DESIGN OF A STRATEGIC MANAGEMENT MODEL FOR RESEARCH IN INSTITUTIONS OF HIGHER EDUCATION

FINAL REPORT

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Public Policy Modeling and Simulation

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DECLARATION

I hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of my own independent work.

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September 2022

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I dedicate this work to God, my parents, Tomás and Borlita for their unconditional love and support.

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PUBLICATIONS ASSOCIATED WITH THIS RESEARCH

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3. "***Evaluation of the Impact of the Colombian Scientific Productivity on the Fulfillment of the Sustainable Development Goals***" was published in: Journal of Environmental Management Tourist (2022) Vol. 23 No 5 (61) 1512-1519, See result 3. The Journal where the publication was made is integrated in Scopus Q3. Available in: https://journals.aserspublishing.eu/jemt/article/view/7220
4. ***Technological surveillance and strategic intelligence model. Book product of the research. (2020)*** Book ISBN:978-958-782-318-9. Integrated in BCI. Avaible in: https://repository.usta.edu.co/handle/11634/28934
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6. ***University governance research experiences in Latin America (2020).*** Book ISBN: 978-958-782-403-2.
7. ***Modernizing institutional management of research and innovation in the Andean region and Latin America*** **(2021)- Mimir Andino.**

1. INTRODUCTION

This study focused on how to design a strategic research management model for higher education institutions based on institutional capacities and the local, regional, national, and international context.

Knowledge and information are currently considered the most valuable resources and the fundamental drivers of a country's social and economic development (1). Research as an activity directed fundamentally to the generation of new knowledge, technological development, and its transfer is gaining increasing relevance, particularly in the context of the higher education systems of the countries, in the UNESCO forum on higher education it was recognized that: "*the knowledge generated by research is the basis for sustainable social development*"(2), likewise, in the forum of Rectors held within the framework of the Summit of the Americas it was emphasized that: "*the university must collaborate with the State and the productive sector for the necessary and urgent advancement of economies limited to the exploitation of natural resources and extractive tasks towards knowledge-based economies, and effective mechanisms must be generated so that the human resources of the universities are available and support innovation in the public and private sectors, promoting applied research to contribute to solving the needs of the people*" (3).

Thus, universities have a fundamental place and role in the generation of new knowledge and its production, expressed in one of the missions or substantive functions recognized for higher education institutions (4, 5). In this regard, it is assumed that society is increasingly directed to be based on scientific knowledge, making higher education and research an essential part of cultural, socioeconomic, and environmentally sustainable development (6-8).

Research as a university function began in higher education institutions in the 19th century, with the main function of guaranteeing the development of society (10), focused both on the production of scientific and technological knowledge and on the training of researchers(6, 11) and is defined as a process of searching for new knowledge characterized

by creativity, innovation of ideas, rigorous methods used and the validation and critical judgment of peers (9), while its purpose is to discover new scientific, artistic, technical and technological knowledge.

Currently, regarding the value given to research as a substantive function, Brunner and other authors mention that: "*The need to develop a capacity to generate knowledge in society and the growing incorporation of research in the university lead to a clear pressure to give greater importance to the academic function of research, compared to the other two basic functions of the university: teaching and extension*" (11-13), thhighlighting the fact that there is a tendency to focus on the reciprocal link of the substantive processes from and towards the research process(14).

In this regard, Monta, et al. (2013) mention that: "*the function of research in universities is fundamentally the generation of knowledge with potential application to the solution of environmental problems, the training of professionals with scientific culture and analytical criteria to analyze and intervene in reality, as well as to provide critical analysis to the dynamics of the environment*" (17).

Thus, it is currently an increasingly common trend to give greater relevance and significance to the research function in the context of university functions. It is important to point out that this recognition is taking place in the context of the so-called narrowing of the knowledge gap and access to opportunities in regions, countries and social sectors (13-14). The United Nations (UN) report on the Sustainable Development Goals shows that although research and development expenditures have increased and now represent 1.7% of GDP worldwide, developed countries invest almost 2.4% of their GDP in this activity, while in developing countries it is only 0.3% (2016: 29). Thus, the report recognizes that: "Even the poorest nations require research capacity or access to research results to progress, and support for research development in these contexts is more urgent than ever" (1, 2, 15).

However, despite the recognition of the importance of research for social development, there are contradictory positions regarding the development of the research function, as was pointed out at the World Conference on Higher Education in 2009 when it was identified that: "*Complex research is conducted in universities, in an environment where*

there is pressure to commercialize knowledge and the need to do so, but at the same time there is pressure in the opposite direction to treat the production and dissemination of knowledge as a public good" (5).

The trends of massification, diversification, globalization and financial restrictions of higher education make the management of higher education governance, processes and procedures increasingly complex, which also includes the management of research, which is approached from diverse and sometimes contradictory perspectives (18).

It is essential to point out that in the context of globalization and the predominant neo-liberal ideology it has been stated: "*The global higher education market is structured in two tiers: the super-league of global research universities that are oriented more by prestige and power than by economic gains as such; and a larger group of institutions of lower status involved in the commercial exploitation of higher education, where the mode of development is expansionist capitalism*"(19). This situation poses a scenario of research interest for developing countries, where systemic understanding and strategic management of research are essential elements to ensure the social welfare of the people. At the UNESCO Forum dedicated to the analysis of trends in the development of higher education and research, it was concluded that the most likely current trends are to widen or maintain the gap between higher education and research between the most economically developed countries and the majority of developing countries (1).

Likewise, tensions are generated in the understanding of the role of research development, where it has been recognized that: "*Although science and technology have been oriented to the reproduction of capitalism, through the creation of a reserve workforce with soft technification and the commercialization of university research, it can also be a vehicle for building a society with other values, practices and objectives*" (16). Thus, the orientation taken by the function of research in higher education institutions will depend, to a great extent, on the understanding of the system for the establishment of policies based on approaches that value the production and effective transfer of knowledge for social development or are limited to its commodification (16).

In this way, and as a function of social progress: "*Today, more than in other historical moments, reflecting on the problems of science in university institutions implies putting on the table at the same time the central challenges and those to be assumed by society*"(6). This connection between social development and scientific and technological development, particularly promoted by universities, is an inalienable part of the relevance and role of higher education institutions (20).

Analyzing the trends and perspectives of the research function in universities, closely linked to the challenges of today's society and the improvement of its management, it is important to consider the articulation between economic agents, social actors and researchers; the need for renewed internal structures; university autonomy in relation to external sources of research funding; the precision, updating and dynamics of university research policies and priorities; the legitimacy and social relevance of lines of research; the institutional channels and forms of dissemination, transfer and application of knowledge and innovation; among others (2, 12, 15, 18, 21, 22).

From the perspective of university social responsibility, seen as a new philosophy of ethical management for universities, the three traditional substantive functions of the university are differentiated with respect to its four basic processes "*from the trilogy to the quartet": education, research, extension and management, and it is emphasized that: "university management is not simply a technical matter of support for the rest of the academic functions, but is part of the academic function of the university precisely as a constituent element of the social function of the university*" (23).

In this context, it is essential to understand that an updated approach to scientific research implies not understanding it as a functional activity of the university separate and independent from the others but analyzing it in its integrality as part of the process of creating new knowledge and technologies (24). Thus, the idea is shared that research management in universities has the objective of strengthening and articulating research, development and innovation activities in different contexts, promoting cooperation among researchers, research groups and institutional networks (17).

In relation to this, at the global level, a group of experts gathered to discuss the future of the role of research in higher education concluded that: "*thoughtful leadership, oriented towards planning for the future, and a sustained commitment to the fundamental mission of research in higher education are key ingredients for policy formulation and implementation, and will be needed more than ever in the coming years*" (24).

A study on the development of the research function, particularly in Latin American universities, pointed out that the future research model will be based on cooperation and will be supported by networks and open knowledge management systems (25), which is closely linked to the management of this activity to achieve its effective operation and improvement(8, 16, 23, 25, 26).

On the other hand, the World Conference on Higher Education defines strategic management as: "the specific ways in which the university organizes and conducts itself to achieve its essential purposes" (7), and is conceived as the process of planning, organization, implementation, control, improvement, and evaluation of university processes in an integrated manner, aimed at increasing their quality, achieving excellence and satisfying social demands (14).

The conference noted that: "the ultimate goal of university management should be the optimal fulfillment of the institutional mission by ensuring high-quality teaching, training and research, and by providing services to the community. This goal requires leadership that combines social vision, including an understanding of global issues, with effective management skills" (21).

It is important to point out that studies on university management have recently approached it from the most varied angles and perspectives, ranging from the democratic participation of the university community in management (24), through its improvement based on reengineering processes(3); to social responsibility in this field(27) and the relevance of strategic information systems (28), among a wide range of edges. Such approaches show the extensive and diverse field of problems and theoretical perspectives from which the deepening of the analysis of university management is approached today, providing interesting contributions and showing the diverse positions that reveal the

complexity of this phenomenon and its theoretical, socio-political and contextual referents of study(29).

Currently, university management, and in particular university governance, is contextualized by a scenario characterized by the strengthening of the State, which reaffirms its central role in defining the objectives and modalities of articulation and development of the university; the rise of so-called university management(14, 26), which generates a strong tension between the academic legitimacy of decisions and the legitimacy provided by the economic profitability of knowledge; the institutionalization of new actors or stakeholders in practically all issues of university life; the rise of entrepreneurial leadership, which generates tensions with respect to exclusively academic leadership; the decline of the academic class in decision-making and the increase in the presence of political and economic powers in the university; and the dilemma of academics between joining the new trends in university government or reclaiming the nature of academic work and asserting their knowledge in institutional decisions (24).

In the analysis and improvement of university research management and in a scenario of new trends in universities, it is stated that managerial approaches and procedures predominate in university management (29) and the need to modernize the organization and management of universities, aimed at meeting the new demands of society to provide relevant knowledge, offer proposals and participate actively in the life of the countries, is highlighted (30).

For several years, studies of university research management have focused on the development of research models and systems for higher education institutions (17); analyzing from good practices in university research management and their expression in international university rankings (18); to the improvement of research resource management based on computer programs (31).

The growing importance of higher education and the scientific research generated therein, as an indispensable ingredient and condition for the promotion and achievement of sustainable development, points to and demands attention and improvement of the

management of this essential and increasingly relevant substantive function of higher education institutions, in order to make it effective and improve its performance (14).

At the same time, diverse and sometimes conflicting approaches and theoretical and ideological perspectives are evident when analyzing the complex processes of university research and its management. Awareness and clarity in this regard are prerequisites for assuming and implementing successful models and mechanisms for university management in today's world (18).

The improvement and effectiveness in the management of university research, particularly in Latin America, should have as guidelines or directives the consideration of aspects such as: overcoming the model and the narrow conception of the university centered only on teaching, rejecting the mercantilized approach, and practice of the university and its functions as an object of profit, effectively prioritizing the need and relevance of university research and its management, responding to the genuine interests of the social sectors associated with the progress of society and its majorities, as well as being sustained by a rigorously scientific and consistent understanding of the function of university research and its management(8).

All of the above leads us to consider that the complexity of today's society, of research activity, and of universities as organizations increasingly demands the need to strategically manage university processes in general and research in particular(13), which requires a systemic understanding of the process and the development of research projects that provide elements of strategic research management in terms of planning, organization, control, improvement, monitoring and evaluation, aimed at increasing its quality, achieving excellence and satisfying social demands(13).

Thus, this research aims to answer the following question: ¿How to design a strategic research management model for higher education institutions based on institutional capacities and the local, regional, national, and international context?

This research sought to propose a model of strategic management of research in higher education institutions that responds to the global challenges of generating new knowledge with social relevance and in scenarios of sustainability, contributing to the generation of

new knowledge, proposing innovative methodologies that contribute to the management of research, to the construction of public policies and that provide elements to higher education institutions to guide the university function in research, which is particularly relevant in the achievement of institutional goals and in regional and national social transformation, contributing to the fulfillment of the objectives of sustainable development.

For this purpose, the following objectives were established to guide the development of the research;

General Objective

To design a strategic research management model for higher education institutions.

Specific Objectives

SO1. To analyze the world academic production in "strategic management of research in higher education institutions" based on a comprehensive search of articles in electronic databases and bibliographic tools.

SO2. To design a methodology that provides elements of strategic research management taking into account the national and international context.

SO3. To build a model of strategic research management based on the analyses carried out to improve decision making in Higher Education Institutions.

In order to comply with specific **objective 1**, a systematic review of the literature was carried out, that is, a structured process of approaching the literature on "strategic management of research in higher education institutions", based on a comprehensive search of articles in electronic databases and bibliographic tools; specifically, the systematic review of the literature was carried out in the following tools: Google Scholar, Scopus and Web of Science, search equations were generated, analysis of the results obtained and narrative reviews of the selected articles. These findings were published in the article entitled: "***Scienfic Reasearch Procedure and Methods used for the support of scientific articles" in the Journal of Positive School Psychology, Vol 6 No 6 of 2022***, see Results 1. The journal in which the publication was made is categorized as Q2 in Scopus. (Available in: https://www.journalppw.com/index.php/jpsp/article/view/8477).

In compliance with **objective 2**, a technological surveillance model was constructed for the strategic management of research in Higher Education Institutions in Colombia. The model was composed of a scientific information system, from which algorithms were generated for information processing using automatic text analysis techniques and natural language processing using complex networks to detect patterns and the configuration of trends related to science, technology and innovation. As a result of the analysis, the article entitled: *"**Construction of a Complex Network Using Technological Surveillance for the Strategic Management of Science, Technology, And Research in Higher Education Institutions in Colombia**"* was published in Turkish Journal of Computer and Mathematics Education Vol.12 No.14 (2021), 1185- 1197, which is presented as Result 2. The Journal in which the publication was made is integrated in Scopus Q3. Available in: file:///C:/Users/olgao/Downloads/10407-Article%20Text-18540-1-10-20210810%20(5).pdf

Once the national context was analyzed in relation to the academic production of researchers of Colombian Higher Education Institutions in relation to the policy documents of Science, Technology and Innovation in the country, an instrument was developed for the evaluation of the contributions of the Colombian scientific production to the fulfillment of the Sustainable Development Goals, configuring a set of national and international Science, Technology and Innovation repositories, a model of topics was built and evaluated with indicators of perplexity and coherence. The article entitled: "***Evaluation of the Impact of the Colombian Scientific Productivity on the Fulfillment of the Sustainable Development Goals***" was published in: Journal of Environmental Management Tourist (2022) Vol. 23 No 5 (61) 1512-1519, See result 3. The Journal where the publication was made is integrated in Scopus Q3. Available in: https://journals.aserspublishing.eu/jemt/article/view/7220

Finally, the inputs generated from the fulfillment of specific objectives 1 and 2 made it possible to propose a research management model for higher education institutions.

2. SCIENTIFIC RESEARCH PROCEDURE AND METHODS USED FOR THE SUPPORT OF SCIENTIFIC ARTICLES

Abstract

This paper addresses the issue of the state of the art where it describes the various procedures that serve researchers when conducting scientific research, where its purpose is to publicize the applied research method with which it supports all the information collected from various academic sources to address the specified topic, thus giving an approach to the tools and methods used for the realization of articles with a scientific character to have a significant impact on the various academic levels to which they are directed as well as to the scientific community itself.

Keywords: Article, Study, Research, Process.

2.1 Introduction

This section describes, step by step, the procedure that was carried out to identify the key studies that give line to the scientific contribution of this research. The literature review procedure to identify these studies, the way they were selected, the results achieved in the review, the way in which the content of the articles was reviewed and the narrative review that derives from this process are described here.

2.2 Literature review: procedure

In this research, a systematic review of the literature was carried out. This means that a structured process of approach to the literature on "strategic direction of research in higher education institutions" was carried out, based on a comprehensive search for articles in electronic databases and bibliographic tools.

Specifically, the systematic review of the literature was carried out in the tools: Google Scholar, Scopus and Web of Science. This choice was based on the fact that these tools cover most of the relevant literature in the field of study with which this research is associated. Finally, it should be noted that this review focused on theoretical and empirical contributions produced during the period between 1995 and April 2020. The choice of this

period is based on the fact that, in the mid- 90s, the strategic role of universities, based on their research results, began to stand out (Koschatzky & Stahlecker, 2009).

2.3 Search equation

In the tools to search for relevant articles, an electronic search was carried out oriented by the key terms that derive from the thematic interests of this research. In addition to this, multiple combinations of the terms that relate to the phenomenon of: "strategic direction of research in higher education institution" were used. Table 1 presents the combinations of terms used in bibliographic tools. It is important to note that the equation was executed only in the English language, given the tradition that universities in developing countries have in transforming the research process into a strategic capacity that allows them to differentiate themselves in the market.

Table 1. Combination of terms defined for the execution of the search equation

Combination of terms	
Strategic management	Scientific research in universities
Strategic	Research in universities
Strategic planning	Research in higher education
Strategic plan	Scientific research in higher education

Source: own elaboration.

Shows how the combination of terms was applied in the bibliographic tools. Finally, the review produced a total of 18

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( TITLE-ABS-KEY ( "Strategic management " OR "Strategic" OR "strategic planning" OR "strategic plan" ) AND TITLE-ABS-
KEY ( "Scientific research in universities" OR "Research in universities" OR "Research in higher education" OR "Scientific research
in higher education" ) ) AND PUBYEAR > 2009
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Figure 1. Search equation editing. Source: Scopus, 2020.

2.4 Results of the systematic review of the literature and selection of studies

The application of the search equation resulted in 87 articles. From this total, those articles that did not have a relationship with the "strategic direction of research in Higher Education Institutions" were eliminated. Articles that address topics that deviate from the study phenomenon of this research were excluded, such as:

. Articles on strategic management in private companies.

. Articles on strategic direction in the education sector in general.

. Articles on quality management in the education sector.

. Theoretic_-Articles on strategic management in public and private companies.

. Articles on strategic human resources management.

. Articles on innovation and research and development, which are not addressed in the framework of higher education.

. Articles that are directly related to the "strategic management of research in higher education". This means that the proportion of useful articles in the review was 20%. This relationship, as a basis for the inclusion of the selected articles, has to do with aspects such as:

- Research as a strategic capacity of universities.

- Alignment of research efforts with the strategic objectives of Higher Education Institutions.

- Strategic problems of Higher Education Institutions, which include problems in improving research.

- Strategic knowledge management in Higher Education Institutions.

- Aspects that affect the strategic development of research in Higher Education Institutions.

- Strategic planning of research in Higher Education Institutions.

- Strategic impact of research in the environment surrounding the University.

- Strategic alliances to strengthen research from higher education institutions.

Procedure for the analysis of articles obtained through literature review

In principle, a detailed reading of each article was carried out. Then, to shape the state of the art, three key elements were extracted from each article: the main purpose-objective,

the methodology (in general terms) and its most important findings. These three elements account for the trends that, at the research level, the analyzed literature has. In addition, they allowed to construct the narrative review that derives from the systematic review of the literature, which is presented below.

Narrative review

This section presents the narrative review that resulted from the process of systematic review of the literature. Contributions to the literature on "strategic management of research in Higher Education Institutions" are presented in a chronological order.

Taylor and Karr (1999), in their article, present a qualitative approach study in which they interpret interviews conducted with 9 universities with a research orientation. This was intended to better understand the strategic problems faced by these institutions and how they should do risk management to achieve excellence. The researchers found that efficacy and excellence must go far beyond restrictive strategic planning, especially when it comes to research. As a recommendation, which results from the study, Taylor and Karr suggest that a holistic view of strategic management in universities should be chosen, including the direction given to research. This arises because the strategic direction of universities overlooks problems of the environment that could be solved through research, if the latter is raised from a strategic direction.

Ziegel and Zervos (2002) present a taxonomy of strategic alliances to promote research, involving universities, for-profit and non-profit organizations and government agencies. Based on this taxonomy, the researchers analyze whether partnerships generate a positive impact on the financial performance of the organizations that participate in them. However, they found that assessing the strategic impact of strategic alliances is not possible, given that it is a complex process that requires the collection and processing of data from various dimensions of analysis. From the perspective of the University women, Ziegel and Zervos emphasize that implementing a strategic direction of research must be based on choosing the right alliance.

Castellanos, Rodríguez and Ranguelov (2004) identified in their study the types of knowledge that act as a support for intellectual capital in a sample of public universities in

Spain. Thus, according to the strategic objectives of the universities investigated, the types of knowledge are identified. This process was carried out through in-depth interviews with the managers and research leaders of the universities under study. As a result of the study, it was found that public universities in Spain carry out a process of strategic direction of research, which affects the improvement of their intellectual capital and, therefore, their competitive advantages.

Atkinson and Blanpied (2008), in their study, illustrate the development and evolution of American research universities. In particular, the researchers argue that they are a recent innovation, which were affected between the 1940s and 1950s by the low state funding for the development of research projects. However, the authors found that, by 1970, the federal government increased financial support for universities, which was key in the flourishing of American university research. Likewise, this support in turn led to a decrease in support per

U.S. industry. Finally, the authors, in their analysis, found that, strategically, the growth of American research was a result of cooperation between universities and industry. In general, the authors point out that this cooperation is an essential variable for a university institution to be at the forefront in the process of knowledge generation.

Serrano (2011), theoretically, states in his article that the conditions of globalization of the new millennium affect the redefinition of the research strategy of universities. However, the author states that universities do not have well-designed research strategies, so they are usually very limited. Therefore, in the article the author describes how to design strategies for research according to the key actors involved. Basically, Serrano argues that universities, to be leaders in research, must strategically improve their ability to attract researchers, improve infrastructure and make alliances with other organizations. In this sense, the author suggests that the way to strategically direct research in universities should follow the paradigm of resources and capabilities. Serrano argues that this consists of directing the research of universities according to the strengths of their researchers and research programs.

Marimón (2012) conducted a study on improving the impact of extension and research on

higher education in medical schools in Cuba. Through a qualitative research approach, it was found that both areas are key in creating competitive advantages for Universities. The results of the research, obtained by Marimón, warn of the importance of continuing with the development of scientific research from a strategic perspective, since it is what allows a Higher Education Institution to generate resources from the extension.

Arveson (2012), in his research, notes that universities and scientific research laboratories are more often faced with densely structured challenges, such as climate change, healthcare, and solutions to improve the performance of organizations. Faced with these challenges, research must be oriented from a strategic perspective, if it is to generate an impact on society. This is why Arverson suggests that universities should make use of conceptual tools such as strategic maps to establish how research efforts will be aligned with the strategic purposes of such institutions. Under this approach, it is possible to create visible and measurable strategies for research processes. In short, strategic mapping helps research leaders make strategic decisions and implement them successfully.

Reddy, Xie and Tang (2016) made a comparison of educational performance between universities in India and China. Within the comparison process, the research capacity of these universities was added. The researchers found that universities in both countries have established research as a process that has strategic objectives. The comparison was based on a bibliometric analysis process. Finally, the researchers suggest that the variables that have the greatest impact on research becoming a strategic asset of universities are: the search for funding, the realization of collaborative projects with both public and private institutions, and the definition of practices and quality standards for the development of research. An important finding of the research is that the Universities of China have research processes in place that, from a strategic point of view, surpass the Indian Universities.

Duan and Deng (2016) assessed the strategic efficiency of 36 Australian universities from 3 perspectives: administrative efficiency, teaching capacity and external research impact. The authors found that universities do not understand what the process of improving their strategic efficiency looks like. Additionally, they suggest that the research process makes

universities more competitive within the education sector, as long as the resources for this process are channeled appropriately.

Barbón-Pérez and Fernández-Pino (2018) Conducted a study on the harmonization of strategic practices in higher education in Ecuador through the integration of knowledge management, science, technology and innovation. The researchers argue that this strategic approach is barely introduced in the universities of Ecuador. To achieve such harmonization, universities, through their knowledge generation processes, are required to produce new opportunities that facilitate the strategic management processes of universities. Finally, the authors propose that, from the key strategic processes of universities, a strategic culture can be created regarding the generation of scientific knowledge.

Mejía-Correa, Vesga-Vinchira and Gaviria-Velásquez (2018) designed in their study a strategy for the management of scientific knowledge at the University of Antioquia, in Colombia. According to the authors, universities that emphasize research should have a strategy for managing scientific knowledge. This should allow the generation of competitive advantages and a better positioning within the fields of knowledge in which they specialize. To achieve a greater strategic impact of the research, the authors propose that three knowledge management tools should be deployed: measuring the level of maturity, identifying knowledge gaps and building knowledge maps. The results of this study showed that knowledge management tools are key to the generation of a strategic direction of research at the university that was a case study.

Mezhouda (2019), in its article, explores the implementation of strategic research planning in Algerian university institutions, from the perspective of an integral management that allows anticipating potential changes in the environment in which these institutions operate. This exploration is carried out by the author focusing, especially, on the strategic planning of the research, which must be aligned with the strategic model of the University, its strategic objectives and key institutional projects. Mezhouda found that research planning is a key resource for universities, improving their performance and achieving their strategic goals. However, this is not an easy task, since research must have great capacity to adapt to the problems of the environment.

Castro and Ion (2019) carried out a review of the literature to set the research agenda regarding the analysis of the perceptions of the new university approach, focused on research and the consequences it produces on the professional development of academics from universities of high production in research in Spain. The authors, in the review, indicate that the current university model is defined by changes in institutional functioning, in the appearance of new structures and in the need to generate economic resources for scientific production. Thus, as a final result of the literature review, Castro and Ion affirm that this university approach, focused on research, leads to a change in the functions and autonomy of academics, which is characterized by approaching research programs from a strategic perspective.

Also as a result of the systematic literature review carried out in this study, Muneeb, Tehseen and Saeed (2020) analysed the influence of dynamic capabilities, operational capabilities, network targeting, social media and supervisory support on the research productivity of PhD students from Malaysia and the UNITED Arab Emirates. In relation to the above, the authors concluded that the aforementioned dimensions have a positive influence on the productivity of doctoral students. However, the authors stress that the influence was stronger in the Malaysian sample than in the UAE sample. Thus, as a general result, Muneeb, Tehseen and Saeed suggest that, although there is a positive influence of these characteristics on research productivity, it should be strengthened from the dynamic capacities of doctoral students in terms of improving their ability to manage knowledge. However, this finding is important, since dynamic capabilities are essential to generate changes in any activity that wants to seek novel strategic results (Teece, 2019).

From another analysis perspective, Wilkins (2020) analyzed the market segmentation process using a strategic group analysis of higher education institutions in the UAE, with a strategic approach to market and competition analysis. This process is used by higher education institutions to gain recognition and positioning. Strategically, the author analyzed the segmentation process in public and private institutions, as well as in elite and specialized institutions. By focusing on these types of institutions, Wilkins concluded that the accreditation of institutions and programmes of this type is of paramount importance

in the UAE university market. Another important finding of this study is that the research carried out by these institutions also responds to the needs of the segments where they seek student enrollment, which is part of the design of their competitive strategies.

Reddy and Murty (2020) found through their study that research requires a certain environment and opportunities for it to have a strategic impact. Therefore, the authors suggest that those in charge of managing research processes should give it a strategic approach, so that university resources can be used effectively (infrastructure and processes). In this sense, Reddy and Murty that both new and experienced researchers must align their efforts with the demands of the environment, which means that they must be used by universities as strategic resources.

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3. CONSTRUCTION OF A COMPLEX NETWORK USING TECHNOLOGICAL SURVEILLANCE FOR THE STRATEGIC MANAGEMENT OF SCIENCE, TECHNOLOGY, AND RESEARCH IN HIGHER EDUCATION INSTITUTIONS IN COLOMBIA

Abstract

This research proposes the construction of a model of technological surveillance for the strategic management of scientific research in higher education institutions in Colombia. This model is composed by an information system that includes scientific articles, intervention plans for the regions and the nation, and information from public policies related to Science, technology, and information (STI). From this data set, the construction of algorithms for information processing was carried out, using techniques of automatic text analysis and natural language processing with complex networks to detect patterns and the configuration of trends related to science, technology, research, and innovation, which are the guiding topics of the national science and technology system. The main results obtained in this research are that the construction of a complex system revealed the topics on which scientific production is focused in the country. In addition, the analysis of the documents related to STI referenced in in public policies analyzed for this research revealed the pressing needs of different sectors and regions in the country. Finally, the research showed that the topics on which scientific research in Colombia is conducted by the educational institutions of the country does not correspond to the needs found.

Keywords: Technology Surveillance, Scientific Research, STI, Innovation, Management.

3.1 Introduction

The pressing requirements of various productive sectors in Colombia have revealed a growing need to increase the participation of science, technology, and information (STI), as well as research, development, and innovation (R+D+i) as key factors to find solutions to the country's problems. Faced with this urgent need, public and private organizations demand the construction of strategic approaches that allow directing the work of scientific research towards solving the issues identified by the most important stakeholders of the National System of Science, Technology, and Innovation of Colombia (SNCTI in Spanish).

In this context, the construction of tools and mechanisms that allow the early detection of elements that facilitate the construction of strategic approaches is a priority. This is why technological surveillance becomes an important tool for organizations. According to Leon (2006):

Technological surveillance (TS) is a concept inherent to technology management (GT), which involves processes of planning, directing, controlling, and coordinating development and implementing information to understand and anticipate technological changes, making an early detection of events that represent potential opportunities or threats.[1] (p. 93)

According to the definition above, technological surveillance has a diversity of elements that can be synthesized in the following areas (Palop & Vicente, 1999):

. Passive surveillance (scanning): Detects information that is important to the objectives or goals of a company.

. Active surveillance (monitoring): Directs strategies to promote capacities and knowledge to the organization from the results of the surveillance related to topics that are objective for the organization.

. Watching. It is a system that articulates the two areas above, as well as the popularization of the information obtained from the surveillance.

In particular, the last two areas (active surveillance and watching) are important to produce improvement alternatives related to the competitive and strategic intelligence of the organization, generating value processes from decision-making.

From this perspective, the sources of information are key assets to fulfill the implicit objectives in the previously mentioned areas. Regarding technological surveillance for STI, repositories and other scientific, academic and research popularization media are essential resources. A large part of these volumes of information and popularization media have chosen to maintain open access policies, which facilitate their analysis, accessibility, transformation, and manipulation. Some of these works present relevant information on

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"Technology watch (TW) is a concept inherent to technology management (TM), which involves processes of planning, directing, controlling and coordinating the development and implementation of information to understand and anticipate technological changes, making early detection of events that represent potential opportunities or threats."

indicators of the dynamics of STI in the country (Zhu et al., 2013) and the companies (Liu et al., 2013).

Scopus, and Web of Science (WOS) stand out among the most important STI and R+D+i repositories. They are bibliographic databases that have allowed researchers to create technology surveillance models (the scanning and monitoring paradigm specifically) related to scientific, technological, humanistic, and sociological aspects using bibliometric indicators obtained through analyzing complex networks. (Zhu et al., 2013; Liu et al., 2013; Liu, Yu, Guo, & Sun, 2014; Liu, Yu, Guo, Sun, & Gao, 2014). Building complex networks using sources related to STI has even made possible the generation of public policy instruments. Such is the case of Kash and Rycoft (2000), who, while representing complex systems using networks, analyzed innovation, development, and technology patterns and trends. In addition to their findings, Kash and Rycoft built indicators to evaluate the effectiveness of public policies on the stakeholders of the system, using the emergent self-organization of the interactions between science, technology, and innovation.

In this sense, the objective of this research is to build a model of technological surveillance to strategically direct research in higher education institutions in Colombia using bibliometric analysis techniques based on network theory. To fulfill this objective, this document presents two sections: in the first one, the construction of the information system is described, as well as the computational and statistical techniques selected to clean and pre-process the information to build the networks. In the second, the results of the construction of the information system are presented, including the respective units of analysis and technological surveillance that aims to reduce the existing gap between scientific research and the needs of the sectors, as well as strengthening scientific and research planning of higher education institutions in Colombia.

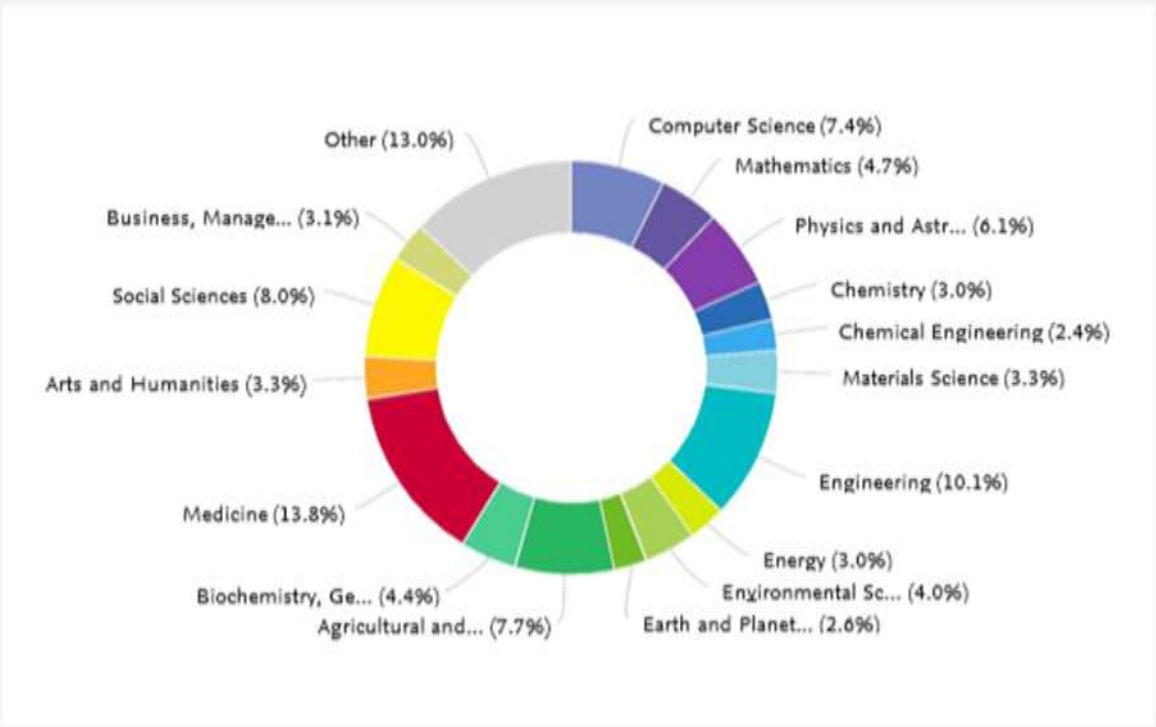
3.2 Materials and methods

Materials

For this study a data set containing information related to the behavior of STI in articles developed in Colombia and published in high-impact journals indexed in Scopus was constructed. The information included in the data set responded to keywords and

summaries found in the articles. Based on them, textual databases were generated. The scope of this research was limited by prioritizing publications made from 2016 to 2020. A total of 66,842 articles were retrieved and their areas of knowledge are presented in the portions shown in Figure 1.

Figure 1. Distribution by areas of knowledge of publications produced in Colombia between 2016-2020.



Source: own elaboration.

In addition to the sources described above, information from the Colombian context describing the main R+D needs in the different regions of the country were also included, as well as the public policies generated by the central government to promote and prioritize State resources to fulfill those needs. Such policies are conditioned by the intention of generating new knowledge, but they also seek to facilitate the production of instruments and tools that allow solving the main problems faced by the most vulnerable population groups. That is why this research included the construction of a textual database with

information related to documents related to STI referenced in public policies in Colombia. In the information included in this database the following topics stand out:

Sustainable bioscience.

Strengthening of the human talent training system.

Policy for the commercial development of biotechnology based on the use of biodiversity.

Green growth policy.

Tax benefits.

2020 Science, Technology, and Innovation Policy.

Methods

At present, building models based on scientific discourse, as well as scientometrics, bibliometrics and everything related to scientific popularization, uses quantitative-qualitative methodologies to recognize patterns, central themes, and feelings, among other morphological aspects of the information disclosed in different scientific repositories. In addition to these components, there are some conditioning factors related to the specificities of the language used (basic, technical, or specialized), the dynamics and the different relationships that can be built between its different units. For this reason, the analysis of scientific discourse must go beyond simple word, term, and concept counts. That is, building models requires multidimensional modeling approaches and formalisms that are useful to establish evaluations of the linguistic entities that are the components of the discourse as a unitary system. In this regard, complex networks become an ideal tool to achieve the a fore mentioned objectives.

Complex networks are graphs that are useful to build representations of systems (Estrada, 2021). The vertices or nodes of the graph are the entities of the system, and the edges are the relationships or interactions between these entities. According to Hu et al. (2008), most of the networks used for purposes similar to the one proposed in this research are called complex real-world networks, due to the number of interactions that their entities have. Typically, their interactions are not subject to random rules and, with this, properties such as emergence, evolution (an important indicator of dynamics), among others, can be quantified. In the last decade, this type of study has become an area with significant growth

in different disciplines in which the works of Grabska-Gradzińska et al. (2012), Molontay and Nagy (2020), Dorogovtsev and Mendes (2013) and Pastor-Satorras and Vespignani (2007) stand out. They have presented approaches that use complex networks to provide solutions to STI issues that are analytical, less reductionist, more holistic or systemic. In other words, the intrinsic elements of a complex network are useful to understand dynamics and processes. For example, the subgraphs of a network are subsystems or configurations of a complex system, and they generate quantitative evaluations useful for decision-making when they are complemented with physics and statistics tools.

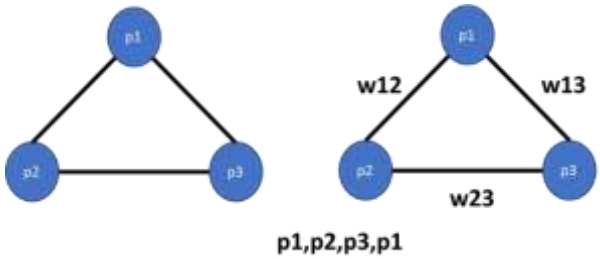
Language is one of the most wonderful tools developed by humans (Pinker, 2003; Bickerton, 2009) and recognizing emerging elements when building a model is a challenge that must be undertaken through complex networks, given the quality and effectiveness of the results obtained by various studies (Markošová, 2008; Mehler, 2008; Choudhury & Mukherjee, 2009; Borge-Holthoefer & Arenas; Solé et al., 2010; Baronchelli et al., 2013; Mihalcea & Radev, 2011; Biemann, 2012, Ferrer-i-Cancho 2005). In addition to these contributions, it is also helpful to keep in mind the definition of language provided by De Saussure, considered the father of modern linguistics (Palop & Vicente, 1999). According to him language is a system in which each linguistic unit is defined by, and only by its relationships (p.). This statement shows the usefulness of complex networks for the study of human language, especially when scientific results are popularized.

The definition of Beckner et al. (2009) is typically used to build complex networks using information collected from scientific popularization media: N=(V,E), in which N is the information network from the scientific articles composed by the entities or vertices that belong to V, and E is the set of edges or interactions that account for the relationships between the entities that comprised the article or scientific work. For the analysis of STI that is required for this type of study, Hu et al. (2008) and Estrada (2012) argue that the linguistic units to be considered should be words under the principle of co-occurrence. Co-occurrence networks (also known as collocation networks) are pairs of linguistic units in certain windows in the text that have a relationship of some kind, such as hierarchy, temporality, sequentiality, as well as other non-real elements (named this way because they

are interaction factors defined by rules or models external to the text such as statistical metrics, mathematics, among others).

In this research, the connectivity of the words will be determined by the sequentially they have in the documents included in the textual databases described in the materials section. This type of connectivity was chosen keeping in mind the results of multiple works (Ferrer-i-Cancho & Solé, 2001; Masucci & Rodgers, 2006; Zhou et al., 2008; Shi et al., 2008; Brede & Newth, 2008; Sheng & Li, 2009; Liang et al., 2009; Grabska-Gradzińska et al., 2012; Liang et al., 2012; Gao et al., 2014), in which it was possible to identify, using the topological measures of networks, key aspects of the discourse, such as central topics, research intentions, trends, among others. Those key aspects allowed the authors to learn the patterns of scientific publications in social communities around specific topics. For this reason, the co-occurrence network under the principle of sequentially used for this research is presented in Figure 2.

Figure 2. Principle of co-occurrence network construction for the analysis of discourse and human language.



Source: own elaboration.

In figure 2, p1, p2 and p3 refer to the words obtained from the keywords found in each of the selected articles and the documents referenced in the public policies related to STI in Colombia (materials section), and the edges refer to the sequential co-occurrence of the words in those sources of information. The frequency in which these words are found in textual databases are represented by w_{12}, w_{13} and w_{23}, and are grouped into the three categories mentioned in the materials section.

Once these networks were created (some generated from the scientific articles and others from the documents related to STI referenced in public policies in Colombia), the next step was to measure their properties and the intrinsic aspects that facilitate the emergence of

nodes, that is, the trends evidenced by the generation of new knowledge in Colombia. In accordance with the objectives of this research, the following metrics were selected:

Density

Degree

Assortativity

Modularity

. Density (Δ)

$$\Delta = \frac{2L}{n(n-1)}$$

Capacity for interaction among words, terms and concepts in the articles and documents related to STI referenced in public policies in Colombia.

Its dimension is between zero and one. The closer it gets to one, the more interaction the terms or concepts used in the document or discourse have.

L is the number of links and n is the number of nodes in the network, therefore n(n-1) is the maximum number of links that can exist in the network.

For this research, density will make it possible to assess the interaction or association of the words used by Colombian scientists in their academic production and the needs raised in the country by the Colombian science and technology regulatory bodies.

. Degree

Number of interactions the words or concepts related to STI in Colombian articles and policy documents have.

The higher the degree, the more important or frequent the word is.

The value of the degree in this research will allow evaluating the centrality of the word in the texts that belong to the analysis category. Thus, to define the fundamental pillars of each unit of analysis, the words with the highest degree in the network must be selected.

. Modularity

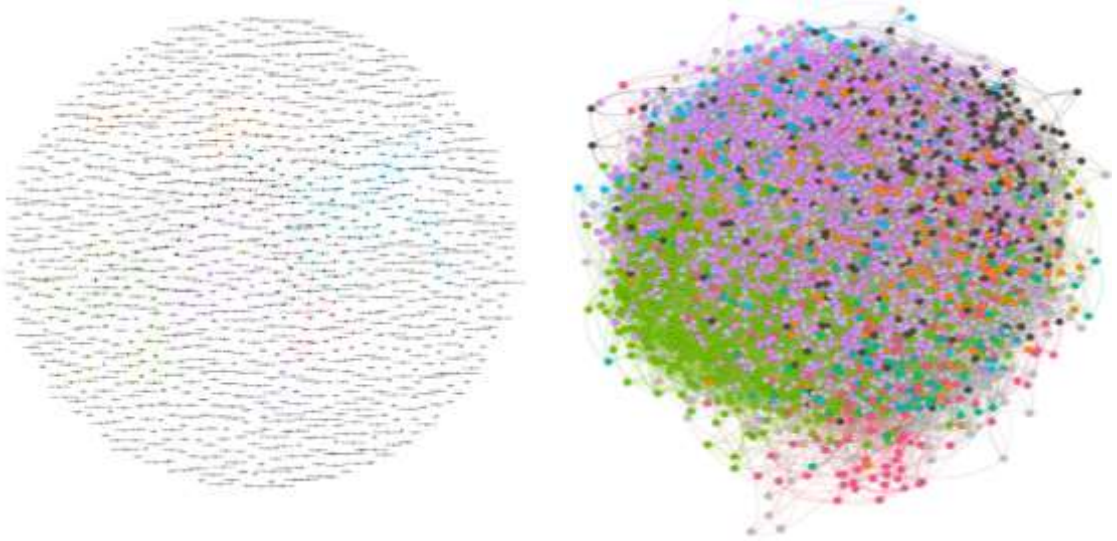
Modularity consists of dividing the network into subgraphs or groups of nodes called modules (or communities) which have strong interactions between them. The technique used to modulate the network was the modularity maximization algorithm (Newman,

2006), which seeks to obtain the maximum and most significant number of modules into which a network can be divided. From the systemic perspective, these subgraphs or modules are subsystems formed in the articles and the documents related to STI referenced in public policies in Colombia. Therefore, these formations are the units by which the most important words will be detected, in accordance with the proportion of nodes of that module compared to the entire network.

3.3 Results and Discussion

Complex networks were built using the scientific production of articles and the documents related to STI referenced in public policies in Colombia and are presented in Figure 3.

Figure 3. Co-occurrence networks of words and concepts found in Colombian scientific articles (1) and STI base documents (2).



(1) **(2)**

Source: own elaboration.

One of the first differences between the two networks built was size. This topological metric reveled the number of terms used in scientific discourse and by government entities that promote science resources and public policies. In the scientific articles 2623 words were found, while 9681 were were found in the documents referenced in the public policies. Out of the total of terms found, 2927 are strongly connected. Despite this similarity, density (Δ) reflects something different: the density of the network of the scientific articles is Δ_1=0.048

and the density of the network of the documents referenced in public policies is Δ_2=0.001. This result reflects that the words used in the scientific articles have more interaction with each other, compared to the terms in the documents referenced in the public policies. This finding is relevant since, despite the fact that the policies reflect that there are topics that are decisive to direct science in favor of meeting the country's needs, their words have little articulation. However, Δ_1 has a low value if the density range is considered. Thus, despite its difference with Δ_2 (the issue of little interactivity or synchronization of scientific topics developed in the country), it is necessary to detail with local measures the identification of the main topics of the network, despite the fact that the interaction of the global network is low. Keeping in mind the above, the assessment of the nodal degree was conducted and presented in tables 1 and 2.

Table 1. Nodal degree of the network of scientific articles published in Scopus between 2016-2021.

Word	**Degree**
Development	560
Sectors	310
Resources	306
Knowledge	234
Sustainable	214
Growth	213
Innovation	202
Green	189
Business	178
Biodiversity	176
Products	174
Processes	173
Energy	168
Services	148
Capacity	122

Word	Degree
Biotechnology	122
Productivity	108
Access	108
Technology	108
Transport	108

Source: own elaboration.

Table 2. Nodal degree of the network of documents referenced in STI public policies.

Word	Degree
Power	6077
Electric	6070
Distribution	4876
Networks, wind	3475
Power, electric	3475
Transmission	3475
Quantum	1966
Computer	1651
Health	1572
Converters	1536
Inverters, dc-dc	1536
Potential, electric	1536
Fuel	1266
Frequency	1251
Systems	1201
Supply	1196
Cells	1157
Pase	1104

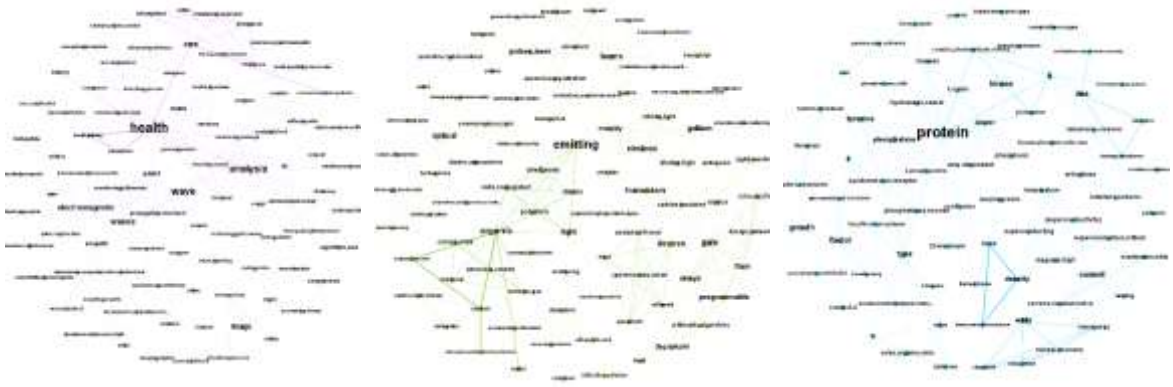
Word	Degree
Agents, infection, methicillin-resistant	1074
Aureus	1074

Source: own elaboration.

Tables 1 and 2 show the limited convergence of the main topics contained in the published research articles and the topics of the documents referenced in public policies for the promotion of science in the country. This divergence between the scientific research conducted by the stakeholders of the country's National Research System and the challenges demanded by the regions in terms of strategies to improve competitiveness has a profound impact on the operationalization of science to face such challenges. In other words, the research conducted in Colombia is focused on trying to address external needs that are more frequently visible in the high-impact popularization media, but do not cover the real challenges of the country. This approach evidences a systemic failure of the Government to articulate stakeholders in scientific research, resources, and policies.

Finally, this divergence is not only evident in the central topics of the reviewed sources, but also found in the driving factors of each one of them. In other words, although words such as development and growth are mentioned, the connectors are much more isolated than the strategic claims of the local and central government of the country. For this reason, the analysis of larger communities in the network was performed using the modularity method defined in section 3.3. This analysis is presented in Figure 4.

Figure 4. Communities detected in the network of scientific articles published in Scopus between 2016-2021.



(1) **(2)** **(3)**

Source: own elaboration.

The main node of the first community is health since the word interacts with specific components that are important for its materialization. These relationships make the design of instruments for health care and the monitoring of variables evident through different quantitative modeling and simulation techniques. Despite the importance of such relationships, none of them is related to the diseases with the highest morbidity and mortality in the most vulnerable regions of the country. The main topic of the second community is particle physics, as well as other terms related to solid state physics, which evidences the focus of research on important topics for academia and the basic sciences. However, such topics are not relevant in the development plans of the country and its most vulnerable regions. The topics of the third community are related to biology, in particular to the "omics" areas (genomics, proteomics, metabolic), and have a very academic approach, little related to the needs identified in the documents referenced in the policies for STI developed in Colombia selected for this research.

3.4 Conclusion

Even though in recent years scientific production in Colombia has notably increased in almost all areas of knowledge, its topics and results have no impact on the country's main challenges. Even the relationships of the main nodes identified in the government's plans and agendas do not have significant depth, which makes the lack of synchronization between scientific research and public policies greater and less useful when it comes to solidifying a model of STI for the country.

On the other hand, building complex networks allowed us to model and represent complex systems mixing different sources of information related to scientific popularization. Likewise, it allowed us to discover patterns in the interactions and topological metrics of these information sources. In them, the predominant topics are basic sciences, computing, and statistical analysis, which are in accordance with academic trends but are not useful to solve the challenges and problems of the different territories of the country.

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4. EVALUATION OF THE IMPACT OF THE COLOMBIAN SCIENTIFIC PRODUCTIVITY ON THE FULFILLMENT OF THE SUSTAINABLE DEVELOPMENT GOALS

Abstract

This research presents the development of an instrument for the evaluation of the contributions of scientific production in Colombia to the development of the main needs of the Sustainable Development Goals (SDG) throughout the country. A data set of national and international science and technology repositories was configured, including those recognized for hosting products highly related to the topics required by the SDGs. Afterward, a topic model was built, in which for each of the sources considered in each SDG, the importance of the number of topics or categories and the distribution of the concepts in each of them was evaluated based on indicators such as perplexity and coherence. Among the most important results, the synchronization of the scientific products related to the objectives "*Fin de la pobreza*", "*Cero hambre*" and "*Salud y bienestar*" stands out, however, despite this decisive result for the fulfillment of the SDGs, the lack of scientific development throughout the national territory limits the impact of the results for the attainment of the agenda for 2030.

4.1 Introduction

One of the main strategies for the materialization of the SDGs in different territories is the evaluation of the performance of the plans and/or activities of Science, technology and innovation (STI). This scientific productivity is stimulated mainly by the elements defined in the 2030 Agenda for Sustainable Development, where 193 States in 2015 adopted this document as the guide for the pursuit of sustainability, from economic, social, human, environmental, and governance perspectives. The 2030 Agenda for Sustainable Development, through its 17 goals (SDG) and 169 targets, has become a global commitment of a transversal and multidimensional nature, in which the STI has a fundamental role (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2015).

In Latin America, the analysis of the relationships between STI and the fulfillment of the SDGs must consider the heterogeneity of the region. Although there are common elements

to all Latin American countries, their internal situations differ significantly and extend to the social and scientific-technical spheres. At the same time, the maturity of innovation systems and the degree of development of research processes diverge (Instituto Complutense de Estudios Internacionales [ICEI] 2020).

The Observatory of Science, Technology and Society, coordinated by the Organization of Ibero-American States (OEI) and the Network of Science and Technology Indicators (RICYT), reports that 57% of Ibero-American researchers carry out their activities in universities, 28% in the business sector and 14% in public institutions. Consequently, the axis of research and academic production continues to be concentrated in universities (ICEI 2020).

On the other hand, between 2008 and 2019 the number of articles published from Latin America in scientific journals registered in Scopus has grown by 87%, a volume notably driven by Brazilian production. Likewise, the number of patents has increased and, in general, the capabilities of the research and innovation system have been strengthened. However, it is necessary to reinforce the transfer and exchange of knowledge, between academia and society, in both the national and regional contexts (ICEI 2020).

In 2019, the contribution of Colombia to world scientific production was 0.33%, placing it below Brazil, Mexico, Chile, and Argentina in the region (Scimago 2020). Likewise, 4.5 articles are published in the country per billion dollars of GDP per capita, which is less than what is published by Argentina (6.8), Brazil (9.7), and Chile (13.2). On the other hand, although in 2019 Colombia was ranked 47th out of 231 countries in the world ranking of the H33 index (Scimago 2020), it was not positioned as one of the three best Latin American countries. Finally, even though the total scientific j

Figure 1. ODS

Source: https://www.un.org/development/desa/disabilities/about-us/sustainable-development-goals-sdgs-and-disability.html

4.2 Materials and methods

Materials

A set of data generated from databases and repositories of science, technology, research, and innovation related to Colombian scientific productivity has been built. Diverse factors were included in the assessment of the impact of the research products in the materialization of the objectives of sustainable development, such as:

. The generation of new knowledge, or the degree of contribution that these products have to face the challenges that exist throughout the country. Additionally, these products must be published in scientific journals indexed in Scopus and Web of Science and must be derived from the research carried out by the actors of the National System of Science and Technology.

. Products with highly significant results and with scalability in the different territorial contexts of the country, according to the needs established by the National Council for Economic and Social Policy within the framework of SDGs in the country.

. Scientific products generated as a result of research calls from the Ministry of Science and Technology of Colombia within the framework of the Horizon 2030 cooperation and financing fund.

. Referents of the Science, Technology and Innovation policy and development plans of the country's provinces and municipalities

Another important criterion for collecting this information was to limit the temporality of each of the records to the last seven years (2014-2021) because it was in that period that the Colombian Science and Technology System generated the greatest promotion of research calls and financing for the training of specialized human talent to meet the demands of the SDGs.

From this information, a data set with the following characteristics was constructed:

. 9566 articles

. 4568 books as a research result

. 2500 book chapters

. 350 documents related to policies, decrees, resolutions, national and regional development plans, as well as the reference documents of the research and funding calls of the Ministry of Science and Technology of Colombia.

Methods

One of the most important characteristics of the data set formed for this research is that all the information is in text format, and, therefore, the construction of the model that will carry out the evaluation of the scientific relevance for the development of the SDGs in Colombia must consider it. In this sense, two methodological processes have been defined to guarantee the construction of a robust model with significant results. The first is related to the quality of the data, and the second process is where the instrument for the evaluation of scientific productivity is elaborated.

The process of improving the quality of the data consists of carrying out cleansing activities and selecting the most important information. For this reason, the proposal by Rentería et al (2022) will be used, where the following algorithmic sequence was established:

. Tokenization. It is a process by which the text is segmented into words, that is, a textual corpus is transformed into a set or list of words. For example, in the text "Sustainable Development Goal", its Tokenization is: "Sustainable", "Development", and "Goal".

. Lemmatization. It is used for the dimensional reduction of a word or sentence transforming it to its base and root form.

. Recognition and Debugging. It is a stage where the selection of main and important words is carried out, based on a heuristic algorithm called a taboo list, which consists of discarding from the document those words that do not provide important information for the compression of the text. Within this debugging, connecting terms such as: "the", and "they", (also known as stopwords) are eliminated.

Once a textual corpus has been obtained, the assessment process begins, to evaluate the configurations of the most important terms of each of the scientific products, considering their co-occurrence, sequentiality and placement. From these results, the alignment to the most important principles of the SDGs was established (in this case, the first 10 were considered, for which the most resources have been defined in the country). With this aim, topics, categories, and unstructured text documents were built from latent variables and multinomial distributions of words, using Topic modeling as the main tool, which is a technique that belongs to Bayesian statistics (Duran et al 2015). Among the most important topic modeling techniques, Latent Semantic Indexing (LSA) (Zhao et al 2015) Probabilistic Latent Semantic Analysis (PLSA) (Hofmann 2001; 1999), and Latent Dirichlet Allocation (LDA) (Blei et al 2015) stand out. According to Duran et al (2015), LDA is one of the techniques that has generated the most significant contributions to the study from different areas of knowledge: social sciences (Ramage et al 2009; Li and Lei 2021; Jacobi et al 2016), economics (Hong et al 2016), health (Paul and Dredze 2014; 2013) among others. For this research, the most relevant approach is the LDA, because the topics built with this model are highly coherent (Stevens et al 2012) and, therefore, it is a vital tool for evaluating the relevance of the results obtained from Colombian scientific productivity, related to the challenges established in the SDGs.

For the construction of the LDA algorithm, the proposal of Duran et al (2015) was used, where given a textual corpus D composed of M documents, with a document d with N_d words ($d \in \{1 \ldots., M\}$), the construction of topics was done as follows:

1. Select a multinomial distribution ϕ_t for topic ($t \in \{1 \ldots., T\}$), from a Dirichlet distribution with parameter β.

2. Select a multinominal distribution θ_d for ($d \in \{1 \ldots., M\}$), from a Dirichlet distribution with parameter α

3. For a word w_n ($n \in \{1 \ldots., N_d\}$) in a document d,

i. Select a topic z_n from θ_d

ii. Select a word w_d from ϕ_{zn}

One of the most important aspects for this algorithm are the variables ϕ and θ, and the hyperparameters α and β that, as recommended by (Duran et al 2015) must be defined from the perspective of latent variables. Therefore, under this principle for the estimation of the parameters in the textual corpus D.

$$P(D|\alpha,\beta)$$

$$= \prod_{d=1}^{M} \int P(\theta_d|\alpha) \left(\sum_{n=1}^{N_d} P(z_{dn}|\,\theta_d)\, P(w_{dn}|\,z_{dn},\varphi) P(\varphi|\beta) \right) d\theta_d d\varphi \quad (1)$$

As the parameters θ and ϕ are part of the integration, it is necessary to build simulation models to establish the inference of these values, according to (Blei et al 2003; Rogers et al 2005; Griffiths and Steyvers 2004; Shivashankar et al 2011; Coelho et al 2010) the best computational alternative for this inference is Markov Chain Monte Carlo. Once the topics have been generated, it is necessary to establish a quality metric for the results obtained, which means, to define the optimal number of topics required to adequately classify all the words of the textual corpus D. In this sense, the most appropriate indicator is Perplexity, which is a measure of information theory, to evaluate how well a statistical model describes a data set (Duran et al 2015), therefore, the lower the quantification of Perplexity, the quality of the results obtained with the model is more reliable. The Perplexity equation (ς) that will be used in this research is the one proposed by (Duran et al 2015; Blei et al 2003):

$$\varsigma = exp\left\{-\frac{\sum_{d=1}^{M} logp\,(w_d)}{\sum_{d=1}^{M} N_d}\right\} (2)$$

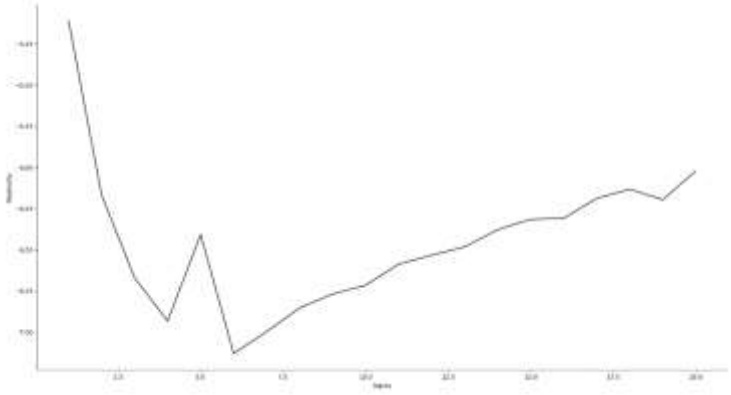
In addition to Perplexity, the coherence indicator (ϑ) is adhered to evaluate the consistency of the words that make up each topic ϕ_i, ϕ_j (see equation 3), to later make a paired comparison based on the Kullback divergence metrics – Leiber (DKL) to establish the main similarities and differences from the distributions of the words in the topics and between the SDGs (Mei et al 2007).

$$\vartheta = log\frac{p(\phi_i, \phi_j) + \epsilon}{p(\phi_i)p(\phi_j)} (3)$$

4.3 Results and Discussion

One of the first results that must be calculated in this research is the value of α and β, which are adjusted with a symmetric distribution $\left(\frac{1}{T}\right)$, therefore, it is important to define the optimal number of topics (T) of the LDA model, from perplexity using (2), for a randomly selected quantity t (see figure 2).

Figure 2 - Assessment of perplexity according to the number of topics



Source: self made

For this case, the number of categories or topics with which it can be modeled in a robust and statistically significant way is six, because it is where ς is minimum, a value that is

repeated in all the SDGs analyzed in this research. Once this value is obtained, the next procedure is to calculate the value of ϑ, for each ODS, as presented in Table 1.

Table 1. Levels of consistency of the topics for each SDG

SDG	Topics	Coherence	DKL
1	6	0.48	5.10
2	6	0.47	6.10
3	6	0.45	4.98
4	6	0.14	10.01
5	6	0.11	20.02
6	6	0.09	25.05
7	6	0.08	35.02
8	6	0.09	10.05
9	6	0.11	8.02
10	6	0.12	7.85

Source: self made

According to the results presented in Table 1, the first three SDGs, in addition to having the highest coherence values, show the lowest values of divergence with the fundamental principles of the United Nations declaration, and for such reason, they will be the prioritized elements to evaluate in this investigation.

ODS 1. No Poverty

This SDG highlights the presence of important terms to address a set of solutions to the problematics that underlie the endogenesis of the objective, within these aspects terms such as “desarrollo”, “económico” and “salud” appear, which are determining aspects for provide a solution to the needs of poverty and reduce the level of entrapment of a large part of the population in the country. In fact, these are the aspects included in the multidimensional poverty models proposed by Alkire et al (2015), who calculate poverty

from a synthetic indicator, employing a ponderation system based on the importance of each dimension in the configuration of welfare antagonists' deprivations.

However, it is necessary to achieve more accurate poverty models, which strategically address the reduction of the intensity of poverty traps and prevent them from becoming transgenerational poverty maps. Therefore, in addition to incorporating these factors, it is necessary to involve aspects related to the habitat, and other dynamizers factors of social welfare, such as access to quality public services, health services, among others. This lack is reflected even in the smaller topics (fewer terms), demonstrating that the scientific development of the country is not generating the evidence to solve the problems of poverty as established by Ramírez et al (2017), Pinilla-Roncancio (2018) and Manzano-Nunez et al (2022). Finally, Cuesta and Pico (2020), mentions that these poverty and inequality gaps have become more acute because of the pandemic.

ODS 2. Zero Hunger

Unlike the SDG "No Poverty", in this objective, the scientific development has led to important results in aspects such as: "Agricultura", "Cambio Climático", "Economía" , " Capital Social" and "Bioeconomía" that according to Khanal et al (2021), are the keys to promote strategies to reduce hunger, because the alterations generated as a result of climate change affect the availability and quality of the product, reducing the presence of some nutrients, proteins and vitamins required for the health wellness. In relation to this last aspect, Blesh et al (2019) mentions that to guarantee the construction of a sustainable model of zero hunger, in addition to a good food security system in the country, it should be considered the support of a good health system, highly inclusive and based on the care prioritization approach from the social determinants of well-being. In addition to a good health system, Sunderland et al (2019), mentions that factors such as adaptation and resilience to climate change must be on the government's agenda to achieve the expected results and impacts boosted by the guarantee of zero hunger in the population. Although these aspects are part of the most important topics (based on the proportion of terms and main components since the creation of the objective) and coherent, the intra-topic analysis shows the lack of a homogeneous model that guarantees its adaptability to the territorial

needs of the country, because most of the implemented strategies are focused on the capital cities of the country, and not on rural (and dispersed rural) contexts.

ODS 3. Good Health and Well-being

Health and well-being is another of the objectives that has a series of initiatives that have been developed in the country involving plans and programs supported by the Comprehensive Health Care Model (Hernandez et al 2019), and whose key aspects are found in the topics with the highest proportion of objective terms ("Salud", "Calidad-Salud", "Atención-Diferenciada", "Cobertura-Integral"). Thus, the fundamental of this model is based on guaranteeing the insurance of the population in the General Health and Social Security System (SGSS), from an inclusive and differentiated approach that guarantees access to health, considering the socioeconomic gaps of the different population groups in the territory. These results are so effective that the country's insurance exceeds 90% of the population in some municipalities, and, in addition, they have established a population screening model considering the vulnerability approaches proposed by Diderichsen et al (2019), which have facilitated access to specialized health services. Part of this contribution is reflected on the presence of these terms in the most important topics: "salud", "cuidado", "sanitario", "humanización", "riesgo", "inclusión", "clase social" and "estratificación". However, researchers such as Roncancio et al (2020), mention that the development of this SDG in the country is not only achieved by guaranteeing the health system of the entire population, but also it is necessary to improve the incorporation of the social determinants of health, because there are sociodemographic and geographic factors that have had an important impact on the configuration of vulnerability that exacerbates the complications of some pathologies in these population groups. This factor was called differential vulnerability by Roncancio et al (2020) and Diderichsen et al (2019) and stablish that a health system must generate elements that mitigate the epidemiological incidence of the differential vulnerability in the welfare of the population. In addition to the above, the Colombian scenario, in most of the territory, converges poverty and a population displaced by internal armed conflict, which also has high rates of morbidity and mortality due to cardiovascular and metabolic diseases, have high prevalence rates in mental illnesses, such

as depression and dysthymia, which according to Rentería-Ramos et al (2019) are increasing pre-existing cardiovascular, metabolic and nutritional complications in the poorest population groups.

4.4 Conclusions

The scientific contribution in Colombia for the development of the SDGs, has increased notably in recent years, as a consequence of the incentives promoted for the actors of the National System of Science and Technology in the country, since the creation of research financing funds focused especially on the development of the needs that are part of the first ten SDGs. Because the closing of the largest gaps that exist in most of the territories is concentrated in the scope of each one of the dynamic components of these SDGs. In relation to the STI and R&D&i products that are generated because of the funded research calls, they are more focused on following international patterns and standards (reviewed from publications in journals indexed in Scopus and WOS), which contain completely divergent elements to the territorial needs of the country.

Even this pattern is preserved for the objectives in which there are less divergences (assessed from the DKL), but with little impact at the national level, because it has a very pronounced bias towards the large cities of the country (investigations are directed to those territories). Leaving out the demands of rural contexts and settlements of population groups that have historically been excluded from the main agendas and state plans, whose situation has been considerably aggravated by the declaration of the pandemic generated by Covid-19. Therefore, it is necessary that new impact indicators of the scientific production of the SDGs be promoted at the country level, based more on territorial needs and the promotion of instruments for decision-making by the local and national government, than on the bibliometric compliance or based on international scientific repositories.

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5. CONCLUSIONS

This study addressed the research question: How to design a strategic research management model for higher education institutions based on institutional capacities and the local, regional, national and international context? To address this question, a systematic literature search was conducted, developing a structured approach process on "strategic management of research in higher education institutions", based on a comprehensive search of articles in electronic databases and bibliographic tools in which essential variables were identified such as strategic alliances, research networks, targeting of objectives, intellectual capital, competitive advantages, context recognition for the development of research programs, academic and administrative efficiency and effectiveness, and level of maturity of research capabilities.

Based on the search, instruments were constructed that allowed the capture of information from public policy documents on CTeI at the national and international level, such as CONPES documents, Development Plans, competitiveness agendas, the mission of wise men, business cluster initiatives, international competitiveness agendas, sustainable development objectives, reputational and regional rankings (QS, Shangai), academic production in mainstream journals (Scopus, Wos) and alternate current (academic Google), institutional repositories and other open access repositories with a CTeI component.

With these documents, a series of mathematical, statistical, and computational techniques and models were developed, articulated with information theory techniques and complex adaptive systems, for the construction of models that allowed the generation of quali-quantitative approximations in the development of research in IES as a key actor of the National Science and Technology System. Among the most interesting findings, there was evidence of a very low synchronization between the bets consigned in the CTeI policies at the national level and the academic production recognized as high impact and of alternating current, demonstrating the low effectiveness of the investment vs. the fulfillment of the goals and guiding principles of the CTeI policies of the country, directly affecting the

effective transfer of knowledge to the communities, increasing and intensifying the gaps of economic and social development of the country.

On the other hand, an analysis of the national production and its articulation with the global goals contained in the SDGs was carried out, and it was found that although research is being carried out to achieve them, it was observed that they work independently, leaving aside the complementarity and relationships necessary for a comprehensive approach that allows greater effectiveness in their fulfillment. Therefore, the methodology used functions as a systemic model for evaluating compliance with the SDGs for a country. This dynamic is not only relevant for the Colombian scenario, but the evidence shows that this same behavior is observed in other countries with a higher level of scientific and technological development.

The model designed allowed us to establish a series of strategies for IES at three levels: strategic, tactical and operational;

Strategic Level

. In the assortativity analysis carried out, a low correlation was observed between the most significant elements of the national policy on CTeI, which shows the need for policy instruments that generate strong interaction links between its determinant elements. Therefore, it is recommended that Minciencias be the entity that guarantees this component, through its different calls for the financing of research projects and activities that promote CTei in the country (31-33).

. It is necessary to promote new indicators of the impact of scientific production and its relationship with the country's policy documents, more based on territorial needs and on the promotion of instruments for decision-making by the national government, than on compliance with bibliometric indicators generated in international scientific bases (31-33).

. Although there are well-constructed policy documents, there is no articulation, no cooperation between the main elements. That is to say, each policy has dynamic elements but there is no overlapping or overlapping between them so that they can collaborate and in a systemic way help solve the problems that underlie the construction of the policy.

. It is suggested that higher education institutions as actors of the SNCTeI articulate their lines of research, activities and strategies for the promotion of CTeI+I+d+i with components related to the interaction of the determining elements of the CTeI policy in the country.

. The study carried out contributes to the measurement model of Minciencias especially in the category of production of new knowledge because it allows; on the one hand, to recognize the elements on which such production should be focused in the country, and on the other hand, to generate inputs so that the measurement not only responds to internationally recognized bibliometric indicators but that there is a focus on the needs and interests of the territories to guarantee the effective transfer of knowledge and the contribution to the transformation of social realities. In particular, new knowledge, innovation, technological development and human resource training products could be managed from the different calls for proposals according to regional needs framed in the themes defined in the country's public policy documents, such as: biodiversity, sustainable energies, public health, information and communication technologies, sustainable development, bioeconomy and sectors, focused on territorial development and identified as relevant in the study developed (31-33).

Tactical Level

Promote the generation of formal and informal education programs, CTeI training strategies that materialize the strategic level of the model in energizing aspects of sustainable development, especially in renewable energies, public health, data analytics, innovation, biodiversity, biotechnology, productivity, sustainable environment, access to technology, transportation and sectors (geographic context), elements identified as very relevant in the policy documents but without interconnection and synchronization (31-33).

Operational Level

According to the nature, mission, institutional vision, educational project, it is suggested to reflect and operationalize in IES the tactical and strategic levels according to the institutional dynamics (31-33).

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7. APPENDIX

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SCIENTIFIC RESEARCH PROCEDURE AND METHODS USED FOR THE SUPPORT OF SCIENTIFIC ARTICLES

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Abstract

This paper addresses the issue of the state of the art where it describes the various procedures that serve researchers when conducting scientific research, where its purpose is to publicize the applied research method with which it supports all the information collected from various academic sources to address the specified topic, thus giving an approach to the tools and methods used for the realization of articles with a scientific character to have a significant impact on the various academic levels to which they are directed as well as to the scientific community itself.

Keywords: Article, Study, Research, Process.

Introduction

This section describes, step by step, the procedure that was carried out to identify the key studies that give line to the scientific contribution of this research. The literature review procedure to identify these studies, the way they were selected, the results achieved in the review, the way in which the content of the articles was reviewed and the narrative review that derives from this process are described here.

Literature review: procedure

In this research, a systematic review of the literature was carried out. This means that a structured process of approach to the literature on "strategic direction of research in higher education institutions" was carried out, based on a comprehensive search for articles in electronic databases and bibliographic tools.

Specifically, the systematic review of the literature was carried out in the tools: Google Scholar, Scopus and Web of Science. This choice was based on the fact that these tools cover most of the relevant literature in the field of study with which this research is associated. Finally, it should be noted that this review focused on theoretical and empirical contributions produced during the period between 1995 and April 2020. The choice of this period is based on the fact that, in the mid-90s, the strategic role of universities, based on their research results, began to stand out (Koschatzky & Stahlecker, 2009).

Search equation

In the aforementioned tools to search for relevant articles, an electronic search was carried out oriented by the key terms that derive from the thematic interests of this research. In addition to this, multiple combinations of the terms that relate to the phenomenon of: "strategic direction of research in higher education institution" were used. Table 1 presents the combinations of terms used in bibliographic tools. It is important to note that the equation was executed only in the English language, given the tradition that universities in developing countries have in transforming the research process into a

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Research Article

Construction of a Complex Network Using Technological Surveillance for the Strategic Management of Science, Technology, And Research in Higher Education Institutions in Colombia

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Abstract: This research proposes the construction of a model of technological surveillance for the strategic management of scientific research in higher education institutions in Colombia. This model is composed by an information system that includes scientific articles, intervention plans for the regions and the nation, and information from public policies related to Science, technology, and information (STI). From this data set, the construction of algorithms for information processing was carried out, using techniques of automatic text analysis and natural language processing with complex networks to detect patterns and the configuration of trends related to science, technology, research, and innovation, which are the guiding topics of the national science and technology system. The main results obtained in this research are that the construction of a complex system revealed the topics on which scientific production is focused in the country. In addition, the analysis of the documents related to STI referenced in in public policies analyzed for this research revealed the pressing needs of different sectors and regions in the country. Finally, the research showed that the topics on which scientific research in Colombia is conducted by the educational institutions of the country does not correspond to the needs found.
Keywords: Technology Surveillance, Scientific Research, STI, Innovation, Management.

1. Introduction

The pressing requirements of various productive sectors in Colombia have revealed a growing need to increase the participation of science, technology, and information (STI), as well as research, development, and innovation (R+D+i) as key factors to find solutions to the country's problems. Faced with this urgent need, public and private organizations demand the construction of strategic approaches that allow directing the work of scientific research towards solving the issues identified by the most important stakeholders of the National System of Science, Technology, and Innovation of Colombia (SNCTI in Spanish).

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Evaluation of the Impact of the Colombian Scientific Productivity on the Fulfillment of the Sustainable Development Goals

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Abstract:

This research presents the development of an instrument for the evaluation of the contributions of scientific production in Colombia to the development of the main needs of the Sustainable Development Goals (SDG) throughout the country. A data set of national and international science and technology repositories was configured, including those recognized for hosting products highly related to the topics required by the SDGs. Afterward, a topic model was built, in which for each of the sources considered in each SDG, the importance of the number of topics or categories and the distribution of the concepts in each of them was evaluated based on indicators such as perplexity and coherence. Among the most important results, the synchronization of the scientific products related to the objectives "*Fin de la pobreza*", "*Cero Hambre*" and "*Salud y Bienestar*" stands out, however, despite this decisive result for the fulfillment of the SDGs, the lack of scientific development throughout the national territory limits the impact of the results for the attainment of the agenda for 2030.

Keywords: Sustainable Development Goals (SDG); research; science; technology; evaluation of the impact.

JEL Classification: Q01; Q55; R11.

Introduction

One of the main strategies for the materialization of the SDGs in different territories is the evaluation of the performance of the plans and/or activities of Science, Technology and Innovation (STI). This scientific productivity is stimulated mainly by the elements defined in the 2030 Agenda for Sustainable Development, where 193 States in 2015 adopted this document as the guide for the pursuit of sustainability, from economic, social, human, environmental, and governance perspectives. The 2030 Agenda for Sustainable Development, through its 17 goals (SDG) and 169 targets (see Figure 1), has become a global commitment of a transversal and multidimensional nature, in which the STI has a fundamental role (https://es.unesco.org/creativity/sites/creativity/files/247785sp_1_1_1.compressed.pdf).