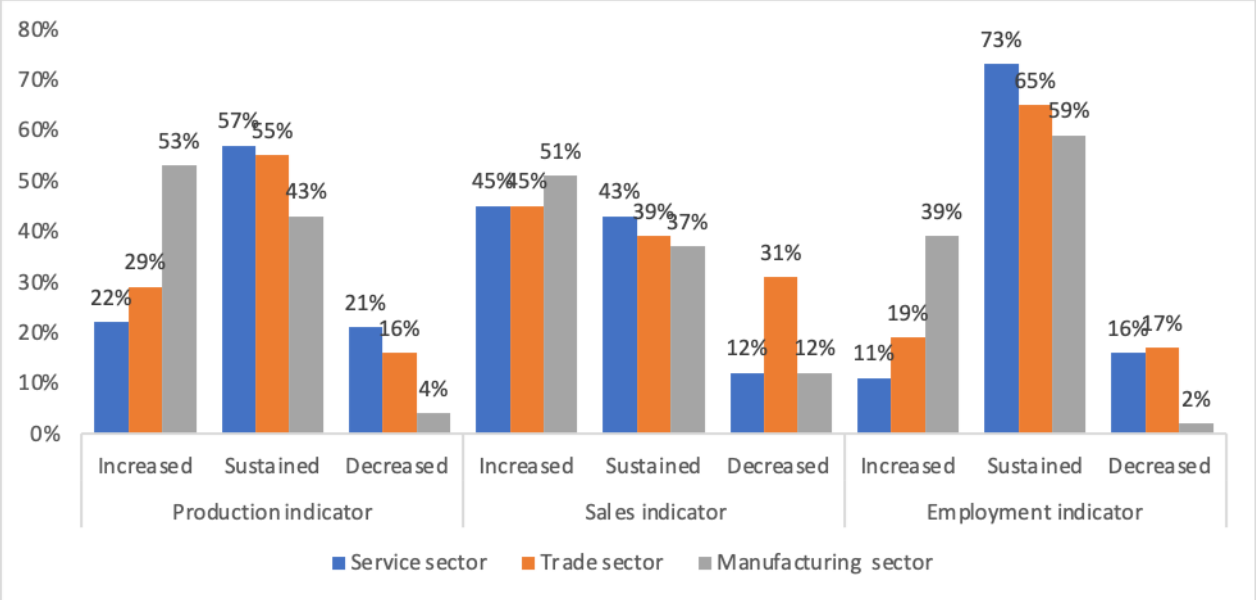


Figure 6. SME business performance in Colombia by 2019.

Figure 6 describes the SME service, trade and manufacturing sectors of Colombia in terms of production, sales and employment performance indicators.

Most of the interviewed managers in the services (57%) and trade (55%) sectors manifested that production had remained stable when compared to that of the previous year. Simultaneously, considerably less managers in these same two sectors stated that production had increased (22% and 29%, respectively) or decreased (21% and 16%, respectively) during the same period. Yet, in the manufacturing sector, most managers (53%) declared that production had increased, whereas 43% of them said it had remained steady and 4% saw it had decreased.

As to the sales indicator, the trend was generally similar to that of production in the manufacturing sector. In effect, about half of the interviewed managers of the three sectors in question had observed sales increases along the year. Slightly lesser percentages of them (around 40%) uttered those sales had remained steady and, finally, only few of them in the services and manufacturing sectors (12%) found that they had decreased. However, this figure was 31% in the case of the trade sector.

In the case of employment, the trend was similar to that of production: Most managers (65% on average) uttered that the indicator had remained stable over the year. In the service and trade sectors, roughly similar numbers of them stated that employment had increased (11% and 19%, respectively) or decreased (16% and 17%, respectively). However, in the manufacturing sector, 39% of managers said that the indicator had increased, while only 2% had perceived a decrease.

In the same business performance study, the evaluated SMEs emphasized that investments were destined to the acquisition of new machinery and equipment (30% of the surveyed companies), the improvement of company infrastructure (29% of them), personnel training (16%), new technologies and infrastructure (8%) and new branches (9%).

For its part, the Colombian Confederation of Chambers of Commerce (Confecámaras) conducted a study on business dynamics. In its assessment of the creation of new productive units [73], they highlight that, by 2019, 2.1% more of the new units productive were created in comparison to 2018. Out of these units, 75.7% correspond to individuals and 24.3% to companies. The greatest increase in the creation of new companies in 2019 was recorded in the service sector (3.4%), followed by the industrial sector with 2.0% and commerce with 1.5%. According to the size of the company as measured by the value of its assets, it was evident that the new productive units are mainly made up of micro-companies (99.6%), followed by small companies (0.37%), while the rest are medium and large companies (0.03%).

In addition, as in different countries around the world in 2020, SMEs production has declined due to the health and economic emergency caused by the global pandemic. Thus, a report issued by *Confecámaras* as of June 2020 shows that economic activities related to the service sector registered the greatest drops in business creation, with a negative variation of -29.6%, followed by the construction sector with -28.3%, industry (-28.2%) and commerce (-21.8%). Naturally, these significant contractions seriously affects the country's productivity [74].

3.3.2 Environmental situation of SMEs in Colombia

The information related to the environmental situation and corporate performance in Colombia is found in few national repositories, with problems related to availability and unprocessed data, which makes it difficult to analyze most of the related indicators [75]. Consequently, there is very little evidence of the specific impact of SMEs on the environment in Colombia. Nevertheless, we took as reference the data sources on some environmental indicators that are grouped in the Environmental Information System (*Sistema de Información Ambiental - SIAC*) and the National Administrative Department of Statistics (*Departamento Administrativo Nacional de Estadística* – DANE). Based on these sources, the report on circular economy indicators for Colombia in 2020 [76] highlights the following:

- In 2017, the use of water for economic activities – as consumed directly from aqueduct services - totaled 713 million cubic meters (m^3) at the national level. Thus measured, the sectors that consumed the most water are the manufacturing industry with 10%, financial and insurance activities (11%), construction, communication, professional and scientific activities (16%), wholesale and retail trade (25%), and public administration and defense (38%).

- From 2017 and 2018 there was an increase in the efficiency of the use of forest products by the manufacturing and construction industries, which went from respectively consuming 18.84t and 19.97t for every billion of added value in 2017, to consuming 17.98t and 19.62t for every billion of added value in 2018.

- The intermediate consumption of energy products by different economic activities in the country amounted to 2.1 million terajoules (tj). Among these products are coal, oil and gas, some petroleum by-products (motor gasoline, kerosene, diesel and fuel oil), liquefied petroleum gas and products originated from biomass, as well as electric power. Most of these products (55%) were consumed by the manufacturing industries; followed by activities associated to water, electric power, gas, steam and air conditioning supply, sewage evacuation and treatment, waste management and environmental sanitation (all of which accounted for 29.3%); and wholesale trade and other economic activities, with 15.5%.

- In addition, the generation of greenhouse gas emissions, which is caused by the production and consumption of fossil fuels and biomass in the different economic activities of the country, totaled 108,248.6 Gigagrams of CO_2eq. In 2017, the most intensive greenhouse-gas-generating activities were those performed by manufacturing industries (654.74 CO_2eq), followed by electricity, gas, steam and air conditioning supply activities (536.86 CO_2eq).

- Regarding organic waste, the sectors with the largest generation of this residue in 2018 were the wood and cork industry, together with paper manufacturing and printing activities, all of which disposed 52,769 kg of waste per billion pesos. These were followed by some non-metallic mineral product industries, which disposed 20,530 kg per billion pesos. As to the generation of hazardous waste, this figure reached 635,518 tons in Colombia in 2018, dominated by mixtures and emulsions with hydrocarbons, which represented 55%; and followed by mineral oil waste, which represented 8%; lead containing waste (8%); coming especially from the manufacture of batteries and electric accumulators; clinical waste generated from health care (7%); and thermal liquid waste from coolant gases (22%).

- In turn, according to Objective No. 12 of the *Como Vamos* Network of Cities' report on sustainable development – which intends to guarantee sustainable production and consumption patterns – for every 3 tons of production, one ton of waste is discarded, which is equivalent to an annual waste of 9.8 million tons [77]. In addition, the rate of recycling and new use of solid waste in Colombia was 8.7%, despite the fact that the solid waste usage rate was 35%[77]. Figure 7 shows the recycling rate report across Colombian cities, Bogota having the highest value for this parameter, while the city of Barranquilla has the lowest one.

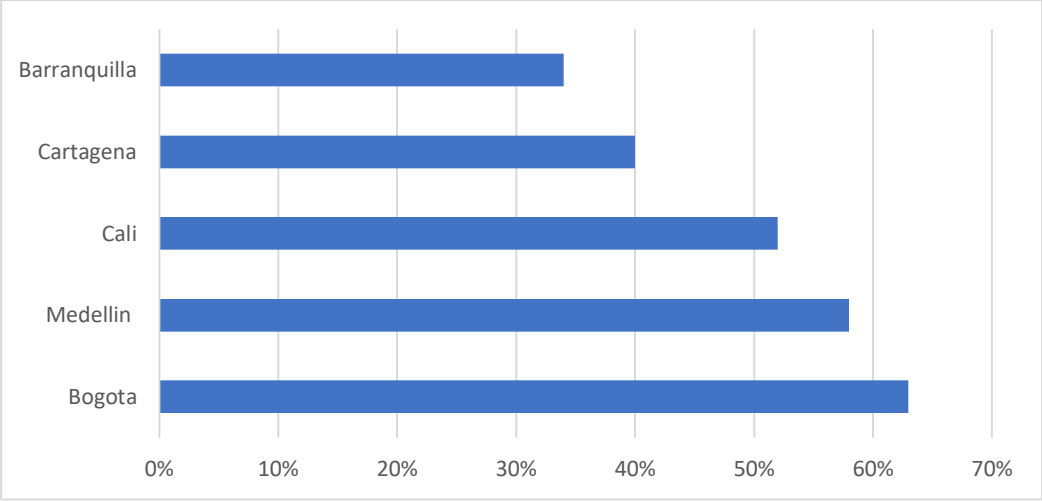


Figure 7. Recycling activity rates across Colombian cities.

3.4 Design of an instrument to evaluate the model

Based on the previous section, which states that the current research focus are SMEs operating in Colombia, the procedure for data collection is defined as the "case study" method. This method was used for factor analysis, quantitative survey analysis for maturity level and simulation to evaluate the comprehensive model.

In this respect, methodology by R. Yin [68] establishes that the case study not only consists of general statistical information sampled through surveys or experiments, but it is also an analytical generalization to illustrate and represent the generation of a theory.

According to R. Yin [68], the case study method is appropriate for new and innovative topics related to a particular mode of empirical research featured as follows:

- Contemporary phenomenon examined in its real context
- Study of a specific topic
- The boundaries between the phenomenon and the context are not clearly evident
- Different data sources are used
- Both single and multiple cases can be studied.

Figure 8 shows the process used to obtain the data once the model to be evaluated was defined in Chapter 4, together with the field study results presented in Chapter 5:

Figure 8. Process followed for the case study methodology

3.5 Conclusions

This chapter presents a detailed analysis of the research methodology used for the development of the current doctoral dissertation. In the first section, the Design Science Research methodology was defined, addressing the relevance, rigor and design cycle and describing the activities executed in each one of them. Likewise, the research focus was analyzed, corresponding to SMEs operating in Colombia, which were addressed through the case study methodology. Therefore, the importance of the sector and its economic, social and environmental behavior is described through updated business performance figures. In addition, it was demonstrated that SMEs in Colombia lack the economic resources to implement sustainability standards. However, efforts must continue to implement mechanisms to reduce impacts and promote the efficient use of ecosystem services in accordance with the needs and challenges of SMEs. On the other hand, the process used to carry out the evaluation and collection of information was specified, as it detailed in the following section.

Chapther 4. Design of the Integral Sustainability Model

4.1 Introduction

The fourth chapter of this dissertation describes and analyzes the Integral sustainability model proposal for SMEs (ISM-S). This novel development is expected to contribute strategically to overcoming the challenge posed by corporate sustainability for this type of business. Therefore, it brings together the factors studied in chapter two of the literature review, which are decision-making management systems, sustainable practices and tools, and social responsibility on the part of employees. Additionally, a new factor is proposed, namely technological and analytic convergence of information. Thus, the correlation of importance between the components that integrate each of the mentioned factors across the different studied authors is analyzed by means of component selection criteria. On these grounds, the components of the ISM-S model are described and, finally, the model is designed and constructed.

4.2 Identification and analysis of the components of the conceptual model

Strategic models are associated to business models, which have emerged as a unit of analysis to create value in products and services according to the needs of customers and the environment. Each company operates under a business model, either consciously or unconsciously [78], making it vital for a company to know how to choose an appropriate model that contributes to innovation and competitive advantage through strategic resources, technology, and cooperative networks [79], [80].

Business models across different interdisciplinary areas have been referred to as "*statements, descriptions, representations, architectures, conceptual models, plans, assumptions, structures, templates, methods, or sets of strategies*" [78]. According to Porter [81], a business model is a gear of different elements set by a company to achieve a specific end. By orienting this definition to sustainable aspects, S. Schaltegger et al. [27] have modified it as follows:

> *"A business model for sustainability helps to describe, analyze, manage and communicate: (i) a company's sustainable value proposal to its customers and all other stakeholders; (ii) the way it creates and delivers this value; and (iii) how it captures economic value while maintaining or regenerating natural, social and economic capital beyond its organizational boundaries."*

In other words, for the current research the concept of business model is defined as a conceptual paradigm of value supported on environmental, economic and social strategies oriented towards the achievement of business sustainability. This concept is formulated under the notion that corporate value proposals may invoke not only financial or economic value, but social and ecological value as well [82], [83]. This is so because, in the context of sustainability, value creation can make use of renewable resources, technological innovations, collaboration with suppliers and promotion of more sustainable consumption for the fulfillment of sustainable development objectives.

Consequently, the current Integral Sustainability Model proposal for SMEs (ISM-S) was based on the clusters identified in the literature review around three key factors: *i) Factor 1. Sustainable decision-making. (ii) Factor 2. Sustainable tools and environmental practices. (iii) Factor 3. Social responsibility and knowledge management.* Then, within each of these factors, the key elements associated to each one of the sustainable development dimensions were extracted and listed (see Tables 6,7, and 8).

Later on, each element was described and given a binomial relevance value by author, according to which 1 is assigned when the component is mentioned by a particular author, and 0 when they do not [78].Finally, an importance correlation was calculated to identify the most relevant components. Below is the equation developed for the identification of the mentioned elements that were later used for the construction of the model.

Analysis for the identification of the components of the ISM-S

The integral sustainability model proposed for SMEs in Colombia (ISM-S) is defined as a set of components which not only belong to the dimensions of sustainable development but are also correlated with the relevance given by each identified factor, ***G= (Ds, F, C, A)***, represented in Equation 1.

$$ISM - S = \{f_i(a_k, c_j): f \in Ds, c \in C, a \in A | i, j, k > 0,\ k = j, i \neq k, j\} \quad (1)$$

Where:

Ds- denotes the dimension of sustainable development.

F- denotes the set of factors belonging to the dimensions of sustainable development, wherein f_i corresponds to the i-th factor, as represented in equation 2.

$$F = \{f_i: f \in Ds, i > 0\} \quad (2)$$

C- denotes the set of components belonging to an author, wherein c_j corresponds to the j-th component, as represented in Equation 3.

$$C = \{c_j : c \in f_i \text{ and } c \in A, j > 0\} \quad (3)$$

A- denotes the set of authors proposing a given component associated to the sustainable development factors of the literature review, wherein a_k corresponds to a particular author, as represented in Equation 4.

$$A = \{a_k : a > 0 \text{ and } a < 5\} \quad (4)$$

As to the selection of the components, an importance correlation is calculated by summing up the most relevant ones and selecting those that are higher than 4, as represented in equation 5:

$$ISM - S = \{csms_i \sum(a_k, c_j) \geq 4\} \quad (5)$$

Table 6. Key components of Factor 1: Sustainable decision-making.

Authors / Components	H. S. Birkel et al.,(2019) [33]		S. K. Mangla et al., (2018) [36]		T. B. Long et al., (2018) [37]		C. H. Hsu et al.,(2017) [46]		P. R. Crowe et al.,(2016) [29]		TOTAL
	D	V	D	V	D	V	D	V	D	V	
C1. Profitability	Liquidity and solvency	1	Overall profit	1	Profitability	1	Reduction of manufacturing, procurement and distribution costs	1		0	4
C2. Capacity	Decision on what and when to invest.	1	Involvement, support and commitment of the management.	1	Clear vision and narrative about what to invest in.	1		0	Condition for efficient resource management.	1	4
C3. Requirements of the customer	Analysis of customer demand / acceptance	1	Understanding the customer and other stakeholder requirements.	1		0	Improving product quality to satisfy the client	1	Promotion of consciousness at the local level	1	4
C4. Coverage	Long and uncertain investment amortization	1	Understanding the importance and benefits of the sustainability initiative	1	Foundations of sustainability	1		0	Measuring the relation between financial expenses and their associated short term debt.	1	4
C5.Governmental		0	Pressure on the part of several governments and non-governmental entities	1	Conforming to external events as commanded by the government.	1	Normativity on customer health and security regarding product use	1		0	3
C6. Monitoring		0	Tracking and auditing of ongoing activities	1		0		0	Provision of accessible information	1	2
C7. Incentives		0	Support from diverse entities to sustainable initiatives	1	Collaboration between companies and external entities	1		0	Creation of collaborative and supportive networks, incremental and experimental approach	1	3
C8. Competitiveness	Changes in competence management	1	Identification of new competitors	1	Constant innovation for better customer satisfaction	1		0	Identification of change promoters and adoption of less hierarchical approaches.	1	4

**D= description of the component by author; *V = relevance value, 0 if not mentioned by the author and 1 if mentioned by the author.*

Table 7. Key components of Factor 2: Sustainable tools and practices.

Components \ Authors	D. D'Amato et al., (2020) [40]		H. T. S. Caldera et al., (2019) [30]		M. Aboelmaged (2018) [41]		Changwichan et al., (2018) [42]		G. C. Oliveira et al., (2017) [43]		TOTAL
	D	V	D	V	D	V	D	V	D	V	
C1. Processes	Identification of processes with stronger environmental impact.	1	Identification of defects in goods and services, and identification of those that do not harm the environment	1	Identification of more relevant processes	1	Emphasis on final tube process.	1	Identification of processes with greater environmental impact through life cycle analysis.	1	5
C2. Evaluation	Analysis and evaluation of environmental impacts	1	Analysis and evaluation of environmental impacts	1	Simplification of processes to guarantee transparency and traceability	1	Financial evaluation of impact reduction	1	Environmental and economic evaluation	1	5
C2. Prioritization	Maximization of energetic and materials efficiency	1	Reduction of the use of ecosystem services. Use of materials and solid waste	1		0		0		0	2
C4. Changes in processes	Replacement with renewable and natural processes	1	Promoting necessary decisions for commitment with sustainability	1	Alignment of organizational strategic objectives with green strategies	1	Promotion of sustainability knowledge	1	Evaluation of different scenarios to propose optimal environmental yield	1	5
C5. Metrics and monitoring	Control of environmental and economic indicator s	1	Use of information: Communication, networks, technology	1	Strengthening synergistic results through continuous improvement.	1	Dissemination of information about environmental problems and application of operational environmental management	1	Selection of the correct economic and environmental indicators to be measured in order to improve the manufacturing process	1	5
C6. Technological innovation	Development of solution applications	1	Development of innovations through smart devices	1	Development of computer application solutions	0	Updating of obsolete machines and tools	1		1	4
C7.Pressures		0	Environmental pressures from customers, news and media, and competitors	1	Involving internal and external stakeholders in process optimization	1					2
C8. Regulations		0	Application of national and regional environmental regulations	1		0	Lack of regulation enforcement	1		1	3

*D= Description of the component by author, *V = Relevance value, 0= not mentioned by the author; 1= mentioned by the author.

Table 8. Key components of Factor 3: Social responsibility and knowledge management.

Authors / Components	W. Kucharska et al., (2019) [7]		J. Batle et al., (2018) [44]		G. C. Wu, (2017) [45]		C. C. Nakamba et al, (2017) [35]		TOTAL
	D	V	D	V	D	V	D	V	
C1. Innovation		0		0	Development of novelties in products, manufacturing, and organizational levels.	1	Development of innovative practices to improve environmental performance in terms of competitive advantage	1	2
C2. Sinergy	Collaborative work among different companies	1	Promotion of associations, synergies, circular processes, systemic approach	1	Supplier evaluation, motivation and direct participation	1	Promotion of collaboration, evaluation, supplier development, audit of labor practices, and risk management.	1	4
C3. Education and transference	Knowledge exchange and cultural attitudes in a hierarchical system	1	Resource allocation and information sharing within and across the organizational hierarchy	1	Exchange of information between the company and value chain actors	1	Ensuring constant on-the-job training and promoting knowledge transfer between employees.	1	4
C4. Culture and commitment	Development of attitudes that are invented, discovered or executed by a group of people as they learn to deal with problems of external adaptation and internal integration	1	Creating and disseminating a behavioral code.	1	Generating consciousness and impact minimization commitment.	1	Ensuring an environmentally sustainable work environment by promoting environmental care practices.	1	4
C5. Reputation	Analysis of the results of the behavior developed by the company over time and its ability to distribute value to internal and external agents	1		0		0		0	1
C6. Metrics and monitoring		0		0		0	Measurement of aspects related to occupational health and safety, product responsibility, employee satisfaction, social reputation, human rights, community development, employee empowerment, compensation, and training	1	1

*D= description of a component throughout its citing authors, *V = relevance value, 0 indicating not mentioned by the author and 1 indicating mentioned by the author.

Therefore, taking into account Equation 5, and from an internal point of view, the key components that allow the construction of the ISM-S are the following:

Table 9. Internal components of the ISM-S

Factors of the model	Internal components
Factor 1. Sustainable decision-making	C1. Profitability, C2. Capacity, C3. Customer requirements, C4. Coverage, C8. Competitiveness.
Factor 2. Sustainable environmental tools and practices	C1. Processes, C2. Evaluation, C4. Process changes, C5. Monitoring.
Factor 3. Social responsibility and knowledge management	C2. Synergy, C3. Education and transference, C4. Culture and commitment

By taking into account the series of components mentioned above, it is analyzed that there are barriers that influence and/or hinder the development of each factor, so it is determined to select other elements such as:

Table 10. Internal and/or external barriers of the ISM-S.

Factors of the model	Internal and/or external barriers
Factor 1. Sustainable decision-making	Financial risk, availability, pertinence, commitment and management
Factor 2. Sustainable environmental tools and practices	Normative referents and new technologies
Factor 3. Social responsibility and knowledge management	Experience and attitudes

Likewise, the analysis of Tables 6, 7 and 8 has allowed the identification of a new transversal factor (Factor 4) likely supporting the development of factors 1, 2 and 3. Thus, Factor 4 corresponds to Technological and Analytical Convergence of Information and, as such it covers the components “technological innovation”, “synergy”, and “metrics and monitoring of indicators”. This factor allows the analysis of the basic information flow of the company as framed by its particular corporate characteristics [84], [85]. The following section illustrates the relation between the theoretical constructs and the components of the ISM-S.

4.3 Conceptual framework: Integral sustainability model for SMEs (ISM-S)

The ISM-S proposed in this research was designed from the factors and components found in the literature review, which allowed conducting this empirical study.

Figure 9 illustrates the ISM-S, which is composed of: ***i) Analysis of factors and components***: Located in the central part of the model, it represents the four dimensions of sustainable development (economic, environmental, social and technological), supported by the four factors studied in the previous section and their associated components. ***ii) Maturity level classification***: Located on the internal edge of the figure, it involves the identification and classification of the current state of maturity of the companies in terms of sustainability. ***iii) Simulation for decision -making***: Located on the external edge of the model, it allows figuring out a sequence of changing events that can be the object of a probabilistic analysis as the company goes through different scenarios to achieve sustainability. Additionally, it mentions the internal and external barriers that may hinder the adequate unfolding of these events.

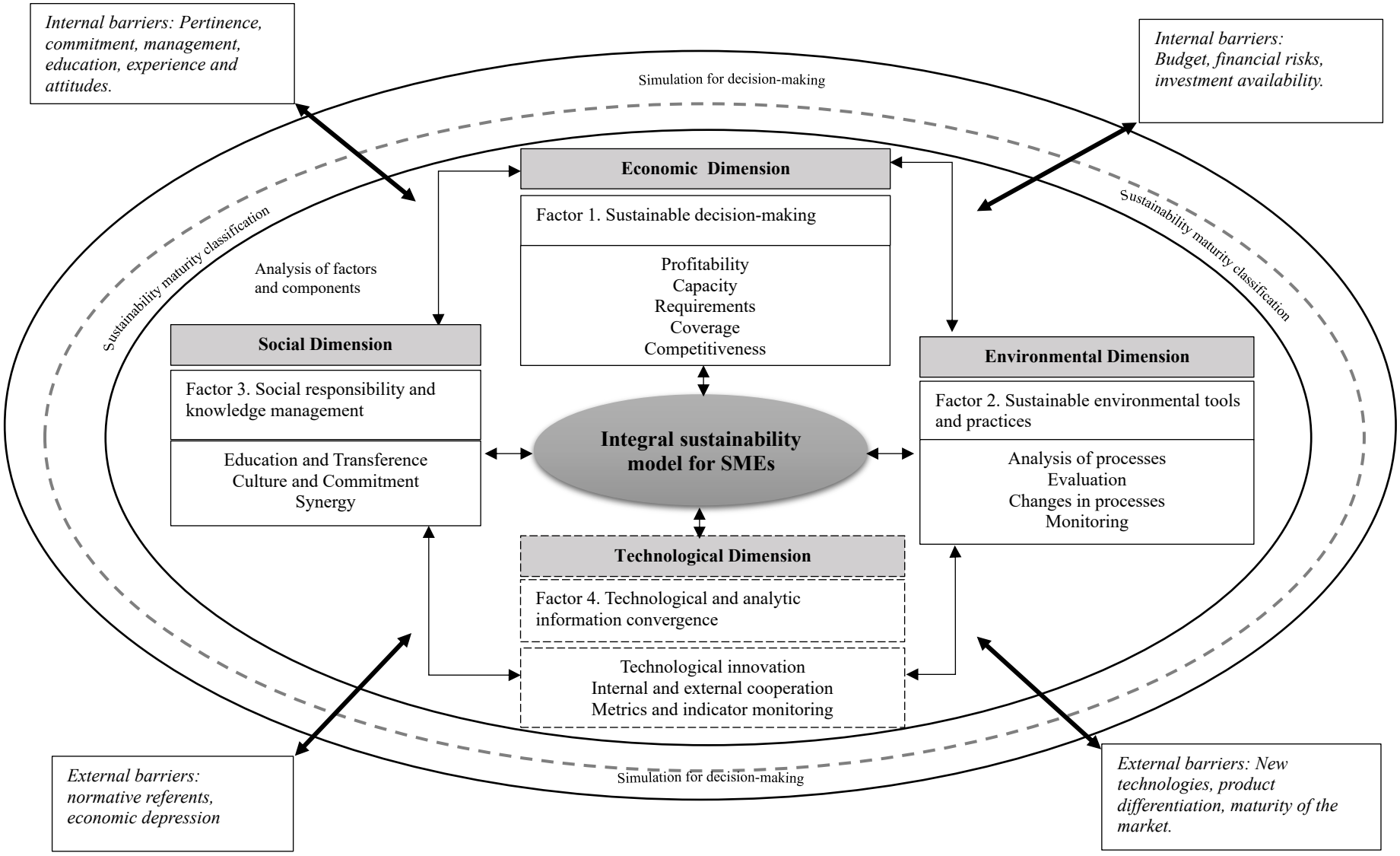


Figure 9. Integral model of sustainability for SMEs, ISM-S

The components that make up the ISM-S are described below:

4.3.1 Analysis of integral factors and components of the ISM-S

- Factor 1. Sustainable decision-making

This factor is supported by the following components: Costs, profitability, capacity, requirements, coverage and competitiveness, which are considered internal elements that make it difficult for SMEs to adopt sustainable strategies and practices. On the other hand, it must be acknowledged that this system represents an increase in business and operational costs and entrepreneurs do not yet perceive any link between organizational improvement and business performance on sustainable issues when investing in environmental sustainability [86], [87]. On the other hand, the benefits of its implementation of the system are likely to generate enough reasons for business owners or managers to adopt sustainable strategies on a voluntary basis.

Thus, the benefits of savings in sustainable strategy implementation scenarios lead to the possibility of net annual savings in raw materials and/or reprocessing [27], [37]. Consequently, the objective aimed in light of this factor is:

To provide orderly, systemic and effective quantitative information about the economic and financial movements that imply investment, change or internal operation improvement in favor of the reduction of environmental impacts and decision-making.

- Factor 2. Sustainable environmental tools and practices

This factor is supported by process-analysis-related components which, coupled to exhaustive policy, mission, organizational and environmental values revisions, are intended to achieve incremental improvements or transformations. Subsequently, the components “environmental impact assessment” and “identification of the company's own environmental goals and objectives” are proposed, since they may influence the fulfillment of sustainable development objectives (SDAs) through internal organizational operations.

Additionally, the component “necessary changes or improvements” is considered in connection with the use of diverse sustainable tools (P+L [88], eco-efficiency [89], frugal innovation[90], product life cycle evaluation [91], and circular economy [30], [92]), those operations that require more attention and action being prioritized. Finally, the monitoring and follow-up component is proposed, which implies a commitment from the top management to approve and take the necessary measures to convey to the employees the activities that are effective in the adoption of sustainability in SMEs. In fact, the aim of this factor is:

Adopting diverse tools and/or sustainable practices that allow improving or reducing the environmental impacts of the company, according to its characteristics or particular needs.

- Factor 3. Social responsibility and knowledge management

This factor is supported by the education and knowledge transfer components, the employees being the main active resource capable of gathering training and creativity to promote innovative and competitive elements in the company. In this way, training, technical assistance and teaching of the implementation of sustainable strategies and practices continue to be fundamental for the environmental and social management of employees. This particular aspect of corporate life needs to be clearly identified, acquired, created, stored, socialized, applied and measured [50], [93]. According to N. Beech et al. [94], if owners and/or managers provide the necessary tools for mainstreaming the culture and necessary components leading to organizational commitment with sustainability responsibilities, employees are likely to dedicate more time and resources to the adoption of sustainability. Thus, the goal contemplated under this factor is:

Generating and promoting a culture of social responsibility and knowledge management within the company, by means of a set of educational actions contributing to the welfare of the organization and its environment.

- Factor 4. Technological and analytic convergence of information

Figure 9 introduces Factor 4: “Technological and analytical convergence of information”, which is supported by the components “technological innovation”, “synergy” and “metrics”. This set of components is aligned with the need these companies still have in the sense of knowing how to use any type of data generated in their internal operations to make value-creating decisions and obtain the information that is relevant to the current situation of the company [84], [85].

Given that an SME requires great effort to achieve competitiveness in the market, the synergy or cooperative work across company networks continues to provide technological innovation benefits aligned with industry 4.0. These benefits focus on interconnectivity, automated learning, and generation and collection of data in real time. Consequently, the objective pursued in light of this factor is:

Developing innovations in the collection, treatment and use of data and relevant information of the company through cooperation networks between companies, thus allowing technological innovation in the production chain and the use of good data analysis to make the best business decisions.

On the other hand, the internal or external barriers that hinder the adoption of the factors identified in SMEs have been included in the ISM-S. According to [30], [37], the barriers that determine uncertainty in a company have been classified in the following categories: Financial risks, external regulatory or government references, incorporation of new technology or machinery, experience or attitudes towards change on the part of employees, and lack of clear vision and leadership from senior management to make decisions.

4.3.2 Sustainability maturity level classification in the ISM-S

The ISM-S proposes to classify the current state of the companies in terms of the factors defined in the previous section, through a Sustainability Maturity Measurement Model (SMMM). Maturity models allow the company to know where it stands in terms of sustainability and how it should move toward it [95]–[97]. In other words, regardless of the economic activity of SMEs, they gradually move in the desired direction when implementing sustainable practices and strategies, from insufficient level, through a sequence that leads them to optimal or consolidated ones (see Figure 10). This allows identifying the factors on which these businesses should focus their efforts in order to improve within the framework of environmental sustainability, which certainly contributes to their decision-making process.

A research questionnaire has been designed that synthesizes a set of questions that aims to collect information on the fulfillment of around 42 characteristics related to the factors studied. Then, the use of a Likert scale of 4 in the maturity model is adequate for this type of work because it was proposed to distribute the fulfillment of the characteristics into 4 ranges. Hence, Level 1 implies the fulfillment of only 5 characteristics, while Level 2 implies the fulfillment of 14 characteristics. Similarly, Levels 3 and 4 require compliance with 27 and 37 characteristics, respectively (see Appendix 4).

In this way, the SMMM brings together the following links, which are described and proposed in the research study: *A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs) based on a data analytics evaluation approach (see* ***Appendix 1****):*

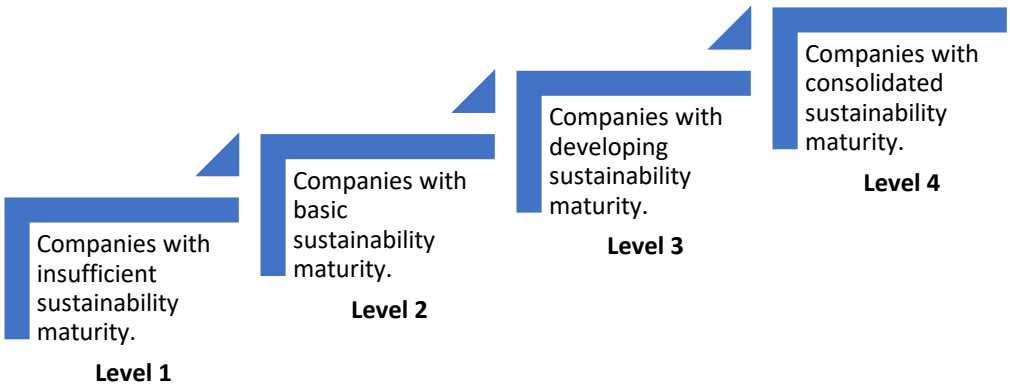


Figure 10. SMMM levels

- Level 1. Companies with insufficient sustainability maturity

Environmental sustainability is not a relevant issue in any of the internal activities contemplated in the agenda of these companies. Therefore, environmental trainings are sporadic or simply not carried out. However, they have implemented some environmental practices such as noise control in operational processes, solid waste collection and classification programs, and activities to encourage the reuse of stationery materials in each department.

- Level 2. Companies with basic sustainability maturity

Environmental sustainability in the agenda of these companies is not among the priority issues, although they try to give importance to the subject. Training on environmental issues and practices is carried out annually or every two years or more. Employees are informed about the environmental impacts caused by their organizations and the corresponding corrective measures. In addition, these companies have implemented environmental practices such as stationery reuse, management of noise level measurement, and solid waste collection and classification programs. Although they do not have environmental management systems in place, they do have an environmental policy.

- Level 3. Companies with developing sustainability maturity

Environmental sustainability in the agenda of these companies does not rank high, although it does have some relevance. They consider that their employees have some environmental management knowledge as a result of adequate investments in human, technological and physical resources to acquire it. Likewise, every six months the employees are trained in the implementation of environmental strategies that are used to improve the operative processes of these companies, who provide spaces for workers to express innovative environmental ideas.

These organizations have also documented their operative procedures. The employees are informed about the environmental impacts caused by their organizations and the corresponding corrective measures. They have implemented an environmental practice agenda including plans to prevent leaks and spills of toxic substances; noise management systems; campaigns to reuse industrial resources; and programs for office stationery reuse, collection and classification of solid waste, recovery of products that customers no longer use, and efficient water and energy use and measurement.

These businesses have defined environmental management systems that contribute to their decision-making processes, thus affecting corporate policies, indicator monitoring and control activities, resource planning and HSEQ modules in their business information systems.

- Level 4. Companies with consolidated sustainability maturity

Environmental sustainability is part of the core strategy of these companies, hence being placed at the top of the priority agenda. They have enough human, financial and technological resources for the acquisition and management of environmental knowledge. For this purpose, they are constantly training their employees, who are able to make good and responsible use of the environmental resources of these organizations.

These companies have tools or mechanisms for their employees to express topical innovative ideas. They document their operational procedures to share knowledge among employees, who are informed about the environmental impacts and corrective measures associated to corporate activities. These organizations implement environmental practice programs such as leak reporting plans covering liquid spills, gas leaks, gas-liquid mixtures, and other non-eco-efficient situations; water and energy measurement, saving and efficient use; solid waste collection and classification; office stationery reutilization; noise management; industrial resource reuse; and verification of final disposal of hazardous waste. In addition, these

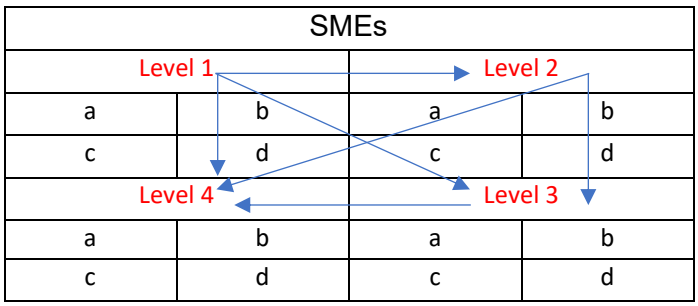
organizations have overt corporate strategies associated to environmental policy, supplier selection and recovery programs for products that their customers no longer use. They also have incorporated control systems for measuring environmental, social, and economic indicators in all links of their value chain. These systems have allowed them to get quality, environmental or occupational health management certifications.

4.3.3 Simulation for decision-making in the ISM-S

With the purpose of establishing a route for SMEs to achieve compliance with the ISM-S, and from a systemic perspective, simulation allows the assessment of a number of options among the economic, environmental, social and technological dimensions implicated in the ISM-S. In this way, the use of stochastic models in the overall modeling process facilitates integrating the components and sub-components that make up the model.

A stochastic model is represented by a collection of random variables that change from one state to another over time. That is to say, along a time period t, $\{\boldsymbol{X_t}\}$ measures aspects that are of interest. At any time t, X_t takes a value 0, 1, 2, or ...; and t being any value within a subset of $(-\infty, \infty)$, from the infinite past to the infinite future [98], [99]. This implies that the subsequent states of the system are determined both by the predictable actions of the process and by a random element.

Among stochastic models, the present study resorted to the Markov processes technique, which consists in a series of events, each of which has a probability of occurrence that depends on the previous event [98], [99]. Therefore, in order for SMEs to achieve the four factors described in the ISM-S and reach the higher level of maturity established in the SMMM, a complex system of routes interprets the process, as illustrated by:



a Factor 1. Sustainable decision- making, b* Factor 2. Sustainable environmental tools and practices, c* Factor 3. Social responsibility and knowledge management, d*. Factor 4. Technologic and analytic convergence of information*

Figure 11. Transition probabilities

For example, according to Figure 11 a SME classified at level 1 could move directly to level 4 or do it indirectly by passing through level 2 or level 3, fulfilling the objectives and requirements of each level in either case. Thus, the Markov chain modeling is carried out by defining those parameters that need to be stochastically simulated, which are expressed as company-specific variables in each of the sectors analyzed in the present study.

The proposed simulation model allows for the establishment of different alternatives, so that a company can achieve sustainability based on the factors that have been established in the ISM-S. This achievement must be fulfilled over a discrete time period time $\{\boldsymbol{X_n} : \boldsymbol{n} = \mathbf{0}, \mathbf{1}, \ldots\}$, and allowing for discrete states, i.e, for any integer variable $\{\mathbf{n} \geq \boldsymbol{o}\}$, and any state $\{\boldsymbol{x_0}, \ldots, \boldsymbol{x_{n+1}}\}$. The probability of a given state (past, present and future) is given by discrete times, expressed as follows:

$$p(x_{n+1} \mid x_{0,\ldots} x_n) - p(x_{n+1} | x_n)$$

That is to say, time *n+ 1* corresponds to the future, while *n* is present and times *0,1,...n-1* are assigned to the past. Hence, the probability distribution of *n+1* depends on the state of the process at time *n*, and not on past times (*0,1...n-1*). The results of this decision simulation are addressed in the next chapter.

4.4 Conclusions

This chapter has addressed the design and construction of the integral sustainability model proposed for SMEs established in Colombia (ISM-S). To start, a brief analysis of the strategic business model definitions employed in this research study allowed highlighting that the ISM-S constitutes a strategic plan designed to improve internal sustainable processes in SMEs. As such, it contributes to the continuous improvement and fulfillment of the company's objectives. A subsequent analysis allowed identifying the factors, relevant components and elements that framed the present discussion: Factor 1. Sustainable decision-making, Factor 2. Sustainable environmental tools and practices, Factor 3. Social responsibility and knowledge management, and Factor. Technologic and analytic convergence of information.

In addition, the ISM-S was outlined and illustrated, the main objective of each factor was described and two additional elements were defined: A maturity level classification through the Sustainability Maturity Model (SMMM) and the decision-making simulation of the ISM-S, implemented through the use of stochastic modeling techniques and Markov processes. This chapter is expected to provide a better understanding of the way economic, social, environmental and technological sustainability can become an essential and integral part of any organization through the central components that must be taken into account to achieve it. In the following chapter, the ISM-S is evaluated through case studies in different SMEs established in Colombia.

Chapther 5. Results from the validation of case studies

5.1 Introduction

This chapter presents the quantitative analysis of the results obtained during the development of the current research work. In the first place, the information gathering strategies – applied through the case study method proposed in Chapter 3 – are presented. Next, the specific elements that make up the Integral Sustainability Model for SMEs (ISM-S) are evaluated through the following items: i) analysis of the adoption of the factors and integral components of the ISM-S, ii) classification of the level of sustainability maturity of the ISM-S, and iii) analysis of the results of the decision-making predictive simulation for the ISM-S, conducted in various economic sectors in Colombia. In addition, the tools employed in each of the evaluated aspects are detailed and a report is provided with the analysis of the most significant results.

5.2 Analysis of the results of the case studies

As mentioned above, to carry out the evaluation of the ISM-S model designed in this research, the guidelines established by the case study method [68] represented in Figure 8 of Chapter 3 were put in practice: Initially, the ISM-S was divided in three parts (see Figure 12). Then, the evaluation tool was designed and applied to two case study groups. Once the information had been collected, it was statistically processed for further data analysis.

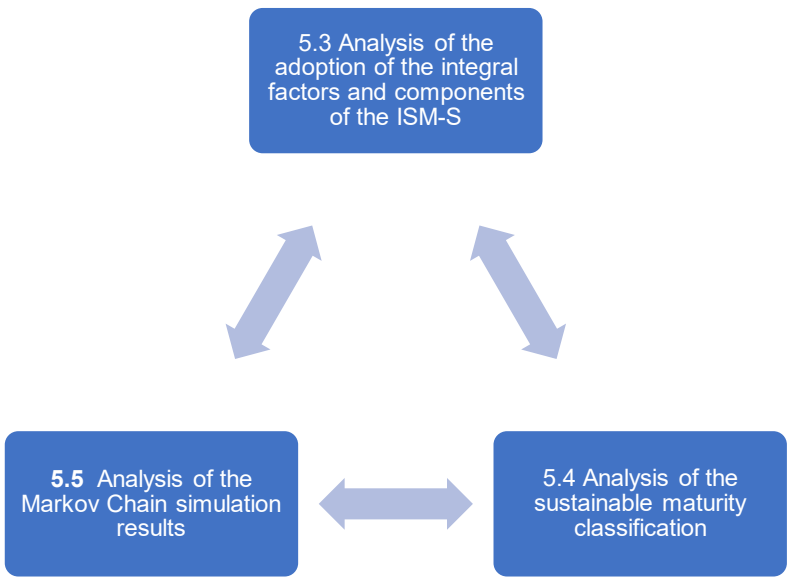


Figure 12. Evaluation and validation of the ISM-S

In the lines that follow, the results obtained in each section of the ISM-S are presented:

a) First group. Case study: Wooden furniture sector.

The questionnaire-type information collection tool was designed and approved by a group of experts (see **Appendix 2**). This questionnaire made it possible to evaluate 17 SMEs in the wooden furniture manufacturing sector for home and industrial purposes in the city of Bogota, Colombia. These were part of the P+L project of *Pontificia Universidad Javeriana* and the Mayoralty of Bogota from 2017 to 2018 (see **Appendix 3**). This information gathering tool allowed for research on:

- What knowledge companies have on the environmental, economic and social dimensions.
- What actions they conduct regarding some of the components of the ISM-S.
- What barriers prevent them from adopting a sustainable strategic model.

The results of this first case study are presented in the following scientific papers: *A conceptual framework for the eco-efficiency assessment of small- and medium-sized enterprises* and *Conceptual Framework for Evaluating the Environmental Awareness and Eco-efficiency of SMEs* [13], [89](see **Appendix 1**).

The results obtained in this research allowed identifying a series of elements and limitations, which were included in the elaboration of a conceptual framework intended to examine how SMEs understand the concept of sustainability and interpret four specific factors: Availability of an environmental management system, environmental knowledge, organizational culture, and environmental monitoring and control. The results of assessing each of these factors indicate the low use of environmental management systems or planning methodologies, lack of knowledge about environmental actions that could be carried out in companies due to low training on this issue, as well as the few mechanisms in place to apply environmental policies, monitoring, and control of resources. However, the group of evaluated companies has demonstrated the need to develop environmental protection, as well as the motivation to continue their search for measures to prevent environmental impacts.

The results obtained in this research suggest that companies make sustained efforts to strengthen environmental synergy, generate networking opportunities, innovate in their activities or services, strengthen knowledge in their activities, implement environmental improvement techniques, perform strategic planning regarding environmental policies, conduct training for business leaders, support associations between universities, companies and the state, get familiar with Colombian environmental regulations, and seek strategies for the evaluation and control of environmental impacts.

Taking into account that not all the elements of the ISM-S were included in the evaluation instrument, a second evaluation was suggested, to be conducted on a significant sample of SMEs based in Colombia. Therefore, a second case study analysis was carried out, as detailed below.

b) Second group. Case study: Manufactures, services, trade and civil works sector.

Once the model evaluation instrument was refined (see **Appendix 4**) and approved by a group of experts, it was applied. This survey is composed of three sections:

- Gathering the general data of the company.
- Inquiry on the adoption of: *I)* Factor 1. Sustainable decision-making: What tools are used to carry out the planning of activities, and processes and the continuous improvement procedures in the company's environmental performance? *ii)* Factor 2. Tools and sustainable environmental practices: What environmental strategies and practices are implemented in companies? *iii)* Factor 3. Social responsibility and knowledge management: To what extent do companies have knowledge of environmental issues, which lead to *iv)* Factor 4. Technological and analytical convergence of information, which was included throughout the questionnaire and is a cross-sectional aspect of the proposed model.

- Inquiry on the barriers and limitations that prevent the inclusion of sustainable practices in the internal operations of the company.

To obtain the contact information of the companies in Colombia, the Orbis® database was used, which is characterized by "[…] including information on some 360 million companies around the world. It is the resource for obtaining company data" [100]. Orbis® shows a list of more than 3,500 micro, small and medium-sized companies (MSMEs) that were active from 2018 to 2019 in Colombia. A total of 1,350 MSMEs with wrong or misspelled contact details were eliminated. Additionally, in calculating a population size of 2,150 MSMEs at a confidence level of 95% and with a margin error of 5%, a sample size result of 327 MSMEs was obtained, for them to be evaluated in the five main cities of Colombia: Cartagena, Barranquilla, Cali, Bogota and Medellin. Interviews were conducted with the managers and personnel in charge of the production and environmental management departments. In addition, the questionnaire was sent to the different contacts by electronic means during 2019, thus achieving compliance with the established sample.

The next section shows the results obtained for each one of the sections evaluated in the questionnaire.

5.3 Analysis of the adoption of the integral factors and components

Based on data from the questionnaire, Figure 13 shows the number of MSMEs that participated in the study as classified by city. It can be observed that the cities of Bogota (26%) and Cali (23%) contributed the most participating companies. In turn, the cities of Barranquilla (19%) and Cartagena (18%) scored similar intermediate numbers, whereas Medellin (14%) had a low participation.

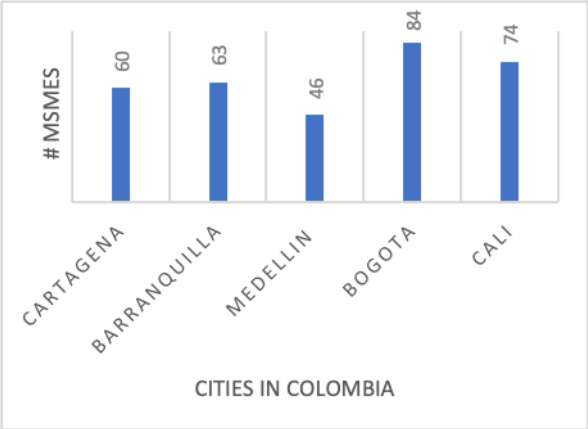


Figure 13. MSMEs evaluated by city Colombia.

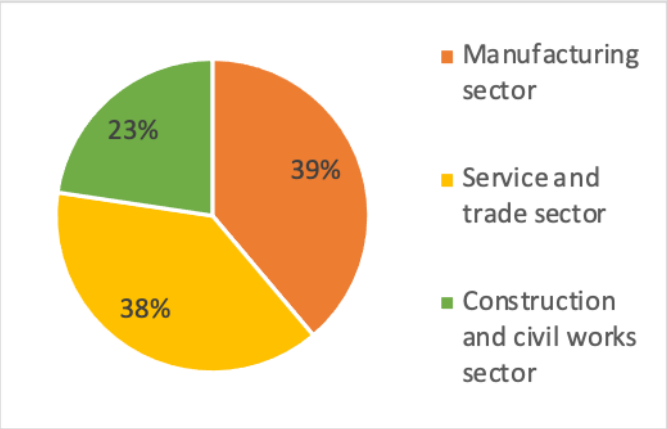


Figure 14. Economic activities of the evaluated MSMEs.

Figure 14 shows the distribution of the sample across economic sectors. According to the *International Standard Industrial Classification of All Economic Activities* (ISIC. Rev. 4), the companies were classified as coming from three main sectors: Manufactures, services and trade, and construction and civil works. The manufactures sector had the largest representation, with 39% of the sampled businesses; followed by the trade and services sector, with 38%; and the construction and civil works sector, with 23%. Likewise, the studied businesses were classified by size, according to the number-of-workers criterion established by Law 590 of 2000 from the Ministry of Commerce, Industry and Tourism of Colombia [101] (see Table 11).

Table 11. Company size classification according to their number of workers

Business type	No. of workers	Surveyed business
Microenterprises	Personnel not exceeding ten (10) workers.	48%
Small businesses	Personnel between (11) and (50) workers.	37%
Medium businesses	Personnel between (51) and (200) workers	15%

Additional general information about the evaluated companies is guild affiliation, which covers only 12.8% of the sample. The remaining 87.2% manifested not being in any type of business guild. Said affiliation links the companies to the most representative guilds of Colombia, namely the Colombian Association of Micro, Small and Medium Enterprises (*Asociación Colombiana de las Micro, Pequeñas y Medianas Empresas - ACOPI*), the Colombian Chamber of Construction (*Cámara Colombiana de la Construcción - CAMACOL*), the Colombian Hotel Association (*Asociación Hotelera Colombiana - ASOTELCA*), and the Hotel and Tourism Association of Colombia (*Asociación Hotelera y Turística de Colombia - COTELCO*).

The following are the results of the second part of the evaluation carried out on the MSMEs.

5.3.1 Factor 1. Sustainable decision-making

The first factor to be evaluated was the decision-making management system, which facilitates the development of environmental strategies in the company. It is considered a guideline for the control of activities, services and products, as such, it allows minimizing environmental

impacts. In the ISM-S proposed in this research, this factor is related to profitability, capacity, requirements, coverage and competitiveness. Figure15 shows the responses of entrepreneurs to the questions related to this first factor.

Factor 1. Sustainable decision-making
Q1. Do you know what an environmental management system is?
Q2. Does your company have an environmental management system?
Q3. Has the company received any environmental certification?
Q4. Does the company have any environmental policy?
Q6. Does the company have an Enterprise Resource Planning system (ERP)?

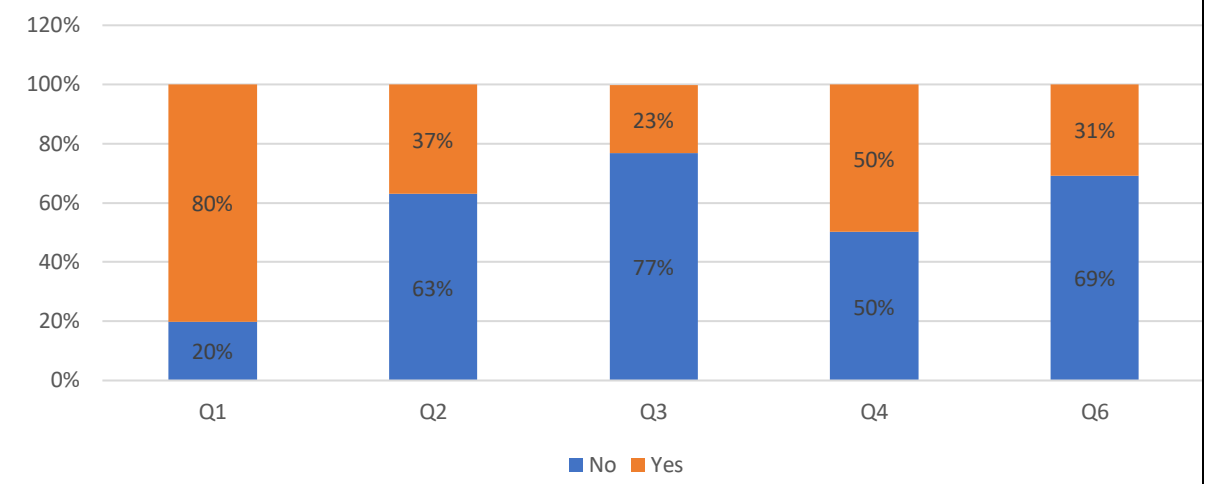


Figure 15. Factor 1. Sustainable decision-making

Based on the evaluation of this factor, it can be observed that 80% of the companies affirm that they know what an environmental management system is. However, 63% of these MSMEs affirm that they do not have a management system in the company, which prevents them from developing objectives and procedures that contribute to the good use of ecosystem services. Additionally, the lack of certifications is an evident problem in these companies, since more than 77% of them state that they do not have any environmental certification, which exposes them to sanctions, including elevated fines. Likewise, around 50% of the studied companies manifested having internal policies that facilitate acting on the surrounding environment. However, 69% of MSMEs claim not having adequate resource planning tools such as ERP. Therefore, it is difficult for them to know which areas of the company they should invest on and how they should distribute their resources.

5.3.2 Factor 2. Sustainable environmental tools and practices

The second evaluated factor are “environmental practices and strategies”, which has been defined throughout this research as the actions that allow reducing the negative impacts caused by the internal processes of the organization, thus changing them towards a sustainable culture conveying simple and useful actions in its daily activities. Within the ISM-S, this factor is related to process analysis, impact assessment, changes in processes and monitoring of ecosystem services (water, energy, waste disposal). The answers to the questions related to this first factor are shown in Figure 16.

Factor 2. Sustainable environmental tools and practices
Q10. Do you understand the notions of ecoefficiency and cleaner production?
Q11. Does your company have an environmental practice program?
Q12. Do you know what circular economy is?
Q13. Has the company set a plan to report liquid spills, gas leaks, gas-liquid mixtures or any other non-ecoefficient situations?
Q14. Has your company implemented environmental practices?
Q15 Does your company have a water saving and efficient use program?
Q16. Does your company have a solid waste collection and classification program?
Q17. Does your company check for the final disposal of dangerous waste (corrosive, reactive, explosive, toxic and flammable materials)?
Q18. Do the employees tend to reuse office stationery materials?
Q19. Does the company use treatments to extend the use of industrial resources such as oils, lubricants, acids, etc.?
Q21. Does the company offer after sales repair service to extend product duration?
Q22. Does your company have any noise level measurement system?
Q23. Does the company have a statistical record of energy and water bills?
Q24. Does the company apply purchase environmental criteria when it comes to supplier selection?

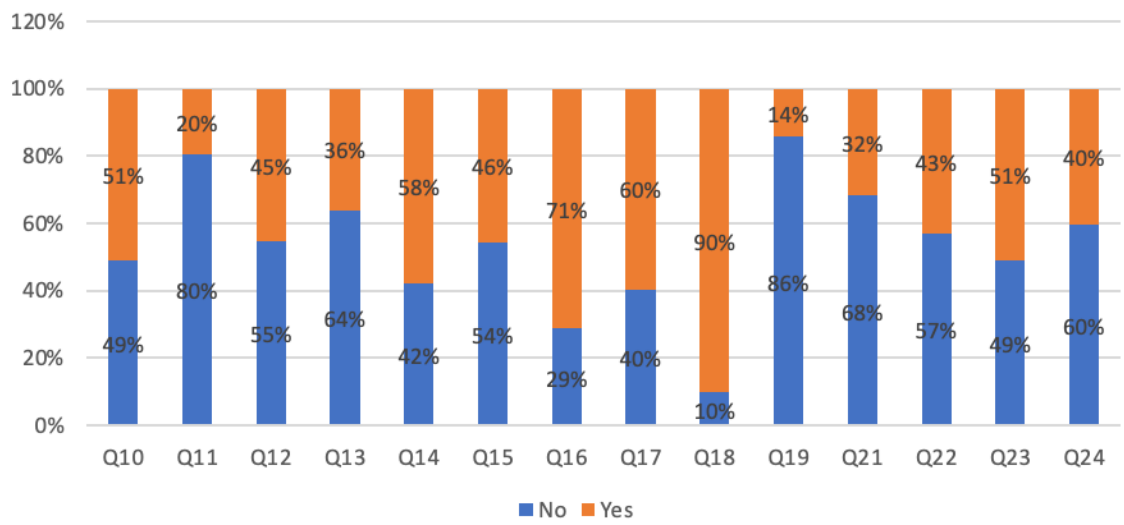


Figure 16. Factor 2. Sustainable environmental tools and practices

Based on the evaluation of this factor, it can be observed that more than 49% of the studied MSMEs knew about the most common sustainability practices that are usually developed by this type of company, such as ecological efficiency, cleaner production and circular economy. However, 80% of them do not have an environmental practice program that allowed them to carry out the application of these practices. Yet, despite not having a formal plan for sustainable environmental improvement, 71% of these firms stated that their employees have good waste disposal classification processes. Likewise, 90% of these MSMEs uttered that their employees tend to reuse office supplies and 86% manifested not appropriately extending the useful life use of products (lubricants, oils, boxes, plastic, etc.) when it is possible.

Likewise, 68% of the MSMEs affirmed they did not offer their clients any repair or post-sale guarantee service, in spite of the fact that this added value is likely to improve their competitiveness in the market. Regarding noise, energy and water controls, 57% and 49% of the companies stated that they did not have statistics that allowed them to analyze the expenses or savings of these services. Likewise, the lack of requirements to select suppliers

in companies was found to be an informal activity represented by 60% of the companies, who considered this selection of suppliers to be based solely on economic criteria.

5.3.3 Factor 3. Social responsibility and knowledge management

The third evaluated factor is "social responsibility and knowledge management", which intends that the members of the company carry out good environmental practices through the identification, creation, storage, socialization and use of knowledge. Therefore, this factor is related to education, knowledge transfer, culture, commitment and synergy in the ISM-S. Figure 17 highlights some answers related to this factor.

Factor 3. Social responsibility and knowledge management
Q31. Have the employees received environmental care training?
Q35. Does the company provide the means for the workers to contribute innovative environmental ideas?
Q36. Do the employees use environmental training to improve productive processes?
Q38. Are the employees informed of the environmental impacts of the organization and the corresponding corrective measures?

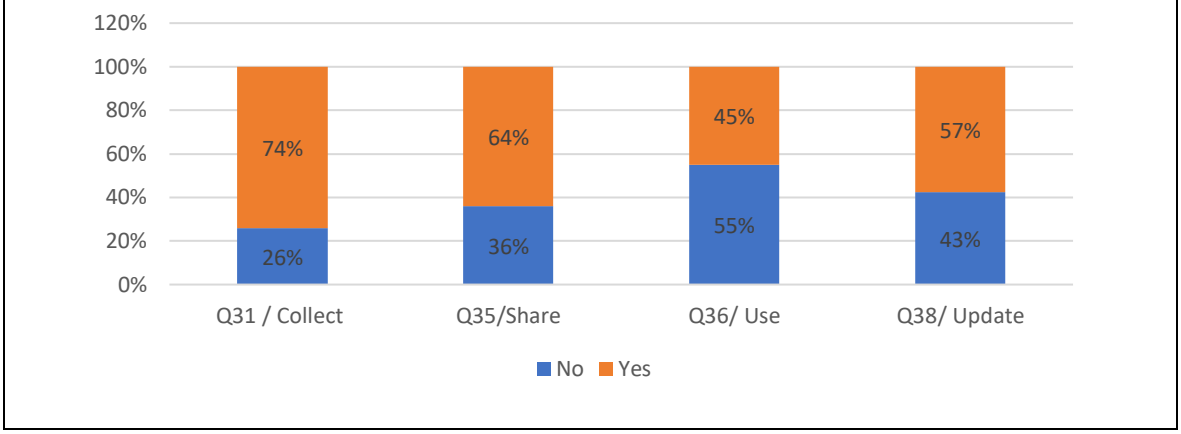


Figure 17. Factor 3. Social responsibility and knowledge management

Based on the evaluation of this factor, it can be observed that 74% of the employees of the studied companies received environmental care training. Regarding the space that companies use for employees to share their knowledge and express innovative ideas, 64% affirm that meetings were the most frequent mechanism. However, these meetings usually occurred once a month, so it is suggested to venture into other strategies such as emails and internal work group networks to generate a cooperative culture in this area.

Likewise, in relation to the use of the knowledge acquired in the training for the improvement of production processes, 55% indicate that they do not do so due to the lack of strategies and application direction, however, today companies cannot avoid the change and commercial transformations despite the uncertainties and fears that the market may generate. Also, around 57% of them affirm that the employees are kept informed of the potential impacts of corporate internal activities and their corrective measures.

5.3.4 Factor 4. Technological convergence and data analysis

The fourth evaluated factor is ‘‘technological convergence and data analysis’’, which has been defined as the development of innovations that allow the collection and treatment of relevant

economic, environmental and social information of the company, leading to the good use of decision-making data. Therefore, this factor is related to the components “technological innovation”, “internal and external cooperation”, and “indicator analysis”. The answers to the questions related to this factor are shown in Figure 18.

Factor 4. Technological convergence and data analysis
Q5. Does your company have environmental indicators?
Q7. Does the company have a HSEQ (Health, Security, Environment and Quality) strategy-control module in the Enterprise Resource Planning (ERP)?
Q20. Does the company recover the products that their customers do not use any more?
Q37. Has the company documented its operative processes?

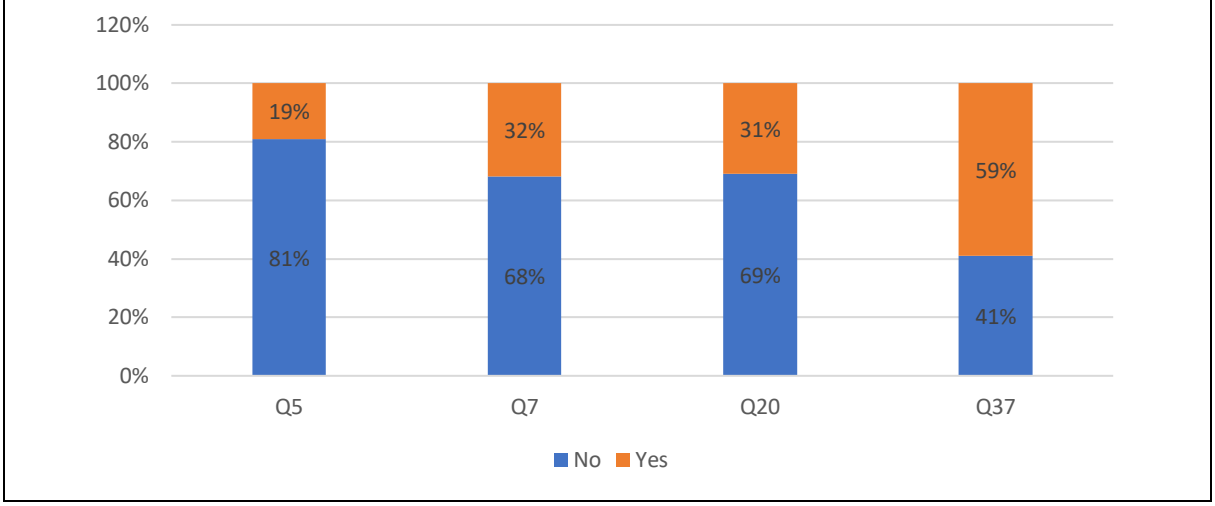


Figure 18. Factor 4. Technological convergence and data analysis

Based on the evaluation of this factor, it can be seen that 81% of the surveyed MSMEs did not have environmental indicators that allowed them to analyze their changes and progress. Likewise, 68% of them affirmed not having specific controls for the planning of environmental resources, occupational health and safety or quality management. Regarding product innovation strategies aimed at their customers, 69% of these companies manifested not recovering the products that their customers no longer used, this being an activity that could contribute to circular economy. On the other hand, 59% of them affirmed that they documented their operational processes. However, it is necessary to continue promoting the systematization of the operational activity documentation, since it is a good strategy for knowledge retention, monitoring of activities, and reprocessing reduction in companies.

In summary, from the analysis of the results on the adoption of factors and components that make up the ISM-S, Table 12 highlights the strengths and weaknesses that have been identified in the MSMEs under analysis.

Table 12. Strengths and weaknesses

Factors	Strengths	Weaknesses
Decision-making management system	They know what an environmental management system is.	Environmental management systems are lacking
	They are interested in setting the bases for environmental certifications.	They have no environmental certifications

Factors	Strengths	Weaknesses
	They are interested in establishing mechanisms for participation among all workers	Lack of strategies to establish quality and environmental policies and implement clean technologies. Difficulties to obtain subsidies for the improvement of productive systems.
	Good knowledge about market needs and demand.	Lack of collaborative partners
	Environmental practices are related to decision-making support systems.	Lack of commitment on the part of the leaders of the organization.
	Related to ecoefficiency and cleaner production issues.	There is need to strengthen methodologies for the implementation and application of cleaner production and eco-efficiency
Sustainable environmental tools and practices	Ecological points and waste sorting are usual practices	Lack of programs to report leaks, emergency plans, energy efficiency, water savings, and noise level measures
	Office stationery reuse is the most widespread environmental practice in the company.	There are no available treatments to extend the use of industrial resources in manufacturing processes
	Good relationship with suppliers	Lack of supplier selection and purchase criteria.
	Appropriation of environmental topics	Worker training is lacking or rare
Social responsibility and knowledge management	They have enough human resources to implement sustainable practices in the company.	Lack of mechanisms and spaces for the transfer of knowledge and contribution of innovative ideas by workers.
	Employees are informed of environmental impacts and corrective measures.	Lack of strategies to incorporate training in the improvement of production processes
	Environmental processes are important.	Environmental issues are not central or priority business items.
Technological Convergence and data analysis	Easiness of information access in all areas of the Company.	Lack of environmental control indicators.
	The operative processes of the company are ordinarily documented.	Lack of documentation in strategic and support processes in companies

5.3.5 Barriers to the adoption of sustainable practices

This section is based on the results of the third part of the information gathering instrument, which is aimed at the analysis of the barriers to the adoption of sustainable practices by MSMEs in Colombia. Figure 19 shows the most representative barriers, the answer options being: 1 (disagree), 2 (undecided) and 3 (agree).

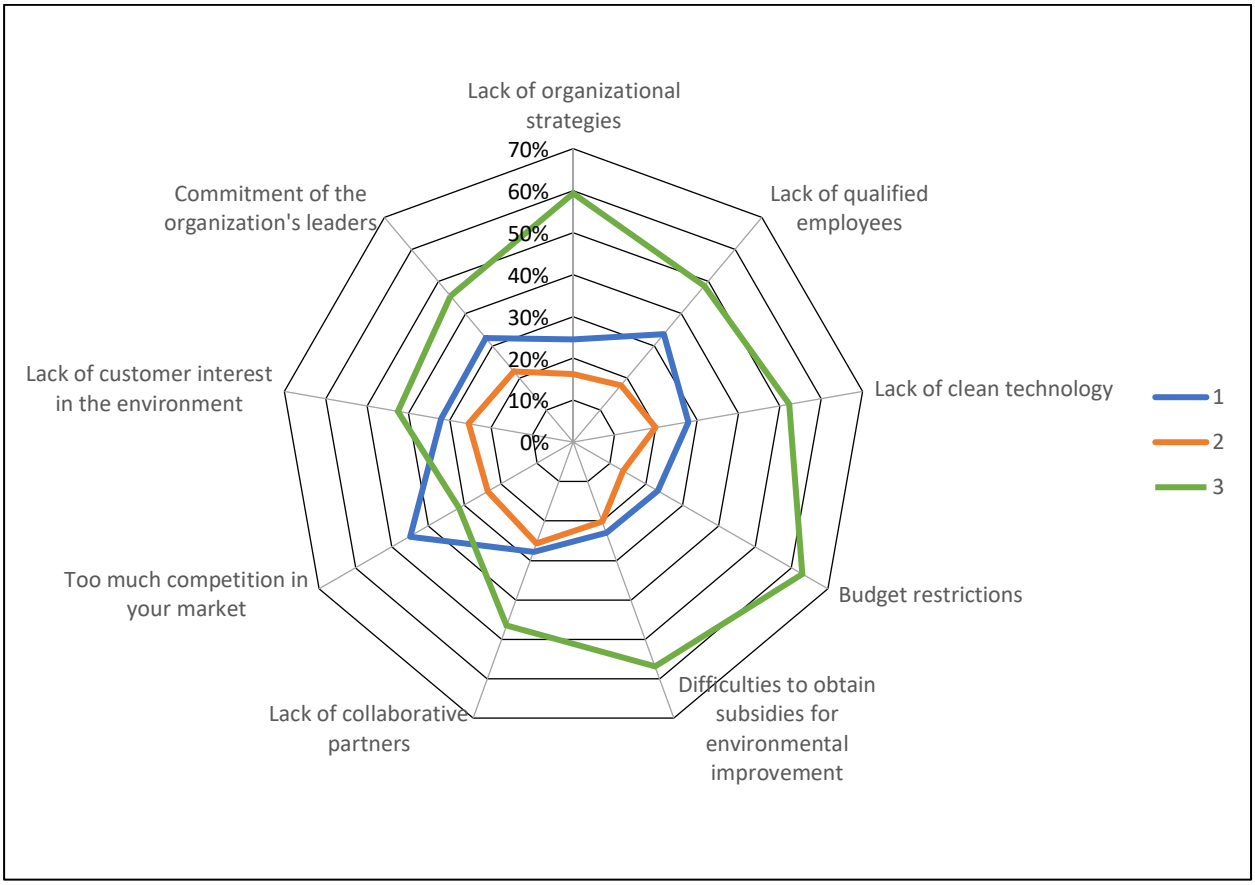


Figure 19. Barriers to the adoption of sustainable practices

Based on the evaluation described above, it can be observed that more than 50% of the evaluated MSMEs agreed that the main barriers to implementing sustainable practices were related to budget restrictions, difficulties to obtaining subsidies, and the lack of organizational strategies, qualified employees, clean technologies, and collaborative partners working for a specific purpose. On the other hand, 30% of these MSMEs did not agree that the number of competitors was a barrier to implement sustainable practices, while 43% of them agreed that the lack of consumer interest in protecting the environment constitutes a barrier. An additional barrier recognized by 46% of the participant businesses was the lack of commitment of the organization's leaders, which was considered to prevents the company from fulfilling environmental, social and economic goals.

5.4 Analysis of the sustainable maturity classification in MSMEs

This section evaluates the “sustainability maturity level” component described in the comprehensive sustainability model proposed in this research. This is done through the development of a Sustainability Maturity Measurement Model (SMMM). This maturity model uses the information gathered by the survey presented in **Appendix 3**. Also, the results of the sustainability maturity classification are presented in the scientific article: *A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs) based on a data analytics evaluation approach* (Under review by the Journal of Cleaner Production, see **Appendix 1**).

Each factor described in the integral sustainability model is analyzed through a series of specific characteristics which, in turn, are assessed in terms of whether they are met (value 1) or not (value 0) at a given level of sustainability maturity. The SMMM is evaluated on a four-level scale based on some of the generic models mentioned above (CMM, Kaizen, PM3s, BPMM). In this scale, *Level* 1 is considered to be insufficient, while consolidated maturity corresponds to *Level* 4 [102]. Accordingly, the higher the level, the larger the number of characteristics it requires to be fulfilled. Thus, *Level* 1 implies the accomplishment of only 5 characteristics, while *Level* 2 implies fulfilling 14 characteristics. By the same token, *Level*s 3 and 4 require the fulfillment of 27 and 37 characteristics, respectively (see **Appendix 4**). In this way, a conceptual definition is provided for each of the maturity levels of the SMMM.

Data analytics uses different methods of analysis for the interpretation of data. Among the most common ones is machine learning (ML), which, more than a simple database to process information, is a programming problem solver. It is a system that, based on a data set provided by the user, has the "ability to learn" by representing data structures and generalizing corresponding behaviors [69], [103]. In phase 3 (“Rigor”) of the current research methodology, a sequence of activities is performed to train and validate the supervised classification algorithms used by the SMMM, as shown in Figure 20.

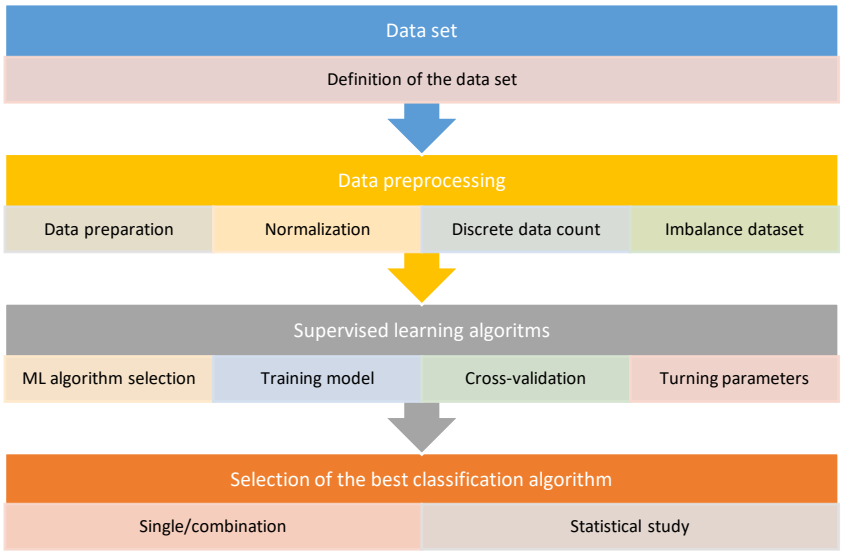


Figure 20. Activities related to supervised algorithm training

After applying the survey (see **Appendix 3**), the answers are usually standardized in a numerical data format, for them to be analyzed by the classification algorithm. Yes/no questions are represented as logical values, *i.e.*, “No” is taken as 0 and “Yes” is taken as 1. Since the questionnaire included multiple choice questions, a conversion to a binary range was carried out, to adjust all the answers to logical values. Therefore, the "totally disagree", "disagree" and "undecided" answers were given a low value (0). Conversely, the "totally agree" and "agree" answers were a high value (1).

Supervised learning works through classification algorithms that allow identifying the category (*e.g.*, a sustainability maturity level) to which a new instance (*e.g.*, a company) belongs, based

on previous observations. These procedures include “Multi-class” algorithms, which handle several classification categories. In the present study, this ranking corresponded to sustainability maturity levels 1 to 4. It must be highlighted that the success of classification algorithms depends on the particular handling of the data set in which they are trained. This handling consists in pre-processing and standardizing the data.

Likewise, in order to avoid over-adjustment of the samples, the *k*-fold Cross Validation technique is employed. In it, the set of training data is divided into *k* subsets and, at the time of training, all subsets are sequentially used as the test set of the model, while the remaining data are taken as the actual training set. This process is repeated *i* times in each iteration. Also, a different test set is selected, while the remaining data are used as training set. Once the iterations have been completed, the accuracy and error values of each model are calculated. Additional accuracy and final error values are obtained by calculating the corresponding averages of the *k* trained models [104]–[106].

To perform the training and validation of the algorithms used in the SMMM, the classification algorithms Support Vector Machine (SVM), Random Forest (RF) and Naïve Bayes (NV) were employed. These procedures were chosen due to their capability to simultaneously solve classification and regression problems by estimating the internal variability of the samples. SVM is used to predict the maturity level of a new sample, based on a set of previously labeled ones. Similarly, RF classifies new samples based on the attributes of prior ones, the classification prediction being the major choice of a decision tree. NV assumes that the predictive variables used to classify a new instance are independent of each other, *i.e.*, the presence of a certain characteristic in the data set is not related to the presence of any other characteristic in it.

In addition, and according to the methodology Design of Computational Intelligence Experiments [69], [107], learning models are used to evaluate the effectiveness of algorithms through different statistical techniques. In the present case, the dimension reduction technique, which consists in shortening the number of random variables under study, was applied. This procedure is commonly assessed through the following metrics: F1-Score, Accuracy, Recall, and Precision. Figure 21 shows the training and validation process for the classification of the algorithms of the SMMM. A 10-fold cross validation procedure was employed, for which the data were divided in two sets: 70% for training and 30% for validation. During the execution of this process, the parameters used for the SVM, RF and NV algorithms were set by default, as described below:

- SVM. C=1.0, kernel='rbf', degree=3, gamma='scale', coef0=0.0, shrinking=True, probability=False, tol=0.001, cache_size=200, class_weight=None, verbose=False, max_iter=- 1, decision_function_shape='ovr', break_ties=False, random_state=None.

- RF. n_estimators=100, criterion='gini', max_depth=None, min_samples_split=2, min_samples_leaf=1, min_weight_fraction_leaf=0.0, max_features='auto', max_leaf_nodes=None, min_impurity_decrease=0.0, min_impurity_split=None, bootstrap=True, oob_score=False, n_jobs=None, random_state=None, verbose=0, warm_start=False, class_weight=None, ccp_alpha=0.0, max_samples=None.

- NV. priors=None, var_smoothing=1e-09

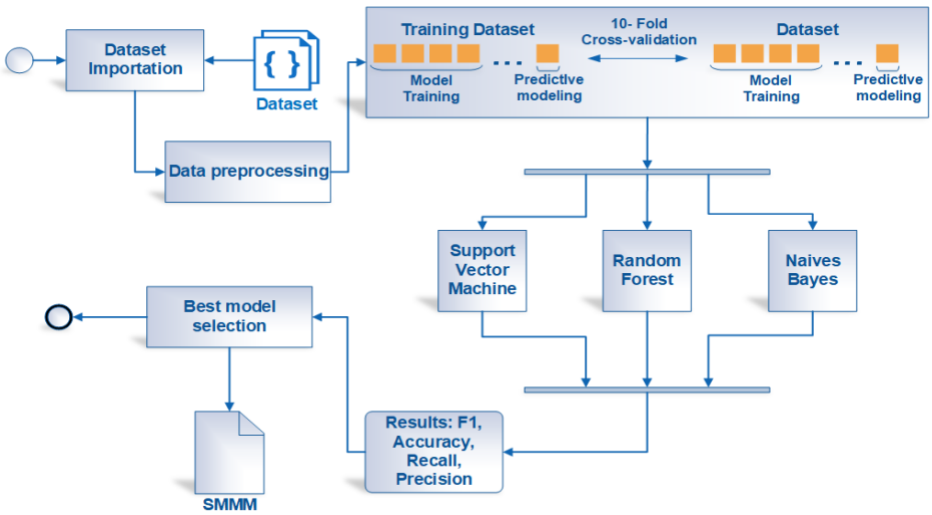


Figure 21. SMMM training and validation process

The methodology Design of Computational Intelligence Experiments [69], [107] comprises several procedures to validate the relevance and performance of the algorithms in question. On these grounds, it is possible to select the best classification algorithm to improve or complement information heterogeneity through data analytics predictors. Relevance is based on repeatedly executing the classification algorithm under the same conditions and with the same set of data and error rates, in order to ensure that the results are not biased. This is done by evaluating the behavior of the mean and standard deviation of all executions. In the present case, a 10-fold calculation of the mean and standard deviation values was carried out for each of the metrics employed in the experiment.

With regards to performance, the test of null and true hypothesis is used to validate which algorithm is statistically better than the others. For this purpose, the assumptions of independence and normality are verified through parametric and non-parametric tests. The Student's t-test (parametric) is used to validate that the means of the training and test samples are independent and significantly different from each other, with all the algorithms reaching higher *p* values than 0.05. The null hypothesis (non-parametric test) is adopted to establish the precision of the models, using the F1-score value to determine a single weighted value of precision and completeness. In addition, these tests are complemented with the confusion matrix, which is used to determine the performance of the algorithms adopted in the training phase.

Using the data analytics approach, this study has proposed a SMMM model, which uses supervised classification algorithms to classify MSMEs according to compliance with different sustainability features. This section presents the results obtained after applying the SMMM model to the sample of studied companies.

In order to determine the sustainability maturity level of the sampled businesses by productive sector, it was necessary to carry out the training, validation and testing of the supervised classification algorithms. Of the 327 MSMEs, 70% were selected for training and 30% for validation, which implied randomly selecting 91 companies, which in turn were divided according to the three sectors studied: manufacturing, commerce and services, and construction and civil works. Table 13 shows the numbers of enterprises that were randomly selected, as grouped by size and productive sector.

Table 13. Assignment of the numbers of MSMEs by productive sector

Enterprise size	Manufactures sector		Service and trade sector		Construction and civil works sector	
	No. of training and validation companies	No. of tested companies	No. of training and validation companies	No. of tested companies	No. of training and validation companies	No. of tested companies
Medium	16	11	9	8	3	3
Small	37	11	36	12	13	13
Micro	42	10	49	12	26	16

In the other hand, the training data were used to ensure that the supervised classification algorithms which recognized patterns and characteristics in the data, thus ensuring a more accurate and efficient performance. Thus, the 10-fold cross validation technique explained in the previous section was used to train the classification algorithms through SVM, RF and NV. Out of the 231 companies that made up 70% of the sample (which were assigned to training and validation), 70% were ascribed to training and 30% to testing. In other words, out of the 231 companies, 162 companies are used to train the classification algorithms and 69 companies to validate the efficiency of the algorithms.

The results of the training and validation process of the SMMM model (see Figure 21) are shown in Table 14. In comparing the SVM, NV and RF algorithms, the one with the highest score and best performance is Random Forests (RF), with 93.10% F1-Score, 93.20% Accuracy, 93.67% Recall, and 93.36% Precision.

Table 14. Algorithm classification results

Classifier	F1-Score (%)	Accuracy (%)	Recall (%)	Precision (%)
Support vectors machine (SVM)	90.13	90.34	90.99	90.92
Naïve Bayes (NV)	92.73	92.84	93.31	92.99
Random Forest (RF)	93.10	93.20	93.67	93.36

Finally, and taking into account the parametric test, the best classification model was found to be RF, as shown in Table 15.

Table 15. Selection of the best model

Classification algorithms	F1-Score (%)	Student's t-test
Support Vectors Machine (SVM)	90.13	0.84
Naïve Bayes (NV)	92.73	0.89
Random Forest (RF)	93.10	0.86

The data set used to apply the test came from the aforementioned randomly selected group of companies that made up 30% of the sample. Additionally, the best classification algorithm (RF) was used to group the companies according to their level of sustainability maturity as contemplated by the SMMM. In Figure 22, the maturity level classification is illustrated by productive sector.

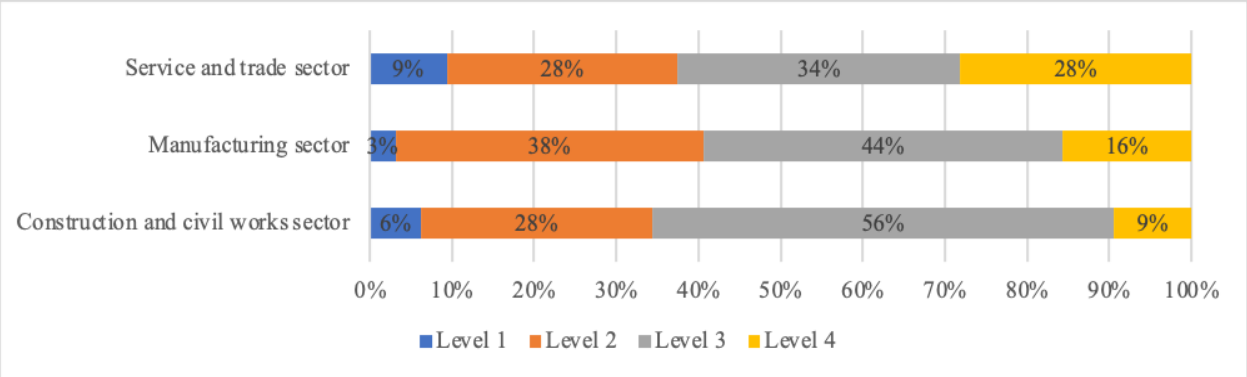


Figure 22. Classification of the sample according to business sectors in the SMMM

As a result of the application of the SMMM model, it can be observed that there is a small number of companies in Level 1 (*i.e.*, *insufficient sustainability maturity*). Nine percent of these companies belong to the Service and trade sector, while 6% of them were in the Construction and civil works sector and 3% in the Manufacturing sector. Following the model, these companies could be said to have insufficient knowledge management, environmental practices and management systems. In other words, they lack environmental strategies and motivations that allowed them to mitigate the effects of their operations and products on the environment.

Level 2 holds companies with basic sustainability maturity. Most of them came from the Manufacturing sector (38%), followed by the Service and trade and Construction and civil works sectors, each of which harbored 28% of organizations at this level. This means that the companies in Level 2 do not have a structured environmental management system, but they did have basic environmental strategy knowledge. This allowed them to design fundamental environmental care practices and policies to minimize likely negative impacts within their internal processes.

The highest percentages were observed at Level 3, which holds companies with developing sustainability maturity. In it, the Construction and civil works sector accounted for 56% of businesses, the Manufacturing sector for 44%, and the Service and trade sector for 34%. Organizations at this level are characterized by the progress and effort they have made, not only in the development of internal environmental strategies, but also regarding the investment of their financial capital on human, technological and physical resources to acquire environmental knowledge and improve operational processes.

For its part, Level 4 accounts for companies with consolidated sustainability maturity, which characteristically exhibit optimal management and sustainability strategies. The largest fraction at this level corresponds to the Service and trade sector, which harbors 28% of these companies. In turn, the Manufacturing sector had 16% of them, followed by the Construction

and civil works sector, which held 9%. Companies at this level possess quality management or environmental management certifications, in addition to environmental practice programs and structured management indicators that allow them to provide and control information on the environmental performance of their operations. Therefore, the results of the classification of the companies in different sustainability maturity levels allow establishing that they are aware of the importance of environmental strategies and practices when implemented in internal processes. However, they exhibit weaknesses regarding the mechanisms used to strengthen environmental plans or programs.

5.5 Analysis of the Markov Chain simulation results

It is of vital importance to use strategies that allow for adequate environmental, economic, social and technological sustainability by managers and entrepreneurs. Therefore, it is necessary to use tools that facilitate decision-making. As described in section 4.3.3, the purpose of this section is to discuss the results of the development of a predictive simulation for decision-making support, which will allow reaching the highest level of sustainability maturity in MSMEs in Colombia. For this purpose, the Integral Sustainability Model for MSMEs (ISM-S) was evaluated through the use of Markov Chains [98], [99].

Therefore, the objectives of the validation of the Integral Sustainability Model for SMEs (ISM-S) focused on:

- Evaluating dynamic scenarios to estimate the transition probability of a sample of companies through a time-related relationship.
- Knowing how long it would take a set of companies to reach a high level of sustainable maturity from an initial level 0.

In order to evaluate the dynamic scenarios to estimate the transition probability, a sequence of levels q_0, q_1, q_2, q_3, q_4 *are* considered, in which the predictive probability of a future event does not take into account the past, but only the present. Hence:

$$\textit{Markov assumption: } P(q_i = a | q_{1\ldots} q_{i-1}) = P(q_i = a | q_{i-1}) \qquad (1)$$

The probability hypotheses correspond to the sequence of events given by the four levels of maturity proposed in this research, which are represented by a Markov chain. These levels are represented as interconnected nodes called "states", while the transitions and their corresponding probabilities are shown as directed lines "→", labeled as "transitions" and represented by Greek letter. For this reason, the current predictive simulation of decision-making through the following components:

Table 16. Markov Chain components

Set of N maturity states.	$Q = \{q_1, q_2, \ldots q_N\}$	$Q = \{q_i \in Q\ ; i \geq 0 \wedge i \leq 4\}$
Transitions through states	$A = \{a_{0,1}, a_{1,1} \ldots a_{n,n}\}$	$A = \{a_i, j \in A\ ; i, j = [0, 4]$
Transition probability matrix	$P = \{p_{1,1}, p_{1,2} \ldots p_{n,n}\}$	p_{ij} *represents the probability of moving from state i to state j.* $\sum_{j=1}^{n} p_{ij=}\ 1\ \forall i, j\ \geq 0$

Initial state distribution probability, q_i, is the likeliness of starting at state i in the Markov chain. Some states j may take value $q_j = 0$, which means they cannot be initial states. $\sum_{i=1}^{n} \pi_i = 1$	$\pi = \pi_N$	$\pi = \pi_1, \pi_2, \pi_3, \pi_4$ *q_0 = initial state* *q_4 = acceptance state*

In addition, the following set of restrictions and assumptions is established, with the purpose of applying the proposed model to real events:

- The second group of case studies will be taken into account (see section 5.2 b), represented by a sample of 327 Colombian micro, small and medium enterprises.
- The normal distribution is met in all states.
- The probability that an enterprise remains in its current state is $q_1 \rightarrow q_1 = \beta$, $q_2 \rightarrow q_2 = \gamma$, $q_3 \rightarrow q_3 = \psi$.
- State q_5, which denotes Probability of permanence of a company in the market, is considered to be is 35% in its first five years of life, which is distributed among the three states q_1, q_2, q_3.
- The annual growth rate of SMEs is 1.6% (based on the growth rate of SMEs in Colombia in 2019).
- The stable states are considered to go from q_0 to q_3. When a company reaches state q_4 it is considered to have reached an acceptance condition.
- qi' is considered to be a state of absorption in which the process tends to remain indefinitely. Then, the probability $q_1 \rightarrow q'_1 = \varphi_1$, $q_2 \rightarrow q'_2 = \varphi_2$, $q_3 \rightarrow q'_3 = \varphi_3$.
- A company cannot move more than three states ahead of its current one. That is, it can only go from a current state q_i to q_i+3. In additional, the probabilities change depending on the original state: $q_0 \rightarrow q_3 = 1$, *whereas* $q_1 \rightarrow q_4 = 2$.
- A company cannot move more than two states ahead of its current one. That is, it can only change from a current state q_i to q_i+2. Again in this case, the probabilities change depending on the original state: $q_0 \rightarrow q_2 = 1$, *whereas* $q_2 \rightarrow q_4 = 2$.
- The transitions $q_1 \rightarrow q_2$, $q_2 \rightarrow q_3$, $q_3 \rightarrow q_4$ must be larger zero and lesser than 1, q_4 being their absorption or acceptance state.
- The possibility that a company moves to a lower level is not considered.
- In addition, the following constraints are considered:

$q_0 \rightarrow q_1 \geq q_0 \rightarrow q_2$
$q_0 \rightarrow q_2 \geq q_0 \rightarrow q_3$
$q_1 \rightarrow q_1 \geq q_1 \rightarrow q'_1$
$q_2 \rightarrow q_2 \geq q_2 \rightarrow q'_2$
$q_3 \rightarrow q_3 \geq q_3 \rightarrow q'_3$
$q_0 \rightarrow q_3, q_1 \rightarrow q_2, q_2 \rightarrow q_3, q_3 \rightarrow q_4, q_1, q_2, q_3, \rightarrow q_5 = 1$
$q_1 \rightarrow q'_1, q_2 \rightarrow q'_2, q_3 \rightarrow q'_3, = 1$

Under these assumptions, a discrete Markov Chain is considered, $\{X_t: t=0.1,...\}$, which describes the mobility dynamics of SMEs through different states denoted by q_i in the present

research study. Therefore, X_t defines the state of company at a discrete time t. In this way the Markov chain graph is:

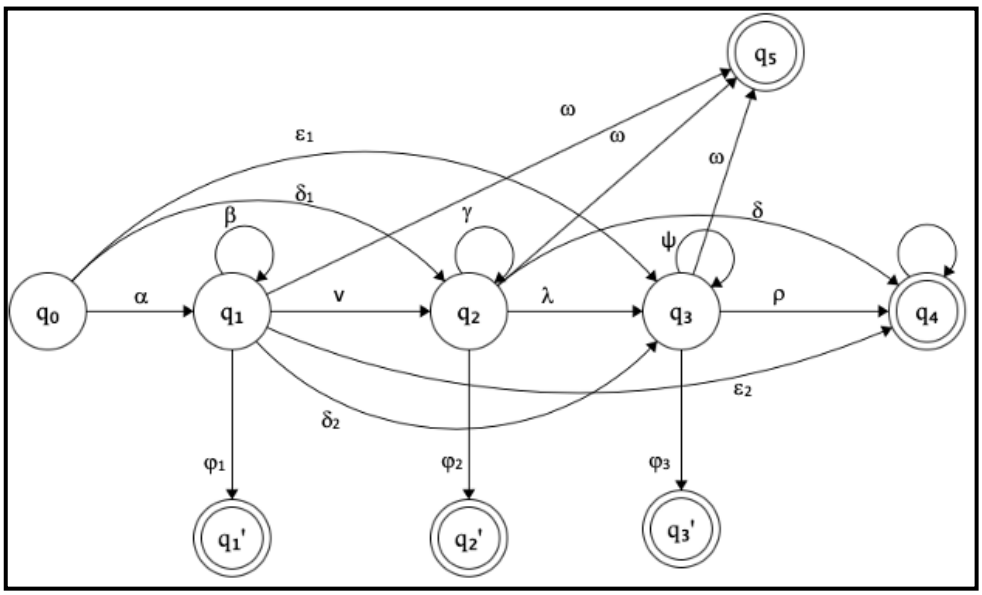


Figure 23. Markov chain of the ISM-S predictive simulation model

The probability of moving from one state to another is identified with Greek letters and yellow color in the following transition matrix (see Table 17):

Table 17. Transition matrix

	q_0	q_1	q_2	q_3	q_1'	q_2'	q_3'	q_4	q_5
q_0	0	α	δ_1	ε_1	0	0	0	0	0
q_1	0	β	ν	δ_2	φ_1	0	0	ε_2	ω
q_2	0	0	γ	λ	0	φ_2	0	δ_3	ω
q_3	0	0	0	ψ	0	0	φ_3	ρ	ω
q_1'	0	0	0	0	1	0	0	0	0
q_2'	0	0	0	0	0	1	0	0	0
q_3'	0	0	0	0	0	0	1	0	0
q_4	0	0	0	0	0	0	0	1	0
q_5	0	0	0	0	0	0	0	0	1

Assuming that in a year 0 starts with 300 companies growing at rate of 1.6%, it would take 5 and 6 years on average to reach 327 business. While these 327 companies are in absorbing states, the new ones have the possibility to go through the four states contemplated by the model.

Likewise, by means of the Generalized Reduced Gradient (GRG) algorithm, which is intended to solve non-linear programming problems, allows calculating a company's probability to move through the different states in question.

The GRG, which is part of a feasible solution known as the starting point, uses successive linearization of the objective function and constraints to reduce the dimensionality of the problem, thus rendering a more manageable subset of variables. In this way, the algorithm

determines the components of the independent variables and expresses the search gradients and direction in terms of those independent variables. Therefore, the probability that an enterprise to moves from one state to another is determined by the transition matrix (P) (see Table 18), considering that the transitions are ≤1∧ ≥0:

Table 18. Transition probability results matrix

	q_0	q_1	q_2	q_3	q_1'	q_2'	q_3'	q_4	q_5
q_0	0,00	0,36	0,32	0,32	0,00	0,00	0,00	0,00	0,00
q_1	0,00	0,31	0,26	0,00	0,10	0,00	0,00	0,09	0,24
q_2	0,00	0,00	0,10	0,10	0,00	0,43	0,00	0,13	0,24
q_3	0,00	0,00	0,00	0,10	0,00	0,00	0,66	0,00	0,24
q_1'	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00
q_2'	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
q_3'	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
q_4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00
q_5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00

On the other hand, the stationary distribution property, which assumes that n companies manage to stabilize in a period of time t, is used to determine the robustness of the model. Therefore, the probability distribution of the Markov Chain converges towards absorption states P^{t+1}. In this sense, the simulation indicates that the model manages to stabilize between P^5 and P^{10}, with an error rate of 3% (see Table 19).

Table 19. Robust matrix

	q_0	q_1	q_2	q_3	q_1'	q_2'	q_3'	q_4	q_5
q_0	0,00	0,00	0,00	0,00	0,05	0,22	0,27	0,11	0,35
q_1	0,00	0,00	0,00	0,00	0,14	0,18	0,03	0,18	0,46
q_2	0,00	0,00	0,00	0,00	0,00	0,48	0,08	0,14	0,30
q_3	0,00	0,00	0,00	0,00	0,00	0,00	0,73	0,00	0,27
q_1'	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00
q_2'	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
q_3'	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
q_4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00
q_5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00

Figure 24 shows the distribution of the assumed error vs. predicted error. The predicted error value (orange line) is so small that it overlaps with the assumed error line (blue).

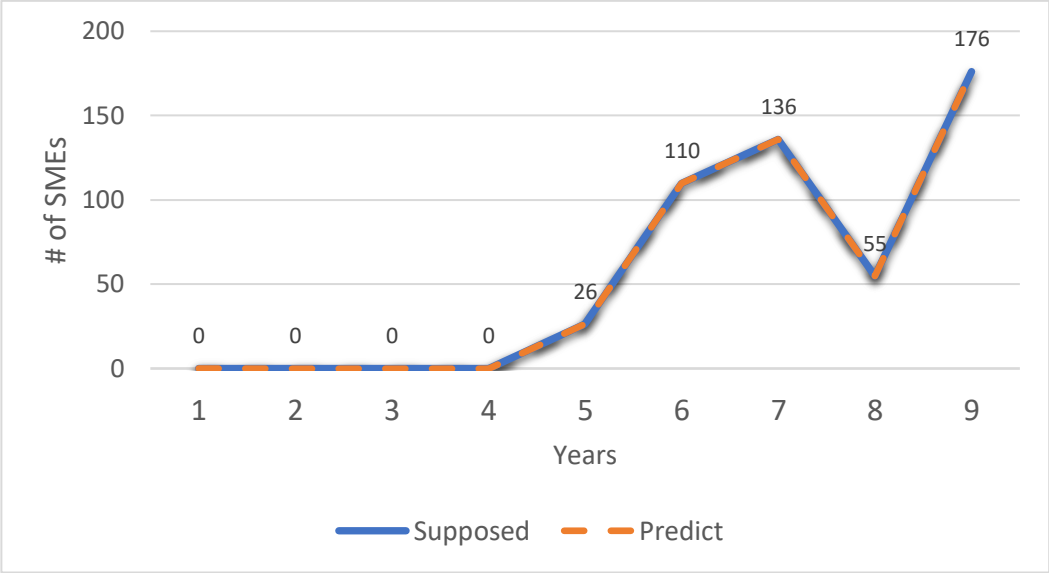


Figure 24. Distribution of the assumed vs. predicted error

In order to know how long it would take for a group of companies to reach a high level of sustainable maturity, a new simulation the predictive simulation model of the ISM-S is carried out taking as an example 5000 SMEs in a period of time t. In Table 20 illustrates how the 5,000 companies are classified over a period of 16 years, according to the assumptions and constraints defined in the model.

Table 20. Forecast matrix of an SME set

Years	q0	q1	q2	q3	q'1	q'2	q'3	q4	q5	Forecast
0	5000	0	0	0	0	0	0	0	0	0
1	0	1803	1598	1598	0	0	0	0	0	0
2	0	552	636	320	180	687	1050	358	1216	358
3	0	169	210	96	236	961	1260	486	1583	128
4	0	52	66	31	252	1051	1323	527	1698	41
5	0	16	20	10	258	1079	1343	540	1734	12
6	0	5	6	3	259	1088	1349	544	1745	4
7	0	1	2	1	260	1091	1351	545	1749	1
8	0	0	1	0	260	1092	1352	546	1750	0
9	0	0	0	0	260	1092	1352	546	1750	0
10	0	0	0	0	260	1092	1352	546	1750	0
11	0	0	0	0	260	1092	1352	546	1750	0
12	0	0	0	0	260	1092	1352	546	1750	0
13	0	0	0	0	260	1092	1352	546	1750	0
14	0	0	0	0	260	1092	1352	546	1750	0
15	0	0	0	0	260	1092	1352	546	1750	0
16	0	0	0	0	260	1092	1352	546	1750	0

In order to determine how long it would take for a company to reach a high level of sustainability maturity (estimated from the number of companies reaching state q_4), the model was run for a new predictive simulation with 5,000 companies. The difference between the number of

companies in period t and the number of companies in period t-1. The number of companies in period t is calculated by summing the numbers of companies from each of periods and dividing the results by the sum of estimated numbers of companies over the same time period (t). This calculation is expressed by the following equation:

$$T=\frac{\sum_{i=1}^{n} i(q_4,i-q_4,i-1)}{\sum_{i=1}^{n}(q_4,i-q_4,i-1)} \qquad (2)$$

For the example, in applying the equation above to 5000 SMEs can be estimated that it takes a company 2.5 years to reach its maximum level of maturity. Hence, sustainable development plans could be defined taking into account this time lapse.

$$T=\frac{0(0-0)+1(0-0)+2(358-0)+3(486-358)\ldots16(546-540)}{546}=2.50$$

5.6 Maturity classification system and decision-making predictive simulation

This system provides support to both business sustainability maturity assessment and decision -making in companies and governmental entities, consists of a series of activities, as shown in Fig. 10. First, a company's user conducts a self-diagnosing survey through a web application. Then, the system captures the information, processes the data and features the company in terms of environmental knowledge management, environmental practices and environmental management systems. Subsequently, the system takes the extracted features and sends them automatically to the Random Forest classifier, which matches them to those that define the SMMM levels, thus estimating the maturity of the company. Finally, the system provides a series of suggestions and guidelines for the company to follow in order to increase its maturity level.

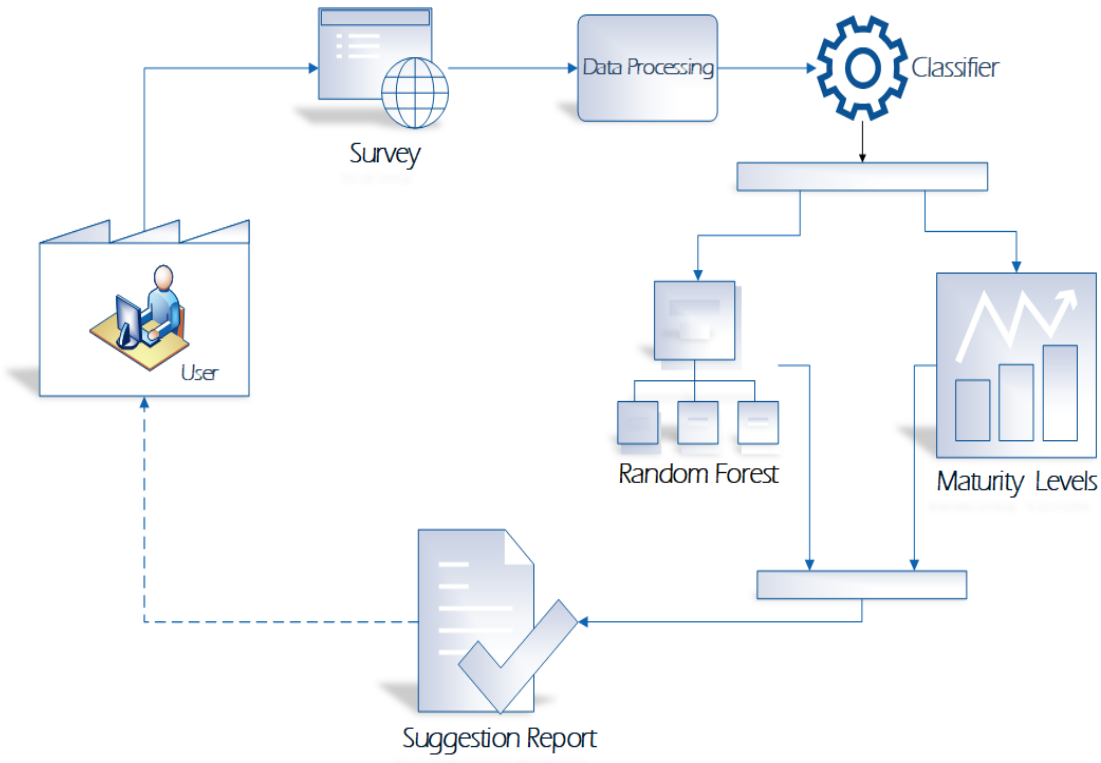


Figure 25. The SMMM system

The development and application of this system is pending for financial approval of the national project.

5.7 Conclusions

After carrying out the evaluation of the ISM-S and using the above-mentioned methods, it can be concluded that the evaluated MSMEs are interested in adopting sustainability models to facilitate the application of good environmental practices in their internal activities, despite the barriers and limitations that have been identified. Likewise, by classifying the companies through the sustainable maturity model, it is evident that most of the companies are at Level 2: Basic and Level 3: In development.

This shows that MSMEs in Colombia are still perceived as one of the sectors requiring great attention and development of new strategies for them to evolve and consolidate in the productive market. As to the evaluation of the model through predictive simulation, the Markov Chains were used to determine the different scenarios that a company can go through when it comes to achieving a certain level of maturity. Based on a set of assumptions and constraints, the results of the probability matrices showed the possible transitions. Likewise, it was determined that in a simulation with 5000 MSMEs, it would take them 2.5 years on average to reach a high level of sustainability (Level 4: Consolidated). This would help companies and project managers to make a plan to implement sustainability strategies.

Chapther 6. General discussion of the Integral Sustainability Model for SMEs

6.1 Introduction

This chapter presents a discussion about the general application of the developed Integral Sustainability Model for SMEs (ISM-S). In addition, the novel aspects in comparison to the current scientific literature and limitations of the model are described. Also, some impacts of the model on academia and practitioner is mentioned.

6.2 Novel aspects of the Integral Sustainability Model for SMEs (ISM-S)

SMEs are the economic engine of Latin America, which is why they strive to develop sustainable management models and strategies aimed at environmental improvement, social development and maximized economic benefits. The current literature review shows that different multidisciplinary approaches have developed of sustainable management tools and strategic frameworks. However, the isolated adoption of sustainability related practices and tools has limited their effective development.

Consequently, the present doctoral dissertation presents an Integrated Sustainability Model for SMEs (ISM-S) based on four key factors identified in the literature review: Factor 1. Sustainable Decision Making; Factor 2: Sustainable environmental tools and practices; Factor 3: Social responsibility and knowledge management; and Factor 4: Technological convergence and information analytics. It is worthwhile noting, at this point, that the analyzed conceptual models are commonly limited by their economic, social or environmental approaches [33], [38]. For this reason, the ISM-S introduces the Technological convergence and information analytics approach, which groups and analyzes Innovation technology, Internal and external cooperation, and Metrics and control indicators.

Developed through the Scientific Research Design methodology, the ISM-S owes its novelty and originality to the fact that it integrates the four factors mentioned above with three systemic validation components: Statistical analysis, Maturity level classification and Simulation of stochastic models for decision making. Figure 26 shows the contribution of the ISM-S with regards to the approaches commonly analyzed in the state of the art.

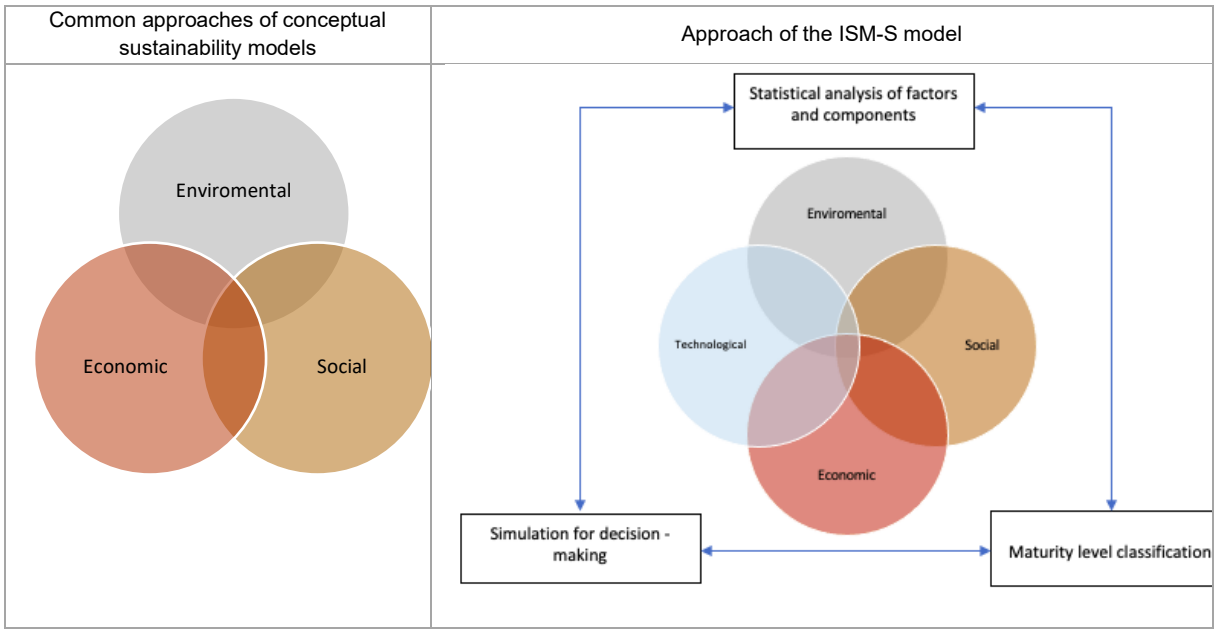


Figure 26. Contribution to sustainability approaches

Through the development of a series of case studies, the ISM-S was evaluated in various SMEs from the Manufactures, Service and commerce, and Construction and civil works sectors in five cities of Colombia. This made it possible to identify strengths, weaknesses and barriers faced by SMEs when it comes to implementing sustainable practices.

The main contribution of the ISM-S is the large scale identification of the sustainability maturity level of SMEs, which is carried out by means of data analysis and classification algorithms. This helps the companies set a corresponding route or plan for the effective and systematic implementation of sustainability. In addition, it opens leeway for influential agents (academia, government and businessmen) to lay out plans and strategies adapted to company-specific needs.

6.3 Limitations of the Integral Sustainability Model for SMEs

In the lines that follow, the limitations of the model introduced in the present work are detailed:

- The ISM-S was developed solely through a qualitative approach, so the results simply allow understanding how the model can be integrated into a business management model.

- The components of the ISM-S were defined through a multidisciplinary work focused on the economic, social and environmental dimensions of sustainability, rather than on models developed under international standards of normalization.

- The ISM-S was evaluated through case studies in SMEs from the Manufacturing, Service and trade, and Construction and civil works sectors in five Colombian cities. However, the participation of these sectors was not balanced, which may have biased the results.

- A broad evaluation of the managers' perception about the integrated components of the ISM-S was not carried out. Therefore, future research efforts could expand the scope of the model by evaluating this perception and analyzing in depth the incorporation of the ISM-S into the supply chain and its stakeholders.

- The ISM-S has been introduced as a conceptual model that contributes to sustainable decision-making management. However, the present work has not introduced a methodology for its application.

6.4 Impact on academic and professional sectors

Based on the literature review and a series of case studies, the current research work introduces a theoretical and conceptual model, namely the Integral Sustainability Model for SMEs (ISM-S). This sustainable management strategic model actually analyzes and evaluates the organizational performance of a series of sustainability-related factors, the definition of which was based on their relevance in the literature on the topic.

The present research also aims to counterbalance the scarcity of theoretically supported and empirically validated studies on sustainable management decision-making in Colombia. This is particularly important when it comes to promoting a culture and a way to sustainability in SMEs, such that it allows them to improve their economic indicators, minimize negative environmental impacts and have their employees adopt a more sustainable and responsible behavior.

The current application of the ISM-S has surveyed the tools employed by SMEs from the studied sectors to carry out the planning of activities and continuous improvement processes. On these grounds, the model is capable of supporting other productive sectors in identifying sustainability-related barriers, strengths and weaknesses. This, in turn, is likely to help them effectively and systemically integrate environmentally friendly practices into their management systems.

6.5 Conclusions

The conclusions of this chapter reveal it is one of the first empirical studies to integrally analyze various sustainability factors in connection with the behavior of SMEs. Therefore, the current framework can be applied to both regional development plans and the evaluation and monitoring of economic indicators in companies. In turn, the model allows them to minimize

negative environmental impacts and have their employees adopt more responsible behaviors. In addition, the ISM-S was developed through the Scientific Research Design methodology. Hence, owes its novelty and originality to the fact that it integrates the four factors with three systemic validation components: Statistical analysis, Maturity level classification and Simulation of stochastic models for decision making. Also, the ISM-S is uniquely positioned in the literature, taking into account the few existing works that comprehensively evaluate the factors exposed in the ISM-S across economic sectors and regions.

Chapther 7. Conclusions and Recommendations

7.1 Introduction

The final chapter of this doctoral thesis presents the conclusions and contributions of the current scientific research. Thus, the first section is framed in a brief summary of the findings and achievements of the proposed objectives. The second section provides useful recommendations for SMEs based on the ISM-S model. Likewise, the third section establishes future research perspectives.

7.2 Conclusions and findings related to the research objectives

The general objective of the present doctoral dissertation is to *Developing an integral sustainability model for SMEs, framed in an environmental management system intended to improve economic indicators, minimize negative environmental impacts and have their employees adopt a more sustainable and responsible behavior*. This general objective was achieved by developing the corresponding activities to each of the different specific objectives, based on the scientific research design methodology and other tools that contributed to the development of the present one. The relevant conclusions drawn from this doctoral thesis are presented below.

> *Specific objective 1: Identifying and analyzing the components of an integral sustainability model.*

- The components that make up the conceptual model are identified and presented in Chapter 2, which begins with an analysis of the concepts of sustainability and sustainable development, leading to the conclusion that these terms are often used without distinction. However, these concepts can be quite different, since in the term “sustainability” indeed, is used for strategic issues related to prevention and resource depletion. In turn, sustainable development involves a multidisciplinary approach with different interests related to prominence and power [14]. Despite these interpretations, the two concepts are still complex to apply in business contexts. Hence, sustainable development proposes the economic, environmental and social dimensions, wherein academia, governments and entrepreneurs must harmonize to achieve a holistic balance.

- The achievement of this specific objective was developed through an exhaustive literature search in topics related to the subject of study. This was done through a systematic search and bibliometric analysis that resulted in the classification of three specific clusters: Sustainability decision-making management system, sustainable tools and practices, and social responsibility and knowledge management. In each one of the three clusters, the most cited research works during the 2016 and 2020 period were selected, classified and related to the dimensions of sustainable

development: Sustainability decision-making management system was related to the economic dimension; Sustainable tools and practices to the environmental dimension; and Social responsibility and knowledge management to the social dimension. In addition, a new dimension was introduced, labeled as Technological, which is related to the factor Technological and analytic information convergence.

- From the analyzed papers, it was possible to identify the importance of applying the sustainability dimensions in the internal processes of SMEs. Likewise, new sustainable practice trends were identified, such as automatic tools for the achievement of industry 4.0, strategies framed in circular economy, and lean and green thinking. However, different research gaps and barriers for the implementation of sustainable practices were detected. This is the case of the lack of financial and investment resources, cooperative networks, resource assignation and control management strategies, and data analysis for self-evaluation in order to know what route these companies should take to achieve sustainability.

  Specific objective 2: Designing and evaluating an integral sustainability model for SMEs, such that it combines sustainable practices and environmental knowledge management in an environmental management system.

- This specific objective was achieved through the use of the Scientific Research Design and Case Study methodologies, which were proposed in Chapter 3 [65], [68]. Thus, after understanding what sustainable strategic models are, a series of activities were carried out, which allowed the conceptual correlation proposed in chapter 4. From this correlation, the Integral Sustainability Model for SMEs (ISM-S) was designed as a strategy to guide small entrepreneurs toward sustainability in their internal operations.

- The ISM-S is composed of different concepts which can be used to contribute to the knowledge and understanding of the adoption of: Management systems for sustainable decision-making, sustainable tools and practices, Social responsibility and knowledge management, and Technological and analytical information convergence. Likewise, the ISM-S includes three specific elements: Analysis of factors and components, maturity level classification, and simulation for decision-making.

- In addition, this objective has been achieved based on a quantitative research wherein a survey was designed to collect information from the SMEs involved in this study. In applying this survey, it was observed that the sector's participation rate was 100% of the selected sample in various economic sectors in Colombia. Therefore, this quantitative study is uniquely positioned in the literature, taking into account the few existing works that comprehensively evaluate the factors exposed in the ISM-S across economic sectors and regions. However, the results might be biased as the respondents to the questionnaires of the case study are not well balanced, since there are around 47% micro-enterprises out of which only 37% are small, and 17% are medium sized enterprises. Nonetheless, this objective certainly contributes to

multidisciplinary fields in Colombia. The results of each factor are shown in Chapter 5 and 6, highlighting the challenges that each sector must face.

Specific objective 3: Validating the model through predictive simulation, in order to assess improvement strategies.

- This objective was achieved in Chapter 5, which uses the sustainability maturity model to classify the 327 studied companies. Within the data analysis results obtained from the Random Forest supervised classification algorithm, it can be seen that about 30% of the companies are at Level 2 (basic), since they meet the 14 characteristics proposed in the sustainability maturity model for that level; about 60% of the companies are at Level 3 (developing), as they meet the 27 characteristics of this level; and about 10% of the companies are at Levels 1 (incipient) and 4 (consolidated). This shows the diversity of situations in which specific activities must be prioritized in order to achieve a consolidated state of sustainability.

- In addition, the validation of the ISM-S has been carried out by proposing a predictive simulation through stochastic models (Markov Chain), in order to analyze the possible routes that a company should take to reach a consolidated level of sustainability maturity, thus complying with the characteristics set out by the ISM-S for each factor. Additionally, to know how long it would take a company to reach Level 4, the behavior of a set of 5000 companies over a period of 16 years is analyzed. Then their behavior was simulated with the stochastic model. The results suggest that the average time taken by a company to reach state 4 (Level 4: Consolidated sustainability maturity) is 2.5 years on average. This would imply that project managers and businessmen would have to work hard on a management plan for the implementation of sustainable strategies.

7.3 Recommendations to SMEs sector

The results of this doctoral dissertation point out that despite the diverse sustainable practices that SMEs carry out empirically, the analyzed businesses do not show a strategic path that leads them to a level of sustainability maturity. However, the interest shown by the sector has been motivating them to undertake the right things and to comply with the characteristics that have been proposed in the ISM-S model.

In analyzing the adoption of sustainable practices and strategies in the studied SMEs, it is demonstrated that academia and governmental entities need to make very strong efforts to continue encouraging and raising awareness in the sector about the importance of introducing innovative strategies in their internal sustainable processes, despite the time and resources barrier that these strategies may generate. Consequently, a series of recommendations are presented to the MSMEs (see Table 21).

Table 21. The recommendations to SMEs

Collaborator	Recommendations
Industry associations	SMEs wishing to embark on the road to sustainability need a self-diagnosis, which can be made through the ISM-S, in order to know which direction, they should take. In this way, they can determine what their basic needs are, their priorities and the goals they wish to achieve.
	Strategies for data analysis that allow decision-making in companies is still a precarious activity. Hence, it is suggested that SMEs have indicators and control tools that allow them to have a vision of their environmental, social and economic performance.
	It is increasingly necessary for companies to strengthen cooperation networks through virtual platforms. Taking into account that around 80% of the studied companies do not belong to any business association, it is suggested that they consider looking into governmental associations in order to be at the forefront of the challenges posed by the economic situation in emerging countries.
Government	It is recommended that the sector develop a strategic plan of sustainable activities in accordance with the predictions of the time it will take to pass from one level of maturity to another. This plan should involve financial aspects, activities to be developed, people in charge, etc. As such, it would contribute to regional development plans as instruments that allow for the analysis of a realistic panorama of progress.
	Financial and environment plans to support SMEs though loans, credit, guarantees on loans and relaxation of laws on loan repayment. Also, a financial and environment plan will also include other types of resources you might obtain, such as in-kind support, volunteer staff, or shared resources from other organizations. This plan may even include convincing another company to take on a sustainability project by SMEs.
	It is expected that SMEs strengthen their training programs with activities and themes aimed at sustainability. Just as well, it is important to find spaces for the generation of innovative ideas that promote business development.
Academia	Regardless of what practices and sustainable tools small businesses may implement, they must be carefully assessed in terms of their profitability, so as to know the resources amounts, they consume and the points of the value chain where there is inefficiency.
	The trend of responsible consumers continues to grow. Therefore, it is suggested that this trend into account, so as to know where they invest their money and what they contribute through their purchasing decisions.

7.4 Future research perspectives

It is possible to consider various studies on strategic sustainability models for the small business sector. However, studies providing a real picture of the current situation of emerging countries in terms of sustainable practice adoption are still incipient. Hence, the potential contribution of these studies to productive improvement and minimization of environmental impacts is correspondingly small.

Therefore, one of the contributions of this research is the conceptualization of a series of important factors and components that a model should have as an orientation tool for

Colombian SMEs. Likewise, this research contributes to the analysis of the sustainability business landscape in emerging countries. Therefore, similar research initiatives to the current one could be reproduced in other emerging countries, to contrast with the current findings on the Colombian reality.

As the present work has been developed in the wood, service and trade, manufacturing, and civil works sectors, it is proposed to venture into other economic sectors to make sustainability maturity comparisons and stochastic simulations of sector evolution in the adoption of sustainable strategies. This type of analysis is expected to allow progress in the recognition of the missing pieces and aspects on which entrepreneurs, academia and government entities should focus to improve in this endeavor.

In addition, the lack of practical guidelines for SMEs to achieve a state of consolidated sustainability maturity continues to be considered as future work. As such, it calls for government agencies and organizations to develop methodologies for implementing sustainable strategies in sectors with limited resources.

The present research has designed a data collection survey which was used in combination with analysis tools in the programming languages Phyton, VOSviewer and Excel. Thus, other analysis tools and methodologies can be used for data modeling and statistical analysis.

Reference

[1] Z. Liao, "Environmental policy instruments, environmental innovation and the reputation of enterprises," *J. Clean. Prod.*, vol. 171, pp. 1111–1117, Jan. 2018.

[2] M. Hachaichi and T. Baouni, "Downscaling the planetary boundaries (Pbs) framework to city scale-level: De-risking MENA region's environment future," *Environ. Sustain. Indic.*, vol. 5, p. 100023, 2020.

[3] T. Elmqvist *et al.*, "Sustainability and resilience for transformation in the urban century," *Nat. Sustain.*, vol. 2, no. 4, pp. 267–273, Apr. 2019.

[4] T. Searchinger, R. Waite, C. Hanson, and J. Ranganathan, "Creating a Sustainable Food Future a CREATING A SUSTAINABLE FOOD FUTURE WORLD RESOURCES REPORT," *World Resour. Rep.*, vol. 1, no. July, p. 558, 2019.

[5] G. Schwan, "Sustainable development goals," *GAIA*, vol. 28, no. 2. p. 73, 2019.

[6] A. Kumar Verma, "Sustainable Development and Enviromental Ethics," *Int. J. Environ. Sci.*, vol. 10, no. 1, pp. 1–5, 2019.

[7] W. Kucharska and R. Kowalczyk, "How to achieve sustainability?—Employee's point of view on company's culture and CSR practice," *Corp. Soc. Responsib. Environ. Manag.*, vol. 26, no. 2, pp. 453–467, 2019.

[8] E. Rauch, P. Dallasega, and D. T. Matt, "Sustainable production in emerging markets through Distributed Manufacturing Systems (DMS)," *J. Clean. Prod.*, vol. 135, pp. 127–138, Nov. 2016.

[9] D. T. Matt, G. Orzes, E. Rauch, and P. Dallasega, "Urban production – A socially sustainable factory concept to overcome shortcomings of qualified workers in smart SMEs," *Comput. Ind. Eng.*, vol. 139, p. 105384, Jan. 2020.

[10] R. Stekelorum, "The roles of SMEs in implementing CSR in supply chains: a systematic literature review," *Int. J. Logist. Res. Appl.*, vol. 23, no. 3, pp. 228–253, 2020.

[11] M. Barbosa, J. A. Castañeda -Ayarza, and D. H. Lombardo Ferreira, "Sustainable Strategic Management (GES): Sustainability in small business," *J. Clean. Prod.*, vol. 258, 2020.

[12] C. Atia *et al.*, "An analysis of the interplay between organizational sustainability, knowledge management, and open innovation," 2017.

[13] J. Vásquez, S. Aguirre, C. E. Fuquene-Retamoso, G. Bruno, P. C. Priarone, and L. Settineri, "A conceptual framework for the eco-efficiency assessment of small- and medium-sized enterprises," *J. Clean. Prod.*, vol. 237, 2019.

[14] T. O. Olawumi and D. W. M. Chan, "A scientometric review of global research on sustainability and sustainable development," *J. Clean. Prod.*, vol. 183, pp. 231–250, May 2018.

[15] J. Mccormick, “The Origins of the World Conservation Strategy,” North Carolina, Estados Unidos, 1986.

[16] G.-H. Brundtland, “Our Common Future: The World Commission on Environment and Development: Oxford University Press,” *New York*, 1987.

[17] W. Chang and S. A. Taylor, “The effectiveness of customer participation in new product development: A meta-analysis,” *J. Mark.*, vol. 80, no. 1, pp. 47–64, Jan. 2016.

[18] Ş. Kilkiş, “Sustainability-oriented innovation system analyses of Brazil, Russia, India, China, South Africa, Turkey and Singapore,” *J. Clean. Prod.*, vol. 130, pp. 235–247, Sep. 2016.

[19] U. Nations, “Rio Declaration on Environment and Development,” *Environ. Conserv.*, vol. 19, no. 4, pp. 366–368, 1992.

[20] U. Nations, “United Nations Conference on trade and development the social responsibility of transnational corporations.” New York and Geneva, pp. 1–75, 1999.

[21] & U. N. D. of P. I. United Nations. Department of Economic, “The Millennium Development Goals Report 2015,” New York and Geneva, 2015.

[22] & U. N. D. of P. I. United Nations. Department of Economic, “COP 15 | UNFCCC.” [Online]. Available: https://unfccc.int/process-and-meetings/conferences/past-conferences/copenhagen-climate-change-conference-december-2009/cop-15. [Accessed: 06-Dec-2020].

[23] G. Schwan, “Sustainable development goals,” *GAIA*, vol. 28, no. 2. p. 73, 2019.

[24] J. Sachs, G. Schmidt-Traub, C. Kroll, G. Lafortune, and G. Fuller, “Sustainable development goals,” *Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN)*, vol. 28, no. 2. p. 73, 2019.

[25] J. Elkington, “25 Years Ago I Coined the Phrase “Triple Bottom Line". Here’s Why It’s Time to Rethink It.,” *Harvard Business Review*, 2018. [Online]. Available: https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it. [Accessed: 04-May-2021].

[26] I. Garbie, *Sustainability in Manufacturing Enterprises: Concepts, Analyses and Assessments for Industry 4.0*, no. January. 2016.

[27] S. Schaltegger, E. G. Hansen, and F. Lüdeke-Freund, “Business Models for Sustainability: Origins, Present Research, and Future Avenues,” *Organ. Environ.*, vol. 29, no. 1, pp. 3–10, 2016.

[28] Margarida Rodrigues and Mário Franco, “The Corporate Sustainability Strategy in Organisations: A Systematic Review and Future Directions,” *Sustain.*, vol. 11, no. 22, p. 6214, 2019.

[29] R. J. Baumgartner and R. Rauter, “Strategic perspectives of corporate sustainability

management to develop a sustainable organization," *J. Clean. Prod.*, vol. 140, pp. 81–92, 2017.

[30] H. T. S. Caldera, C. Desha, and L. Dawes, "Evaluating the enablers and barriers for successful implementation of sustainable business practice in 'lean' SMEs," *J. Clean. Prod.*, vol. 218, pp. 575–590, 2019.

[31] J. M. Müller, "Sustainable Industrial Value Creation – An Analysis of Industry 4 . 0 with Special Regard to SMEs (The Crest of the Innovation Management Research Wave) A collection of the top ISPIM Dissertation Award 2019 submissions Sustainable Industrial Value Creat," no. January, 2020.

[32] H. Liu, S. J. Kim, H. Wang, and K. H. Kim, "Corporate sustainability management under market uncertainty," *Asia Pacific J. Mark. Logist.*, 2019.

[33] H. S. Birkel, J. W. Veile, J. M. Müller, E. Hartmann, and K. I. Voigt, "Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers," *Sustain.*, vol. 11, no. 2, Jan. 2019.

[34] C. Meschede, "The sustainable development goals in scientific literature: A bibliometric overview at the meta-level," *Sustain.*, vol. 12, no. 11, 2020.

[35] C. C. Nakamba, P. W. Chan, and M. Sharmina, "How does social sustainability feature in studies of supply chain management? A review and research agenda," *Supply Chain Manag.*, vol. 22, no. 6, pp. 522–541, 2017.

[36] S. K. Mangla, S. Luthra, N. Rich, D. Kumar, N. P. Rana, and Y. K. Dwivedi, "Enablers to implement sustainable initiatives in agri-food supply chains," *Int. J. Prod. Econ.*, vol. 203, pp. 379–393, Sep. 2018.

[37] T. B. Long, A. Looijen, and V. Blok, "Critical success factors for the transition to business models for sustainability in the food and beverage industry in the Netherlands," *J. Clean. Prod.*, vol. 175, pp. 82–95, 2018.

[38] C. H. Hsu, A. Y. Chang, and W. Luo, "Identifying key performance factors for sustainability development of SMEs – integrating QFD and fuzzy MADM methods," *J. Clean. Prod.*, vol. 161, pp. 629–645, 2017.

[39] P. R. Crowe, K. Foley, and M. J. Collier, "Operationalizing urban resilience through a framework for adaptive co-management and design: Five experiments in urban planning practice and policy," *Environ. Sci. Policy*, vol. 62, pp. 112–119, Aug. 2016.

[40] D. D'Amato, S. Veijonaho, and A. Toppinen, "Towards sustainability? Forest-based circular bioeconomy business models in Finnish SMEs," *For. Policy Econ.*, vol. 110, no. June 2018, p. 101848, 2020.

[41] M. Aboelmaged, "The drivers of sustainable manufacturing practices in Egyptian SMEs and their impact on competitive capabilities: A PLS-SEM model," *J. Clean. Prod.*, vol. 175, pp. 207–221, 2018.

[42] K. Changwichan, T. Silalertruksa, and S. H. Gheewala, “Eco-efficiency assessment of bioplastics production systems and end-of-life options,” *Sustain.*, vol. 10, no. 4, p. 952, Mar. 2018.

[43] G. C. Oliveira Neto, R. R. Leite, F. Y. Shibao, and W. C. Lucato, “Framework to overcome barriers in the implementation of cleaner production in small and medium-sized enterprises: Multiple case studies in Brazil,” *J. Clean. Prod.*, vol. 142, pp. 50–62, 2017.

[44] J. Batle, F. Orfila-Sintes, and C. J. Moon, “Environmental management best practices: Towards social innovation,” *Int. J. Hosp. Manag.*, vol. 69, no. October 2017, pp. 14–20, 2018.

[45] G. C. Wu, “Effects of Socially Responsible Supplier Development and Sustainability-Oriented Innovation on Sustainable Development: Empirical Evidence from SMEs,” *Corp. Soc. Responsib. Environ. Manag.*, vol. 24, no. 6, pp. 661–675, 2017.

[46] C. H. Hsu, A. Y. Chang, and W. Luo, “Identifying key performance factors for sustainability development of SMEs – integrating QFD and fuzzy MADM methods,” *J. Clean. Prod.*, vol. 161, pp. 629–645, 2017.

[47] R. M. Dangelico, D. Pujari, and P. Pontrandolfo, “Green Product Innovation in Manufacturing Firms: A Sustainability-Oriented Dynamic Capability Perspective,” *Bus. Strateg. Environ.*, vol. 26, no. 4, pp. 490–506, May 2017.

[48] J. Klewitz and E. G. Hansen, “Sustainability-oriented innovation of SMEs: A systematic review,” *Journal of Cleaner Production*, vol. 65. Elsevier, pp. 57–75, 15-Feb-2014.

[49] A. Urbinati, D. Chiaroni, and V. Chiesa, “Towards a new taxonomy of circular economy business models,” *J. Clean. Prod.*, vol. 168, pp. 487–498, Dec. 2017.

[50] C. J. Chiappetta Jabbour *et al.*, “Who is in charge? A review and a research agenda on the ‘human side’ of the circular economy,” *J. Clean. Prod.*, vol. 222, pp. 793–801, Jun. 2019.

[51] C. J. C. Jabbour, A. B. L. de S. Jabbour, J. Sarkis, and M. G. Filho, “Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda,” *Technol. Forecast. Soc. Change*, vol. 144, pp. 546–552, Jul. 2019.

[52] T. B. C. Onyido, D. Boyd, and N. Thurairajah, “Developing SMEs as environmental businesses,” *Constr. Innov.*, vol. 16, no. 1, pp. 30–45, 2016.

[53] N. R. Mosteanu, A. Faccia, A. Ansari, M. D. Shamout, and F. Capitanio, “Sustainability integration in supply chain management through systematic literature review,” *Qual. - Access to Success*, vol. 21, no. 176, pp. 117–123, 2020.

[54] A. Majumdar and S. K. Sinha, “Analyzing the barriers of green textile supply chain management in Southeast Asia using interpretive structural modeling,” *Sustain. Prod. Consum.*, vol. 17, pp. 176–187, Jan. 2019.

[55] G. C. Oliveira Neto, R. R. Leite, F. Y. Shibao, and W. C. Lucato, “Framework to

overcome barriers in the implementation of cleaner production in small and medium-sized enterprises: Multiple case studies in Brazil," *J. Clean. Prod.*, vol. 142, pp. 50–62, 2017.

[56] P. Heikkurinen, C. W. Young, and E. Morgan, "Business for sustainable change: Extending eco-efficiency and eco-sufficiency strategies to consumers," *J. Clean. Prod.*, vol. 218, pp. 656–664, May 2019.

[57] A. G. Besné, D. Luna, A. Cobos, D. Lameiras, H. Ortiz-Moreno, and L. P. Güereca, "A methodological framework of eco-efficiency based on fuzzy logic and Life Cycle Assessment applied to a Mexican SME," *Environ. Impact Assess. Rev.*, vol. 68, pp. 38–48, Jan. 2018.

[58] A. M. Biscotti, E. D'Amico, and F. Monge, "Do environmental management systems affect the knowledge management process? The impact on the learning evolution and the relevance of organisational context," *J. Knowl. Manag.*, vol. 22, no. 3, pp. 603–620, 2018.

[59] I. R. Edvardsson, T. Yigitcanlar, and S. Pancholi, "Knowledge city research and practice under the microscope: A review of empirical findings," *Knowl. Manag. Res. Pract.*, vol. 14, no. 4, pp. 537–564, 2016.

[60] S. Ayuso and F. E. Navarrete-báez, "How Does Entrepreneurial and International Orientation Influence SMEs' Commitment to Sustainable Development? Empirical Evidence from Spain and Mexico," *Corp. Soc. Responsib. Environ. Manag.*, vol. 25, no. July 2017, pp. 80–94, 2018.

[61] R. Stekelorum, I. Laguir, and J. Elbaz, "Cooperation with international NGOs and supplier assessment: Investigating the multiple mediating role of CSR activities in SMEs," *Ind. Mark. Manag.*, vol. 84, pp. 50–62, 2020.

[62] D. Ravasi and M. Schultz, "Responding to organizational identity threats: Exploring the role of organizational culture," *Acad. Manag. J.*, vol. 49, no. 3, pp. 433–458, 2006.

[63] J. Batle, F. Orfila-Sintes, and C. J. Moon, "Environmental management best practices: Towards social innovation," *Int. J. Hosp. Manag.*, vol. 69, pp. 14–20, 2018.

[64] A. Dresch, D. P. Lacerda, and J. A. V. Antunes, *Design science research : a method for science and technology advancement*, 1st ed. Springer International Publishing, 2015.

[65] R. Weber, "Design-science research," in *Research Methods: Information, Systems, and Contexts: Second Edition*, 2017, pp. 267–288.

[66] J. M. W. Wayne C. Booth, Gregory G. Colomb, *The craft of research*, 3rd ed. Chicago, 2008.

[67] John W. Creswell, *Research design : qualitative, quantitative, and mixed methods approaches*, 4th ed. Thousand Oaks, California 91320, 2014.

[68] R. Yin, "Chapter 4: Collecting case study evidence," in *Case Study Research: Design and Methods*, Ilustrada., vol. 5, SABIO, Ed. Los Angeles: Sage Publications, 2009, pp. 99–126.

[69] C. Fernandez-Lozano, M. Gestal, C. R. Munteanu, J. Dorado, and A. Pazos, “A methodology for the design of experiments in computational intelligence with multiple regression models,” *PeerJ*, vol. 2016, no. 12, pp. 1–22, 2016.

[70] Oficina de Estudios Económicos; MinComercio, “Dinámica de la economía colombiana,” Bogotá D. C, Colombia, 2019.

[71] DANE - Dirección de Censos y Demografía, “Censo Nacional de Población y Vivienda 2018, Colombia,” *DANE*, 2019. [Online]. Available: https://sitios.dane.gov.co/cnpv/#!/. [Accessed: 08-Sep-2020].

[72] E. Q. C. Rosmery and Montes Rodríguez, “Encuesta de desempeño empresarial, cuarto trimestre 2019.pdf,” Barranquilla, Colombia, 2020.

[73] Confecámaras, “Dinámica de creación de empresas en Colombia, Enero-diciembre de 2019,” Bogotá D. C, Colombia, 2019.

[74] Confecámaras, “Dinámica de creación de empresas en Colombia, Enero- junio de 2020,” Bogotá D. C, Colombia, 2020.

[75] A. M. González and M. A. Echeverry-Galvis, “Indicadores ambientales y desempeño ambiental: Colombia en el índice de desempeño ambiental (EPI) (2006-2014),” *Ambient. y Desarro.*, vol. 23, no. 44, Jun. 2019.

[76] Departamento Administrativo Nacional de Estadística- DANE, “Economía circular 2020, Primer Reporte,” Bogotá D. C, Colombia, 2020.

[77] Luis Hernán Sáenz, “Territorializando los ODS en las ciudades de Colombia ¿Hacia dónde vamos?,” Bogotá D. C, Colombia, 2019.

[78] B. W. Wirtz, A. Pistoia, S. Ullrich, and V. Göttel, “Business Models: Origin, Development and Future Research Perspectives,” *Long Range Plann.*, vol. 49, no. 1, pp. 36–54, Feb. 2016.

[79] C. M. DaSilva and P. Trkman, “Business model: What it is and what it is not,” *Long Range Plann.*, vol. 47, no. 6, pp. 379–389, 2014.

[80] M. Peric, J. Durkin, and V. Vitezic, “The Constructs of a Business Model Redefined: A Half-Century Journey,” *SAGE Open*, vol. 7, no. 3, pp. 1–13, 2017.

[81] M. E. Porter and M. R. Kramer, “Creating Shared Value,” *Harv. Bus. Rev.*, vol. 89, no. February, pp. 1–17, 2011.

[82] N. Bocken, F. Boons, and B. Baldassarre, “Sustainable business model experimentation by understanding ecologies of business models,” *J. Clean. Prod.*, vol. 208, no. October, pp. 1498–1512, 2019.

[83] F. Boons and F. Lüdeke-Freund, “Business models for sustainable innovation: State-of-the-art and steps towards a research agenda,” *J. Clean. Prod.*, vol. 45, pp. 9–19, Apr. 2013.

[84] S. M. Chege and D. Wang, “The influence of technology innovation on SME performance

through environmental sustainability practices in Kenya," *Technol. Soc.*, vol. 60, 2020.

[85] N. U. Khan, S. Li, S. Z. Khan, and M. Anwar, "Entrepreneurial orientation, intellectual capital, IT capability, and performance," *Hum. Syst. Manag.*, vol. 38, no. 3, pp. 297–312, 2019.

[86] E. Passetti and A. Tenucci, "Eco-efficiency measurement and the influence of organisational factors: evidence from large Italian companies," *J. Clean. Prod.*, vol. 122, pp. 228–239, May 2016.

[87] E. Jové-Llopis and A. Segarra-Blasco, "Eco-Efficiency Actions and Firm Growth in European SMEs," *Sustainability*, vol. 10, no. 2, p. 281, 2018.

[88] B. Van Hoof and M. Thiell, "Anchor company contribution to cleaner production dissemination: Experience from a Mexican sustainable supply programme," *J. Clean. Prod.*, vol. 86, pp. 245–255, 2015.

[89] J. Vásquez, G. Bruno, L. Settineri, and S. Aguirre, "Conceptual Framework for Evaluating the Environmental Awareness and Eco-efficiency of SMEs," *Procedia CIRP*, vol. 78, pp. 347–352, 2018.

[90] K. T. Shibin, R. Dubey, A. Gunasekaran, Z. Luo, T. Papadopoulos, and D. Roubaud, "Frugal innovation for supply chain sustainability in SMEs: multi-method research design," *Prod. Plan. Control*, vol. 29, no. 11, pp. 908–927, 2018.

[91] C. Favi, M. Germani, M. Mandolini, and M. Marconi, "Implementation of a software platform to support an eco-design methodology within a manufacturing firm," *Int. J. Sustain. Eng.*, vol. 11, no. 2, pp. 79–96, 2018.

[92] S. Nosratabadi, A. Mosavi, S. Shamshirband, E. K. Zavadskas, A. Rakotonirainy, and K. W. Chau, "Sustainable business models: A review," *Sustain.*, vol. 11, no. 6, Mar. 2019.

[93] H. I. Stål and M. Babri, "Educational interventions for sustainable innovation in small and medium sized enterprises," *J. Clean. Prod.*, vol. 243, 2020.

[94] N. Beech, D. Devins, J. Gold, and S. Beech, "In the family way: an exploration of family business resilience," *Int. J. Organ. Anal.*, vol. 28, no. 1, pp. 160–182, 2020.

[95] X. Shi, T. Baba, D. Osagawa, M. Fujishima, and T. Ito, "A Maturity Model for Sustainable System Implementation in the Era of Smart Manufacturing," *IEEE Int. Conf. Emerg. Technol. Fact. Autom. ETFA*, vol. 2019-Septe, pp. 1649–1652, 2019.

[96] F. Odważny, D. Wojtkowiak, P. Cyplik, and M. Adamczak, "Concept for measuring organizational maturity supporting sustainable development goals," *Logforum*, vol. 15, no. 2, pp. 237–247, 2019.

[97] Y. S. Dharmawan, G. G. Divinagracia, E. Woods, and B. Kwong, "Inter-dependencies on BPM maturity model capability factors in deriving BPM roadmap," *Procedia Comput. Sci.*, vol. 161, pp. 1089–1097, 2019.

[98] R. F. Bass, *In Stochastic Processes*. Cambridge: Cambridge University Press, 2011.

[99] R. Coleman, “What is a Stochastic Process?,” in *Stochastic Processes*, Springer Netherlands, 1974, pp. 1–5.

[100] Bureau van Dijk, “Bureau van Dijk | Private company information – Orbis,” 2020. [Online]. Available: https://www.bvdinfo.com/en-gb. [Accessed: 27-Feb-2020].

[101] Bancóldex, “Clasificación de empresas en Colombia ,” vol. 2017, no. Abril. 2017.

[102] J. B. S. dos Santos-Neto and A. P. C. S. Costa, “Enterprise maturity models: a systematic literature review,” *Enterp. Inf. Syst.*, vol. 13, no. 5, pp. 719–769, 2019.

[103] E. Alpaydin, *Machine Learning : The New AI*, MIT Press. Cambridge, MA, 2016.

[104] T. Fushiki, “Estimation of prediction error by using K-fold cross-validation,” *Stat. Comput.*, vol. 21, no. 2, pp. 137–146, Oct. 2011.

[105] I. Klyueva, “Improving Quality of the Multiclass SVM Classification Based on the Feature Engineering,” in *Proceedings - 2019 1st International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency, SUMMA 2019*, 2019, pp. 491–494.

[106] L. G. Moreno-Sandoval, E. Puertas, F. M. Plaza-Del-Arco, A. Pomares-Quimbaya, J. A. Alvarado-Valencia, and L. Alfonso Ureña-López, “Celebrity profiling on twitter using sociolinguistic features notebook for PAN at CLEF 2019,” 2019.

[107] G. Tsiliki, C. R. Munteanu, J. A. Seoane, C. Fernandez-Lozano, H. Sarimveis, and E. L. Willighagen, “RRegrs: An R package for computer-aided model selection with multiple regression models,” *J. Cheminform.*, vol. 7, no. 1, p. 46, Dec. 2015.

[108] E. Jové-Llopis and A. Segarra-Blasco, “Eco-efficiency actions and firm growth in European SMEs,” *Sustain.*, vol. 10, no. 1, 2018.

[109] E. Rauch, M. Dallinger, P. Dallasega, and D. T. Matt, “Sustainability in Manufacturing through Distributed Manufacturing Systems (DMS),” *Procedia CIRP*, vol. 29, pp. 544–549, 2015.

Appendices

Appendix 1. DESCRIPTION OF THE SCIENTIFIC PUBLICATIONS DERIVED FROM THE THESIS

Title	A conceptual framework for the eco-efficiency assessment of small- and medium-sized enterprises
Authors	Vásquez, J., Aguirre, S., Fuquene-Retamoso, C. E., Bruno, G., Priarone, P. C., & Settineri, L.
Published in	Journal of Cleaner Production, 237, 117660. https://doi.org/10.1016/j.jclepro.2019.117660
Date	July 15th, 2019.
Abstract	The mitigation and prevention of environmental impacts is still a challenge for most companies, especially for small- and medium-sized enterprises (SMEs). The literature shows that researchers are paying attention to the concept of eco-efficiency, revealing companies' significant efforts to develop sustainable methodologies due to consumer pressure or government enforcement. However, concrete initiatives implemented at SMEs remain scarce. The aim of this paper is to present a conceptual framework to examine how SMEs understand the concept of eco-efficiency and implement other sustainability strategies through the identification of the following four specific factors: availability of an environmental management system, environmental knowledge, organizational culture, and environmental monitoring and control. In this paper, limitations and research gaps in the specific context are analyzed, and a conceptual framework allowing the eco-efficiency implementation to be assessed is proposed. An exploratory study has been carried out in17 SMEs of the wood industry in Bogotá, Colombia. The results show that most SMEs are unaware of existing sustainability strategies and environmental practices. Nevertheless, all SMEs agreed that the environment requires more attention and thus are interested in sustainability strategies to help decrease the negative impact of companies and increase their cost-effectiveness and competitiveness.
Keywords	Conceptual framework; eco-efficiency; small and medium-sized enterprise; sustainability strategy; wood industry
Specific contribution to the doctoral thesis	Chapter 1, Chapter 2, Chapter 3, Chapter 4, and Chapter 5.
Contribution to research	The paper contributes to the previous literature in several ways. First, few SMEs are able to invest large amounts of resources to undertake multiple eco-strategies [108]. SMEs in Latin America have difficulties in enforcing their industry to more sustainable and eco-efficient processes. Hence, this research contributes to the existing debate about the strengths and weaknesses of the SMEs in the context of sustainability. Second, the analyses of eco-efficiency here proposed are still scarce in emerging countries. In general, empirical studies are performed in rich industrialized countries, while this study is focused on an emerging market that faces significant challenges when addressing sustainable development [8], [109]. Finally, the present study is expected to be relevant for business leaders, as it indicates whether current eco-strategies are sufficient or whether adjustments are needed.

Title	A sustainability maturity model for micro, small and medium-sized enterprises (MSMEs), based on a data analytics evaluation approach
Authors	Vásquez, J., Aguirre, S., Puertas, E., Bruno, G., Priarone, P. C., & Settineri, L.
Published in	Journal of Cleaner Production
Date	Initial date summited: Aug. 19th, 2020 (under review).
Abstract	A maturity model for micro, small and medium enterprises (MSMEs) is introduced in order to assess the level of implementation of sustainability strategies and practices in this type of business. According to the literature, few sustainability maturity assessment models intended for MSMEs have integrated the three factors currently examined: environmental knowledge management, environmental strategies and good practices, and environmental management systems. The sustainability maturity model proposed here for MSMEs is capable of supporting the effort of companies on their way to achieving both environmental sustainability and the improvement of their production systems. The model encompasses a four-level qualitative scale and uses supervised classification algorithms to categorize companies through data analysis techniques. After applying the model to a group of MSMEs of different productive sectors in Colombia, the results show that 6% of the companies were at an insufficient level, 31% were at initial levels, 45% at sustainability maturity development, and 18% at a consolidated level. The latter implies greater attention from decision makers to the strengthening of sustainability progress capabilities and, hence, to the definition of a maturation route.
Keywords	Sustainability; maturity model; data analytics; small and medium-sized enterprises.
Specific contribution to the doctoral thesis	Chapter 1, Chapter 4 and Chapter 5.
Contribution to research	The main contributions of the current research study are manifold. First, the development of a SMMM that allows assessing the degree of sustainability maturity and integrating the management of environmental knowledge, strategies, good environmental practices, and management systems in the internal processes of MSMEs. Second, regardless of economic activity, the model should allow MSMEs to gradually move through sequential levels of implementation of sustainable practices and strategies. That is, from the basic or incipient to the optimal or consolidated. Third, the identification of the factors on which MSMEs should focus their improvement efforts within the framework of environmental sustainability. Said recognition likely contributes to the decision-making processes of entrepreneurs, researchers and government entities. Finally, data analysis allows evaluating internal management in companies by means of data behavior, which, in turn, facilitates diagnosing and predicting company needs within the framework of environmental sustainability.

Title	Development of an integral model of sustainability for the improvement of the environmental and productive process in small and medium enterprises (SMEs)
Authors	Vásquez, J., Aguirre, S., Settineri, L. (2020).
Published in	Second National Meeting of Doctoral Students in Engineering, ENEDI-ACOFI 2020, published in the proceedings of the event https://www.acofi.edu.co/eiei2020/enedi-2020/
Date	September 18th, 2020.
Abstract	Small, and medium enterprises (SMEs) are the engine of economic, environmental, and social stability in many countries. However, recently SMEs have been facing instability in their sales, production and feature a decrease in employment that generates negative growth in the gross domestic product in emerging countries. It is expected that academics, the government, and industrial sectors are aware of the importance of developing sustainable models to improve production systems within the framework of sustainable development. Considering that in the literature, there are multiple sustainable models, their practical implementation in production systems is a debate topic as there is no standard guide to the processes and activities that should be followed in their adoption. The objective of this study is to design a comprehensive sustainability model for SMEs through the analysis of the interrelationships and dependencies of sustainability factors and a perception analysis evaluating 327 SMEs in Colombia, using the design science research, *design of experiments in computational intelligence,* and case study as research methods. The analysis of the results indicates that SMEs studied showed significant variations in the use of the adoption of sustainable strategies, allowing the identification of weaknesses and strengths so to focus efforts by decision-makers.
Keywords	Sustainability model; strategies; small, and medium enterprises.
Specific contribution to the doctoral thesis	Chapter 1, Chapter 4, and Chapter 5.
Contribution to research	Consequently, the following research question is: What are the interrelationships between the elements and factors of sustainability models? In order to answer this question, the main objective is to develop a comprehensive sustainability model adapted to MSMEs through the analysis of sustainability factors. This study is based on the methodology of research science design and case study. Also, the contribution of this research is: First, the design of a new integral model that combines a series of productive and environmental strategies that allow companies to have a route of achievement to sustainable development. Second, research to have an overview of the situation of MSMEs in Colombia in reference to the proposed model. Finally, the model allows decision-makers in the industry to satisfy market needs without affecting the environment.

Title	Conceptual Framework for Evaluating the Environmental Awareness and Eco-efficiency of SMEs
Authors	Vásquez, J., Bruno, G., Settineri, L., & Aguirre, S. (2018).
Published in	Procedia CIRP, 78, 347-352. https://doi.org/10.1016/j.procir.2018.09.062
Date	September 9th, 2018.
Abstract	Environmental problems are increasingly impacting society and nature. For this reason, companies are expected to become aware of the importance of seeking strategies and measures to mitigate and prevent environmental impacts. The growing concern about the availability of natural resources for future generations and their survival has been the premise for decision-making in the industrial sector to improve the quality of life and preserve the environment. In this domain, important concepts such as sustainable development and eco-efficiency have been developed. They represent the trend to achieve a balanced use of resources and a reduction of environmental pollution by preventing waste and establishing economic returns. The aim of this paper is to present a conceptual framework for evaluating the eco-efficiency of small and medium-sized enterprise (SMEs) through four main factors: analysis, identification and evaluation, integration, and an action plan. As a result of the analysis, sustainability strategies are proposed to decrease the negative impact and increase the cost-effectiveness and the competitiveness of the SMEs.
Keywords	Sustainable development; eco-efficiency; environmental monitoring
Specific contribution to the doctoral thesis	Chapter 1, Chapter 2, and Chapter 3.
Contribution to research	Sustainability development requires time and cost for a SMEs. This makes it necessary to develop new methodological guidance tools. The environmental and economics strategies are oriented towards the development of new productive practices. The proposed conceptual Sustainability framework uses four factors exploiting many advantages for sustainability application and evaluation. First of all, it is easier for a SME to understand how to apply environmental practices and interaction. The factors addressed in the framework can be easily adapt to different SMEs environments, depending on the research preferences. The integration factors are another advantage of the proposed framework. The factors can be easily implemented in different organizational process such as incentives, identification of responsibilities in the company, improvement in the levels of communication and training based of sustainability strategies and principles.

Title	Development of eco-efficiency models in small and medium enterprises -SMEs
Authors	Vásquez, J., Aguirre, S., Fuquene-Retamoso.
Published in	8th International Conference on Production Research – Americas 2016 in Chile.
Date	October 27th, 2016
Abstract	This article presents the analysis of the state of the art of academic works that have proposed or developed eco-efficiency models in small and medium-sized companies internationally and in Colombia. To this end, a comparative analysis is carried out to establish the level of application and development of these models in these types of companies. As a result, it was found that there is a great effort at the international level to develop sustainable methodologies that contribute to solving the problem of the low environmental management capacity of this sector, wich is due to limited resources. The incorporation of Eco-efficiency is due to pressure from clients or authorities and not to the company's own purposes. In the case of Colombia, the development of the eco-efficiency strategy is limited and it has not been fully explored. Therefore, it is limited to proposing and analyzing theoretical tools, and dooes not constitute a practical application whose impact can be identified.
Keywords	Eco-efficiency; small and medium enterprises; sustainability
Specific contribution to the doctoral thesis	Chapter 1, Chapter 2, and Chapter 3.
Contribution to research	According to the review of the research works used as input in this article, two types of ecoefficiency models were found: Theoretical and applied. The theoretical models help to define environmental policies and metrics for decision-making, and the applicable models serve for the elaboration of economic and environmental indicators, besides allowing reductions in water consumption, atmospheric emissions, waste and energy savings in different SMEs. With respect to the research conducted at the national level, it can be highlighted that eco-efficiency is a strategy that has recently been adopted in different economic sectors in Colombia. This has been integrated with other environmental management methodologies that analyze the life cycle of a product, thus determining the impacts that are generated in the management of the supply chain. In this sense, it is recommended that Colombian SMEs use as a reference those eco-efficiency models that have had positive results at the international level. Just as well, it is recommended to seek and implement eco-efficiency strategies in their processes and/or products, so as to assume responsibility for the environment, making their productive activities more competitive, and adapting and redesigning existing productive systems to the needs of the market and the environment.

Appendix 2. INFORMATION COLLECTION TOOL APPLIED TO SMES. CASE STUDY: WOODEN FURNITURE FOR THE HOME AND INDUSTRIAL USE.

This questionnaire is part of the research project called "Development of an integral model of sustainability for the improvement of the environmental and productive process in small and medium enterprises in Colombia", which is approached as an Engineering Doctoral research study at Pontificia Universidad Javeriana, Colombia and at the Doctoral program in Management, Production and Design of the Politecnico di Torino, Italy. The main objective of this questionnaire is to know and determine the level of development of sustainable strategies and practices in the SMEs of the furniture sector in the city of Bogotá, Colombia. In order to analyze the behavior of the sector and determine the strengths and weaknesses in terms of management components, culture, knowledge and monitoring.

The results and conclusions will be shared during the Cleaner Production Workshop held by Pontificia Universidad Javeriana and the Mayor's Office of Bogotá, scheduled for December 6, 2017.

We thank you for your kind collaboration.

Contact Information	
Name of the Company:	Date:
Your role in the firm:	
e-mail:	

For each of the items below please tick the most appropriate response. The possible answers are: 4 for 'definitely yes' (DS), 3 for 'probably yes' (PS), 2 for 'probably not' (PN) and 1 for 'definitely not' (DN).

FACTOR 1: Environmental management system within an organization	1	2	3	4
Does your company have an environmental management system?				
Are the environmental problems important for your company?				
Is your company interested in implementing an environmental management system?				
FACTOR 2: Knowledge about the environment	1	2	3	4
Does your company have any knowledge on the Sustainable Development topic?				
Does your company have any knowledge on environmental practices?				
Does your company have any knowledge on the Eco-Efficiency topic?				
Has your company implemented environmental practices?				
FACTOR 3: Cultural organization	1	2	3	4
Are your employees concerned about the care of the environment?				
Have your employees received any environmental care training?				
Are your employees informed about the environmental situation within the company?				
FACTOR 4: Monitoring and environmental control	1	2	3	4
Does your company buy raw material with the green seal?				
Does your company have environmental indicators or other tools for environmental control?				
Are you aware that Colombian environmental legislation applies to your company?				

Thank you very much for your cooperation.

Appendix 3. INFORMATION COLLECTION TOOL APPLICATION APPLIED TO SMEs. CASE STUDY: WOODEN FURNITURE FOR THE HOME AND INDUSTRIAL USE.

Zasca
Centro de Servicios Empresariales
Muebles y Madera

Workshop developed at Zasca, December 2017.

Appendix 3. INFORMATION COLLECTION TOOL APPLIED TO SMES. CASE STUDY: MANUFACTURING, SERVICE AND COMMERCE SECTORS, AND CIVIL WORKS.

Dear Owner/ Manager of small business.

My name is Jenifer Vasquez, a student of the Doctoral program in Engineering at the Pontificia Universidad Javeriana, Colombia; and of the Doctoral Program in Management, Production, and Design at the Politecnico di Torino, Italy. I am currently gathering relevant information from the industrial and/or service sector for the elaboration of my degree project: "Development of an Integral Model of Sustainability to improve the environmental and productive processes in small and medium enterprises (SMEs)".

Therefore, a survey has been designed so that entrepreneurs belonging to micro, small and medium enterprises in Colombia can collaborate with us in providing information about their company, with the aim of evaluating the proposed model and determine the barriers and/or levels that the sector presents when implementing environmental practices in their production chain. For this reason, we invite you to be part of this academic research by answering this online questionnaire: https://forms.gle/yajYXEHsCQsr7BEp7

We thank you in advance for your attention and hope to continue strengthening the links between University and small industrial sector. The compilation of the survey is anonymous, and all data collected will be treated in an aggregated manner in accordance with Colombia's privacy law. For more information, please contact me at Jenifer.vasquez@javeriana.edu.co

Your opinion is important for our study!

Jenifer Vasquez A., M.Sc.
Ph.D. student
Faculty of Engineering
Pontificia Universidad Javeriana

Section 1.

Information of the company	
Name of the company:	City:
Your role in the firm:	
Number of employees in your company:	
Does the company belong to some type of business association?	

Section 2.

For each of the items below please tick the most appropriate response.

Factor 1. Sustainable decision-making	Yes	No
Q1. Do you know what an environmental management system is?		
Q2. Does your company have an environmental management system?		
Q3. Has the company received any environmental certification?		
Q4. Does the company have any environmental policy?		
Q5. Does your company have environmental indicators?		
Q6. Does the company have an Enterprise Resource Planning system (ERP)?		
Q7. Does the company have a strategy-control HSEQ (Health, Security, Environment and Quality) module in the Enterprise Resource Planning (ERP)?		
Q8. Are the main environmental policies and legislation established by the government to be applied in your company clear enough for implementation?		
Q9. Are environmental practices and the manufacturing or service delivery processes related to decision-making support?		

Factor 2. Sustainable environmental tools and practices	Yes	No
Q10. Do you understand the notions of ecoefficiency and cleaner production?		
Q11. Does your company have an environmental practice program?		
Q12. Do you know what circular economy is?		
Q13. Has the company set a plan to report liquid spills, gas leaks, gas-liquid mixtures or any other non-ecoefficient situations?		
Q14. Has your company implemented environmental practices?		
Q15 Does your company have a water saving and efficient use program?		
Q16. Does your company have a solid waste collection and classification program?		
Q17. Does your company check for the final disposal of dangerous waste (corrosive, reactive, explosive, toxic and flammable materials)?		
Q18. Do the employees tend to reuse office stationery materials?		
Q19. Does the company use treatments to extend the use of industrial resources such as oils, lubricants, acids, etc.?		
Q20. Does the company recover the products that their customers do not use any more?		
Q21. Does the company offer after sales repair service to extend product duration?		
Q22. Does your company have any noise level measurement system?		
Q23. Does the company have a statistical record of power and water bills?		
Q24. Does the company apply purchase environmental criteria when it comes to supplier selection?		
Q25. Do you consider that your suppliers comply with the environmental legislation?		

Factor 3. Responsabilidad social y gestión del conocimiento	Yes	No
Q26. Does the company consider that its employees have elevated environmental management knowledge?		
Q27 Does the company have enough human resources for environmental knowledge acquisition?		
Q28. Does the company have enough financial resources for environmental knowledge acquisition?		
Q29. Does the company have enough technological resources for environmental knowledge acquisition?		
Q30. Does the company have enough physical resources for environmental knowledge acquisition?		
Q31. Have the employees received environmental care training?		
Q32. Are environmental trainings conducted on a monthly, bimonthly or trimonthly basis?		
Q33. Are environmental trainings conducted every six months?		

Q34. Are environmental trainings conducted every year or more?		
Q35. Does the company provide the means for the workers to contribute innovative environmental ideas?		
Q36. Do the employees use environmental trainings to improve productive processes?		
Q37. Has the company documented its operative processes?		
Q38. Are the employees informed of the environmental impacts of the organization and the corresponding corrective measures?		
Q39. Select the option that best reflects the relevance of environmental sustainability in your company's agenda: it is part of the core strategy and is at the top of the priority agenda.		
Q40. Select the option that best reflects the relevance of environmental sustainability in your company's agenda: it is relevant for some activities, but not for all the company.		
Q41. Select the option that best reflects the relevance of environmental sustainability in your company's agenda: It is not among the priority items of the agenda, but it is given some importance.		
Q42. Select the option that best reflects the relevance of environmental sustainability in your company's agenda: It is not relevant for any of the company's activities.		

Section 3.

Do you consider that the following topics are barriers to implementing environmental practices in your company? The possible answers are: 5 for strongly agree, 4 for agree, 3 for undecided, 2 for disagree, 3 for strongly disagree.	1	2	3	4	5
The lack of organizational strategies					
The lack of qualified employees					
The lack of clean technology					
Budget restrictions					
Difficulties to obtain subsidies for environmental improvement					
Lack of collaborative partners					
Too much competition in the market					
Lack of customer interest in the environment					
Commitment of the organization's leaders					

Appendix 4. CLASSIFICATION OF THE FACTOR-DESCRIBING CHARACTERISTICS ACCORDING TO THEIR FULFILLMENT REQUIREMENT AT EACH MATURITY LEVEL.

Factor	No.	Characteristics	Level 1	Level 2	Level 3	Level 4
Environmental knowledge management	1	Employees are considered to have a high level of environmental management knowledge.	0	0	0	1
	2	Sufficient human resources are available for environmental knowledge acquisition.	0	1	1	1
	3	Sufficient financial resources are available for environmental knowledge acquisition.	0	0	1	1
	4	Sufficient technological resources are available for environmental knowledge acquisition.	0	0	0	1
	5	Sufficient physical resources are available for environmental knowledge acquisition.	0	1	1	1
	6	Employees are trained on environmental care.	0	1	1	1
	7	Environmental training is conducted on a monthly, bimonthly or trimonthly basis.	0	0	0	1
	8	Environmental training is conducted every six months.	0	0	1	0
	9	Environmental training is conducted on a yearly basis.	1	1	0	0
	10	Adequate channels are offered for the employees to present environmentally innovative ideas.	0	0	1	1
	11	The employees use Environmental Training to improve production processes.	0	0	1	1
	12	The company has documented its operative processes	0	0	1	1
	13	The employees are well-informed about the environmental impacts caused by the organization and their corrective measures.	0	1	1	1
	14	Environmental sustainability is part of the central strategy of the company and is among the first priorities on the agenda.	0	0	0	1
	15	Environmental sustainability is relevant for some parts of the company agenda, but not for all of it.	0	0	1	0
	16	Environmental sustainability is not among the priorities of the company agenda, but has some importance	0	1	0	0
	17	Environmental sustainability is not relevant for any activity on the company agenda.	1	0	0	0
Environmental practices and strategies	18	The employees understand the topics involved in environmental eco-efficiency and cleaner production.	0	0	0	1
	19	The Company has an environmental practice plan or program.	0	0	1	1
	20	The employees understand the topics involved in circular economy.	0	0	0	1
	21	The company has established a plan to report outflows, such as liquid substance spills, gas leaks, gas-liquid mixtures and other non-eco-efficient situations.	0	0	1	1
	22	Environmental practices have been implemented.	1	1	1	1
	23	A water saving and efficient use program is in operation.	0	1	1	1
	24	A solid residue collection and classification program is in operation.	1	1	1	1
	25	The company verifies the final disposal of hazardous residues (corrosive, reactive, explosive, toxic and flammable waste).	0	0	0	1
	26	Employees tend to reuse office stationery materials.	1	1	1	1

Factor	No.	Characteristics	Level 1	Level 2	Level 3	Level 4
	27	Treatments to extend the use of industrial resources, such as oils, lubricants, acids, etc., are in force.	0	0	1	1
	28	The products that the customers no longer use are recovered.	0	0	0	1
	29	An after-sales repair service to extend the useful life of products is in force.	0	0	0	1
	30	Noise level measuring systems are in operation.	0	1	1	1
	31	The company keeps a statistical record of power and water bills.	0	0	1	1
	32	Environmental purchasing criteria are in place in the selection of suppliers.	0	0	0	1
	33	The suppliers comply with the environmental laws in force.	0	1	1	1
Management systems	34	Employees have knowledge of environmental management systems.	0	1	1	1
	35	An environmental management system is in operation.	0	0	0	1
	36	The Company has been environmentally certified.	0	0	0	1
	37	An environmental policy is currently in force.	0	1	1	1
	38	The main environmental policies and legislation established by the government that have to be applied within the company are clear.	0	0	1	1
	39	The company makes use of operating environmental indicators.	0	0	1	1
	40	Manufacturing or service delivery processes and environmental practices are related to decision-making support.	0	0	1	1
	41	An Enterprise Resource Planning (ERP) system is in operation.	0	0	1	1
	42	The company has an HSEQ (Health, Safety and Environmental Quality) module for strategy control in its ERP systems.	0	0	1	1
		Total fulfilled characteristics	5	14	27	37