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Article

Academic research contributions from Ibero-American countries to general knowledge, engineering, and computer science up to 2023 and COVID impact

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Abstract: Although commonly, competitive intelligence analysis is applied to companies, where new investments and operation expenditures are considered along with changes in the market, competitive intelligence can be applied to different countries' academic research production, which impacts science, technology and innovation making a difference in their competitiveness. This work shows the academic research production for all areas of knowledge, and also specifically for engineering and computer science, from all the Ibero-American countries, based on the SCOPUS database from 2001 to 2023. The results show that based on the volume of their academic production, for an affordable analysis, the Ibero-American countries can be classified into three groups, considering an order of magnitude difference for each group. The leading group is composed of countries producing between 200,000 and about 2 million documents, the second group of countries producing between 20,000 and 200,000 documents, and the third group of countries producing between 2,000 and 20,000 documents. The COVID pandemic impacted all the countries which showed a decrease in annual production over the last two years. The results also show the priority areas of knowledge that these countries invest in and the main countries that they collaborate with. The behavior of production for engineering and computer science is like that of general production, but there are some specific internal factors for specific countries such as in the case of Brazil, the country in which production fell most dramatically, followed by Spain and Colombia. On the other hand, Peru and Ecuador show a high interest in engineering and computer science. This work offers a high value decision-making tool to leaders in academic research, the principals of research driven institutions and investors from industry in Ibero-America. The academic production is related to the size of the GDP and the percentage of the GDP invested by a country in research development and innovation.

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1. Introduction

Commonly competitive intelligence (CI) is used among enterprises to understand how, in a given area, a specific company could show a highly competitive level or even maintain or sustain such a level by being resilient or even avoiding a crash, considering, for instance, that just 50% of the companies in the stock market show a life cycle of five years [1]. The root of CI is linked to the military history of China described in The Art of War by Sun Tzu. In time, it was systematized, becoming competitive intelligence gathering, a skill used in information acquisition; then, it evolved into competitive intelligence for strategic decision-making, including counterintelligence. More recently, CI has been divided into three categories: market intelligence, competitor intelligence, and technological intelligence, and in all cases, evaluation and forecasting are a must [2].

Today, CI is not only applied to secure financial resources from a specific country but also utilized in universities and research centers across various fields of knowledge, particularly in higher education. This strategic approach helps academic institutions enhance their capabilities, adapt to the changing educational environment, and stay at the forefront of advancements in research and innovation.

Several studies have focused on analyzing the application of competitive intelligence in various aspects of higher education. Institutions of higher education can enhance public engagement by integrating CI techniques within the strategic framework outlined by the American Association of State Colleges and Universities (AASCU) in "Stepping Forward as Stewards of Place." This model emphasizes internal strategic planning aligned with regional communities and policy environments. The incorporation of CI practices enables universities to optimize information gathering and strategic planning, thereby improving decision-making processes among administrators.

Some authors [3] have elucidated the procedural aspects of the CI model and illustrated its synergistic integration with the existing Stewards of Place model, offering state universities a strategic advantage in augmenting their efforts for more effective public engagement. Other authors have presented a study that has a dual objective: first, to provide insights into competitive intelligence practices within the under explored domain of the higher education sector, and second, to examine the factors influencing these practices, considering the limited existing research on this subject. Hence, it has proved valuable for prospective research endeavors or organizational entities with a structured model to investigate the determinants of CI practices. This includes an exploration of how these factors either facilitate or impede such practices [4].

In [5] a study that aims to furnish foundational insights for research on university strategic practices and competitive intelligence is presented. It delves into the current environment of university strategic management, initiating an exploration by analyzing the interplay between CI and university strategic management. An emphasis is placed on discussing strategic analysis and selection within the university's strategic management processes. This includes a comprehensive examination of the stages of strategic selection, implementation, and evaluation, particularly considering their interaction with CI. The findings underscore the interconnected and integrated relationship between strategic management and CI in higher education institutions, offering valuable insights for both academic research and practical applications in the field of university strategic management and CI.

Some researchers have dedicated their efforts to constructing a theoretical framework aimed at delineating and categorizing CI practices within Spanish universities. Their findings reveal that the application of CI is characterized by discontinuity, tactical approaches, reactivity, and a notable absence of formalization [6]. In [7] the impact of hard skills, soft skills, organizational learning, and innovation capabilities on the performance of lecturers in Indonesian Islamic universities is investigated. The research, based on 244 valid samples from a population of 261, utilizes the Structural Equation Modeling (SEM) method with SmartPLS 3.0 software, revealing positive and significant direct effects of these factors on lecturer performance. Additionally, this kind of analysis is necessary when looking for countries to invest in, for instance, when regionalization and nearshoring is the new rule for big companies [8, 9]. Moreover, a bibliometric analysis on innovation and CI in business revealed widely distributed scientific production with few specialists identified. The study emphasized the innovation cluster as central, indicating a strong connection between CI and innovation processes within companies. However, there is a lack of publications on CI in small and medium-sized enterprises and regarding patents. The authors conducted a descriptive statistical analysis, underscoring the diverse adjacent topics in CI research [10, 11]. In [12], a study was presented that concluded that top management actively engages in addressing both personal and CI activities. A total of 66.67% of respondents agreed that the company utilizes CI reports as decision-making tools, considering CI as a crucial instrument in the decision-making process.

Studies about academic research production are pertinent due to the fact that the world has undergone rapid changes, driven by shifts in technology, the economy, politics, culture, ideology, geopolitics and recently the COVID pandemic. One lesson from the past is that, after the Black Death, the epidemic of bubonic plague, of the roughly 30 universities that existed in Europe, five were wiped out. However, after the shock, certain universities came back and thrived. Thus, today, because of the financial shortfall faced by universities around the world, some could close but other could merge or even completely change their models. [13]. Additionally, the impact of funding by overseas students is important for certain universities and research centers. Specifically, for those universities and countries in which subsidizing research depends on the income from international students, the drop in revenue will strongly impact their production. For instance, just in 2020, Australian universities (mainly the research-intensive ones) expected to lose between 2 billion to 3 billion USD from Chinese students, which represents more than 20,000 full-time positions and around 7,000 researchers [13].

Thus, similar cases are occurring around the world. Today, investments from countries in research, development, and innovation (R+D+I) are driven by the implementation of public policies, but the main indicator is the invested proportion of their gross domestic product. This work aims to identify changes and trends in academic research contributions from Ibero-American countries in all fields of knowledge, and also in engineering and computer science specifically, between 2021 and 2023; these changes are driven by research and development in information and communication technologies (ICT) and also Industry 4.0 and artificial intelligence.

Finally, we have to consider that systems in Ibero-America are not disconnected from the global situation and trends by considering at least two aspects: a) The past global cycle: Between 1945 and 1991, the USA won the Cold War I against the Soviet Union because the USA understood that it was a technological race; thus the USA was open to attracting talented migrants and protecting their intellectual property. However, around 2014 the USA saw China as a new opponent [14]. b) The current global cycle: In 2012, some journalists began to talk about a new Cold War between the USA and its allies versus Russia and China, but this situation was formally considered in an academic way in 2014 [15]. Then in 2018 it was formally called the US-China trade dispute, after the Office of the US Trade Representative (USTR) announced the imposition of tariffs for 1,300 Chinese products. The USA imposed a 25% import tariff for Chinese "industrial significant technology" under section 301 of the Trade Act of 1974. Then restrictions from the USA against China were stricter, motivating that many Chinese prepared and talented people to came back to China. As a result, in the academic and research field, the USA is replacing that Chinese talent with talented ambitious people from other countries, which requires that conditions be generated to favor that kind of migration, one way is moving toward "No Open Access Research" [16]. Thus, this new Cold War II has been conducted since 2018 through "No Open Access Research" which will affect Ibero-American countries. If we consider this, there are two kinds of research and ways to develop technology, surface research (open access) and deep research (no open access). This new Cold War will have a strong impact on Ibero-American countries and other countries, but this new Cold War will be different because, for instance, today, there is Huawei, but in the first Cold War, there was not something similar that existed inside and outside the Soviet Union. This work delves into competitive intelligence gathering as a skill in information acquisition, with the expectation that it can contribute to strategic decision-making. In the following sections, the methodology is presented, followed by the results and discussion, and finally, conclusions are provided.

2. Methodology

To achieve our main objective, this study comprises specific steps to achieve particular objectives. It is important to remark that the target data to obtain are the contributions to academic research production for all knowledge areas produced by the Ibero-American countries, and also specifically for engineering and for computer science. According to convention, Ibero-America is formed by 22 countries: Andorra, Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Chile, the Dominican Republic, Ecuador, El Salvador, Spain, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Portugal, Uruguay and Venezuela. For extracting information, the SCOPUS database is the primary source for the period from 2001 to 2023. To conduct a comprehensive analysis, this study will follow the steps bellow:

1. Obtain the total number of academic research documents produced and identify the overall position for each Ibero-American country. As mentioned in the introduction, it could be linked to the portion of the gross domestic product (GDP) that each country invests in R+D+I to obtain benefits in the future [17] [18].
2. Analyze the trends in publications based on the annual production of academic research for all areas of knowledge by country to identify competitive behaviors among countries.
3. Determine the areas of knowledge that are a priority for each country and where they center their investments for R+D+I. Here, our particular interest is to determine if engineering and computer science belong to the priority areas, which could indicate how competitive a country is in these areas of knowledge. The number of areas of knowledge to analyze will be determined by the contribution percentage in terms of publications.
4. Examine the main academic types of publications published by countries to observe where they center their results. The number of types of publications to analyze will be determined by the contribution percentage in terms of publications.
5. Identify the top countries that are collaborating with each country; they could be considered as the main partners or competitors for the Ibero-American countries.
6. Analyze the trends in publications based on the annual production of academic research for engineering by country, to identify competitive behaviors.
7. Analyze the trends in publications based on the annual production of academic research for computer science by country to identify competitive behaviors.
8. Identify those Ibero-American countries that were more and less affected by the COVID pandemic in terms of academic production. Due to the closure of universities and research centers in Ibero-America at the end of March, the inertia in publications could be considered to continue for all of 2020, and the expected impact could be considered after March 2021 and beyond.

Steps 6 and 7 will be particularities of the general case considered in step 2. The general methodology indicated is based on the ADVNETLAB methodology [19,20].

3. Results

As the result of the first step, the volume of production for each country was obtained in close relation to the percentage of GDP invested in R+D+I. The results, derived from SCOPUS data, reveal that Spain leads scientific production in Ibero-America with 2,172,834 documents. In contrast, Andorra exhibits the lowest production, totaling a mere 455 documents. For the analysis of scientific production, to incorporate the competitive intelligence approach, we conducted a categorization into three distinct groups that appeared in a natural way, where scientific production does not differ by more than one order of magnitude compared to the results obtained from the preceding country. In this way, the first group comprises countries with the production of more than 200,000 documents; the second group encompasses those with production between 20,000 and 200,000 documents, and the third group includes countries with production between 2,000 and 20,000 documents. To avoid a fourth group of only one country, Andorra is excluded from the analysis due to its very low production, which is an order of magnitude lower than the preceding country, which is Nicaragua with 2,799 documents. The relationship between R+D+I investment and the overall academic research production by country is depicted in Figure 1, which clearly indicates the three distinct groups according to each country's development in the production of knowledge.

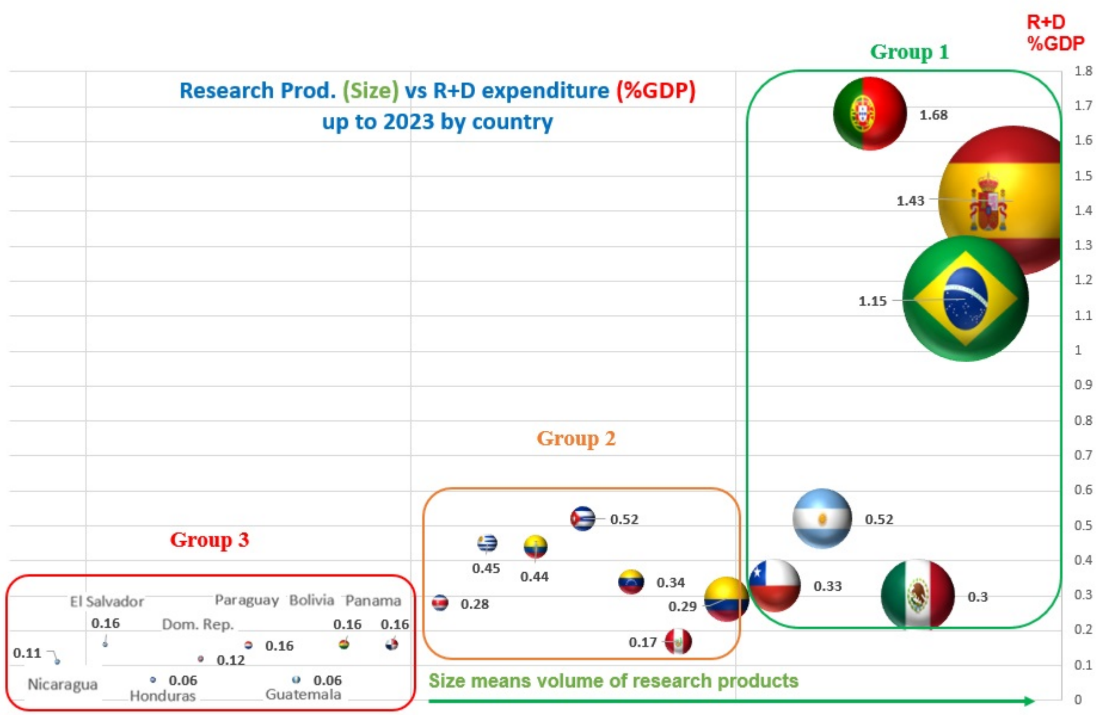

Figure 1. Relation between R+D+I investment and the total academic research production by country.

3.1. General ranking by production

After applying the first step of the methodology, based on the search criteria detailed in the previous section, information was extracted from the SCOPUS database. The academic research production from the 21 Ibero-American countries (Andorra is not considered as it has 455 scientific documents, which falls below the minimum compared to its predecessor, Nicaragua, as explained before) is listed in Table 1 for group 1, Table 5 for group 2, and Table 9 for group 3, where the GDP and the percentage of the GDP invested in R+D+I by each country are indicated. Group 1 contains those countries that contributed more than 200,000 publications including Spain, Brazil, Mexico, Portugal, Argentina, and Chile, as shown in Table 1. Group 2 contains those countries contributing 20,000-200,000 publications, including Colombia, Cuba, Venezuela, Peru, Ecuador, Uruguay and Costa Rica, as shown in Table 5. Finally, we found a third group including seven countries, specifically Panama, Bolivia, Guatemala, Paraguay, the Dominican Republic, Honduras, El Salvador, and Nicaragua, which contribute 2,000-20,000 publications, as shown in Table 9. In order to include more information in the tables, those countries that gained a GDP position in 2023 with respect to the year 2022 are indicated in green, those without changes are indicated in black, and those that lost at least one position are indicated in red.

3.2. Group 1 (G1): Ibero-American countries producing more than 200,000 documents

Table 1 shows the total number of publications in SCOPUS by country for group 1, including the corresponding position of GDP by country and the R+D+I expenditure invested by country with respect to GDP as a percentage. At this point, the substantial R+D+I investment of Portugal prompted us to consider the identification of a non Ibero-American reference country exhibiting a similar level of R+D+I investment. Canada (# 10) is characterized by an economic profile similar to those of Brazil(# 9) and Mexico(# 12) with respect to the GDP, so it was used as a reference for data validation purposes. To enrich the analysis, for all resulting graphs, two types of markers will be indicated:

1. Vertical lines indicate when a country definitively surpasses their closest competitor.
2. The number of publications in 2022, is shown as a reference due to the return to the workplace that occurred in most of the countries at this time, although the World Health Organization (WHO) declared the end of the pandemic in May 2023.

Table 1. Academic research production up to 2023 for group 1.

200,000 < # DOCUMENTS < 2,500,000				
No	Country	Production	GDP position 2023	R+D+I expenditure (%GDP)
Reference	Canada	3,027,707	#10	1.7%
1	Spain	2,172,834	#15	1.43%
2	Brazil	1,505,879	#9	1.15%
3	Mexico	519,457	#12	0.3%
4	Portugal	505,700	#50	1.68%
5	Argentina	337,849	#24	0.52%
6	Chile	262,011	#45	0.33%

Figure 2 shows the annual distribution of publications in the 21st Century for the six Ibero-American countries producing more than 200,000 documents. From this, it is possible to identify three pairs of countries with similar amounts of production, such as Spain and Brazil. The second pair is formed by Mexico and Portugal, where traditionally Mexico occupied the third position, until 2010. The third pair is Argentina and Chile, where traditionally Argentina occupied the fifth place until 2018. In this case we found that although the R+D+I investment of Spain is lower than that of Canada, its annual production is not so different from that of Spain. It is remarkable that all the countries indicated in Figure 2 reduced their annual production over the last two years, 2022 and 2023; this reduction could be attributed to the impact of the COVID-19 pandemic and the public policies adopted by some of these nations in the domains of higher education.

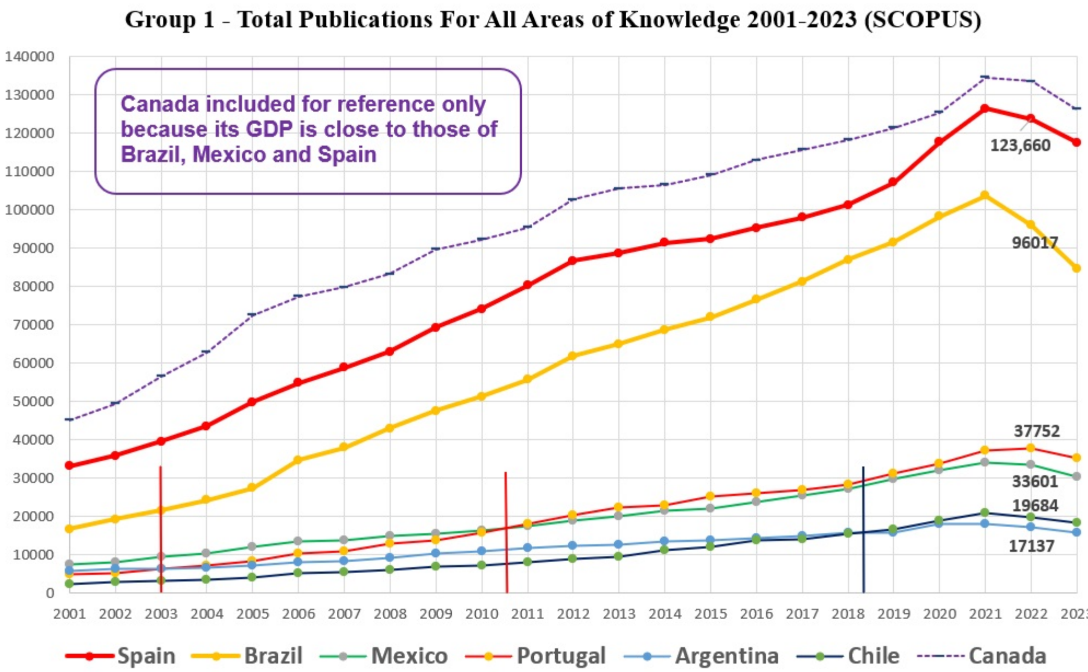

Figure 2. Total publications for group 1 countries by year (+200,000).

It is important to indicate that although the social isolation began in March 2020, publications in 2020 and 2021 follow the inertial of research work, as journals and conference papers take time to publish; thus, the pandemic impact is shown starting in 2022. Furthermore, there are additional characteristics that enable the analysis of scientific production behavior within this group:

1. Pair Spain-Brazil: These countries were the two most affected countries, but Brazil reduced its production by almost 19,000 documents over the last two years vs a reduction of almost 9,000 by Spain in the same period. In addition to COVID' s impact, for Brazil, this reduction is also attributable to the budget cuts imposed by the Bolsonaro government on universities in 2019 [21].
2. Pair Mexico-Portugal:
   (a) In 2003 Portugal overcome Argentina's production, which could be explained by two factors: one is the high R+D+I investment of Portugal compared to the research, development and innovation (R+D+I) investment of Argentina (less than one third of Portugal's) and the other is the reduction of the GDP of Argentina in 2002.
   (b) In 2010 Portugal surpassed Mexican production, which also could be explained by two facts: one is the high investment of Portugal (the highest in the group, 1.68%) and the other is the stagnation of Mexico in R+D+I investing by decades (the lowest in the group, 0.3%). If it is true that Mexico's economy has been recovering since 2019, increasing its GDP, it is also true that the extra income has been invested in the medical area and infrastructure, maintaining the same low investments in R+D+I as in the past, but avoiding social problems.
3. Pair Argentina-Chile:
   (a) Argentina democratized higher education, allocating the same budget to support more researchers, reducing the per-capita investment. Meanwhile Chile increased the budget for

CONICYT (now ANID) to fund research projects, provide training for researchers through doctoral studies and postdoctoral programs, and enhance research infrastructure in universities.

(b) Chilean universities implemented an incentive program for researchers who publish articles in journals indexed in the Web of Science. Also, while Chile continues to increase its GDP, Argentina is losing ground in GDP rankings, even though the Argentinian percentage of investment in R+D+I is higher than in the Chilean case. All this caused Chile to overcome Argentina in 2018.

4. Canada case:
In 2017, David Naylor the former president of Toronto University, warned the Canadian scientific community about "the flagging investment in research and development", which indicated a research crisis in Canada [22]. Then, in 2023, we see that Spain is very close to Canada, even though Spain has been decelerating since 2012.

Each country has its own public policies for R+D+I investments, so countries prefer to center their investments in specific areas of knowledge. Table 2 shows the top five areas of knowledge from the 26 considered by SCOPUS, where medicine is the priority for all countries. Note that when engineering and computer science appear, they are indicated in blue and orange respectively.

Table 2. The top five areas of knowledge by country for group 1 (ENG-Engineering, COMP-Computer science).

#	Spain %	Brazil %	Mexico %	Portugal %	Argentina %	Chile %
1	Medicine 17.8	Medicine 16.4	Medicine 13.6	Medicine 11.9	Medicine 15.5	Medicine 13.6
2	ENG. 7.7	Agriculture 10.6	Agriculture 9.3	ENG. 11.2	Agriculture 11.7	Phy.&Ast. 9.7
3	Biochem. 7.4	ENG 7.6	ENG 9.2	COMP 8.8	Biochem. 9.2	Agriculture 8.0
4	Phy.&Ast. 7.2	Biochem 6.7	Phy&Ast 9.2	Phy.&Ast. 6.9	Phy.&Ast. 8.1	Social CS 7.5
5	Chemistry 6.3	Phy.&Ast. 6.5	Biochem 6.5	Biochem 6.2	Chemistry 6.0	Earth&Planet 7.3

When considering the type of contribution, SCOPUS considers journal papers, conference papers or proceedings, books, and book chapters. However, the first two types combined represent above 84%, following a Pareto trend, as can be viewed in Table 3.

Table 3. The top two main types of publications by country for group 1.

Type	Spain	Brazil	Mexico	Portugal	Argentina	Chile
Article (A)	74.2%	77.8%	74.9%	66.5%	81.5%	79.4%
Conference paper (CP)	10.9%	10.9%	12.5%	17.9%	6.5%	8.1%
A + CP	85.7%	88.7%	87.4%	84.4%	88.0%	87.5%

The top 10 countries that collaborate closely with the group 1 countries are shown in Table 4, where the top six countries that collaborate with group 1 countries are indicated in blue. Also, it can be noticed that for Spain, collaboration with the countries in group 1 is not a priority; it has Portugal in the 7Th position. On the other hand, Argentina is more collaborative with other members of group 1, collaborating with four out of the five possible countries, Spain, Brazil, Chile, and Mexico, just considering the top 10 for each country.

Table 4. The top 10 collaboration countries by country for group 1.

#	Spain	Brazil	Mexico	Portugal	Argentina	Chile
1	USA	USA	USA	Spain	USA	USA
2	UK	UK	Spain	UK	Spain	Spain
3	Italy	France	UK	USA	Brazil	UK
4	Germany	Germany	France	Brazil	Germany	Germany
5	France	Spain	Germany	Germany	France	France
6	Netherlands	Italy	Brazil	France	UK	Brazil
7	Portugal	Canada	Canada	Italy	Italy	Italy
8	Switzerland	Portugal	Italy	Netherlands	Chile	Argentina
9	Belgium	Australia	Colombia	Switzerland	Canada	Canada
10	Canada	Argentina	China	Belgium	Mexico	Australia

3.2.1. Group 1: Contributions to engineering

In terms of academic research contributions in engineering, Figure 3 also depicts three pairs. For the first pair Spain-Brazil, Brazil has experienced stagnation since 2019, attributed to budget cuts to universities initiated that year [23].

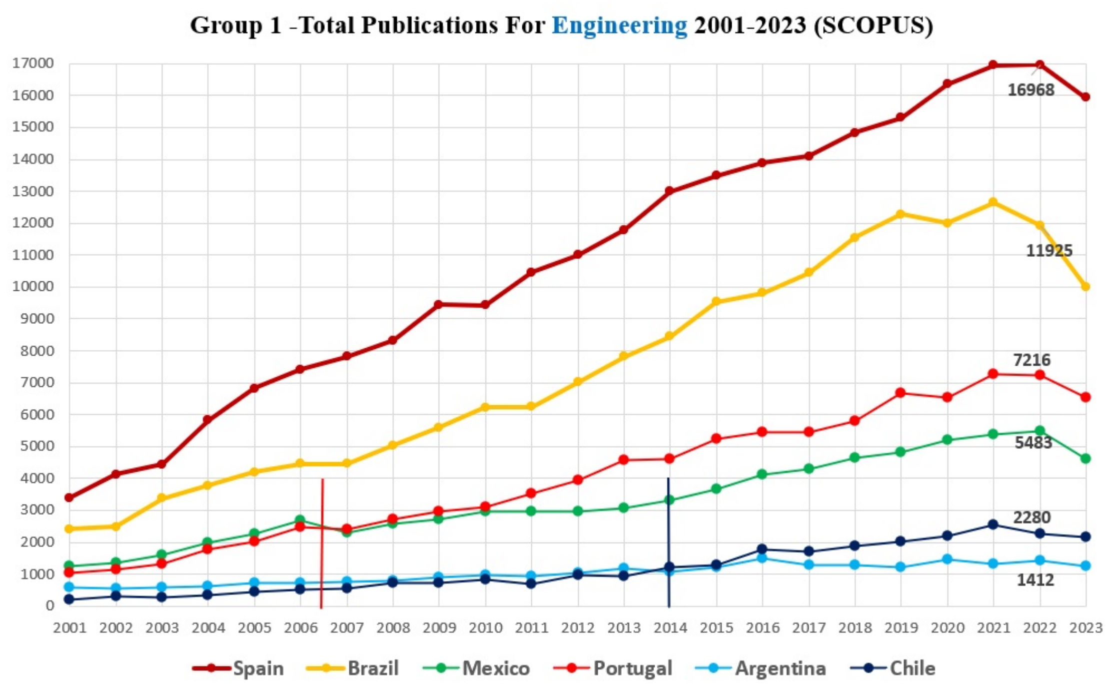

Figure 3. Publication trend in engineering for group 1.

In 2006, in Engineering, Mexico yielded its third place to Portugal, predating its overall drop to third place in 2010. Similarly, in 2014, Argentina was surpassed by Chile, losing its fifth place before eventually slipping to the fifth general position in 2018. Furthermore, there are additional characteristics that enable the analysis of scientific production behavior in engineering within this group:

1. Pair Spain-Brazil: Two internal factors keep Brazil from reaching Spain's production in engineering:

(a) In the period 2014-2016 (Dilma Rousseff's term) and in the period 2016-2018 (Michel Temer's term), there was a decrease in the budget for the maintenance of public federal universities, impacting science research funds. However, the production in engineering was not impacted according to the graph, showing the high resilience of the Brazilian research system.

(b) In January of 2019, Bolsonaro's agenda applied significant budget cuts and staff reductions in public universities, which produce most of the research in Brazil, advocating for tuition fees and promoting privatization. During the pandemic, Bolsonaro announced in August 2020 an 18.2% cut in unrestricted budgets for federal universities in 2021 [21, 24].

2. Pair Mexico-Portugal: Although the behavior shown in Figure 3 could have the same explanation as in the general case, the Mexican stagnation in R+D+I and the reduction in 2007 in engineering coincide with the drug war that began in 2006 in Mexico when Calderon became president, diverting Mexican income to maintain the war and causing R+D+I to stagnate.
3. Pair Argentina-Chile: The behavior shown in Figure 3 could have the same explanation as in the general case.

3.2.2. Group 1: Contributions to computer science

In terms of academic research contributions for computer science, the annual production is shown in Figure 4, where for the first pair, Brazil showed a significant decay in 2019, which can not be because of the COVID pandemic, so it must be due to internal factors. For the second and third pairs the behavior in computer science is similar to the engineering case:

1. Pair Spain-Brazil: The Brazilian case could be explained as in the engineering case.
2. Pair Mexico-Portugal: It could be explained as in the engineering case.
3. Pair Argentina-Chile: It could be explained as in the engineering case, but the effect for computer science occurred in 2004, ten years before the effect in engineering, showing today an almost twofold difference in production, where Chile has the clear advantage.

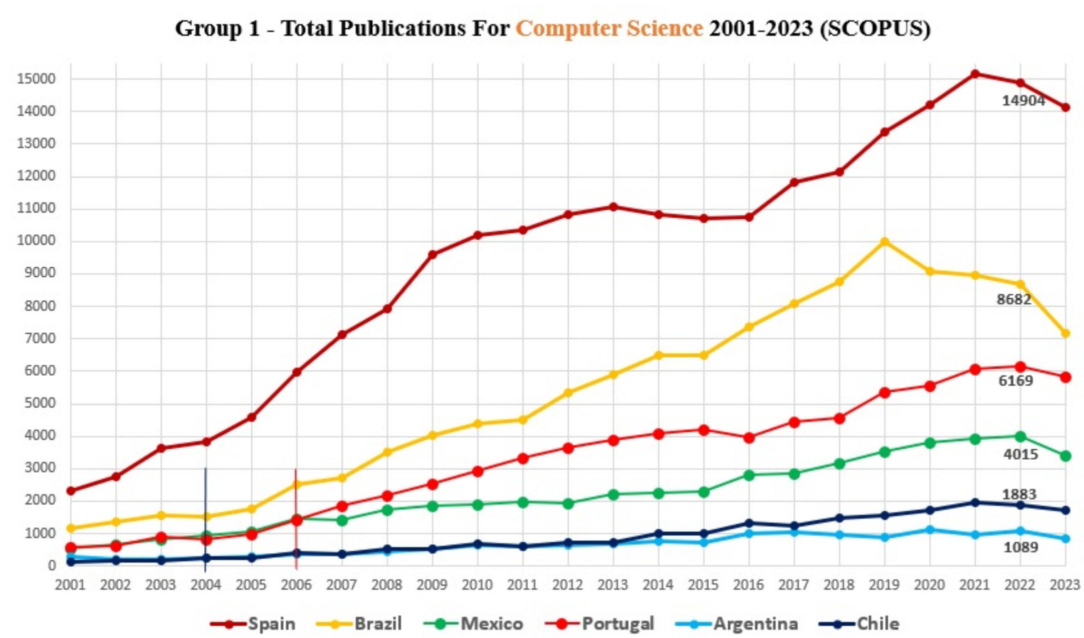

Figure 4. Publication trend in computer science for the group 1.

3.3. Group 2 (G2): Ibero-American countries producing between 20,000 and 200,000 documents

3.3.1. Group 2: Contributions to all areas of knowledge

Figure 5 shows the annual distribution of publications in the 21st century for the seven Ibero-American countries with production between 20,000 and 200,000 documents, also referred to as group 2, as shown in Table 5. As indicated in the figure, the leader of the group was Venezuela from 2001 to 2006, when Colombia surpassed it; since then, Colombia has been the leader of the second group. Then, Cuba passed Venezuela in 2010 and Peru in 2014. It took 17 years for Venezuela to be surpassed by the other countries of the group. From 2016 to the middle of 2019, Ecuador had more academic research contributions per year than Peru, as shown in Figure 5 by a blue rectangle. It also can be seen that from the middle of 2019 to 2023, Peru increased its academic contributions; meanwhile, Ecuador decelerated. The following aspects should be highlighted:

Table 5. Academic research production up to 2023 for group 2.

	20,000 < # DOCUMENTS < 200,000			
No	Country	Production	GDP position 2023	R+D+I expenditure (%GDP)
7	Colombia	193,696	# 43	0.29%
8	Peru	66,212	# 51	0.17%
9	Venezuela	59,942	# 72	0.34%
10	Cuba	57,685	# 63	0.52%
11	Ecuador	51,779	# 65	0.44%
12	Uruguay	34,050	# 84	0.45%
13	Costa Rica	23,237	# 75	0.28%

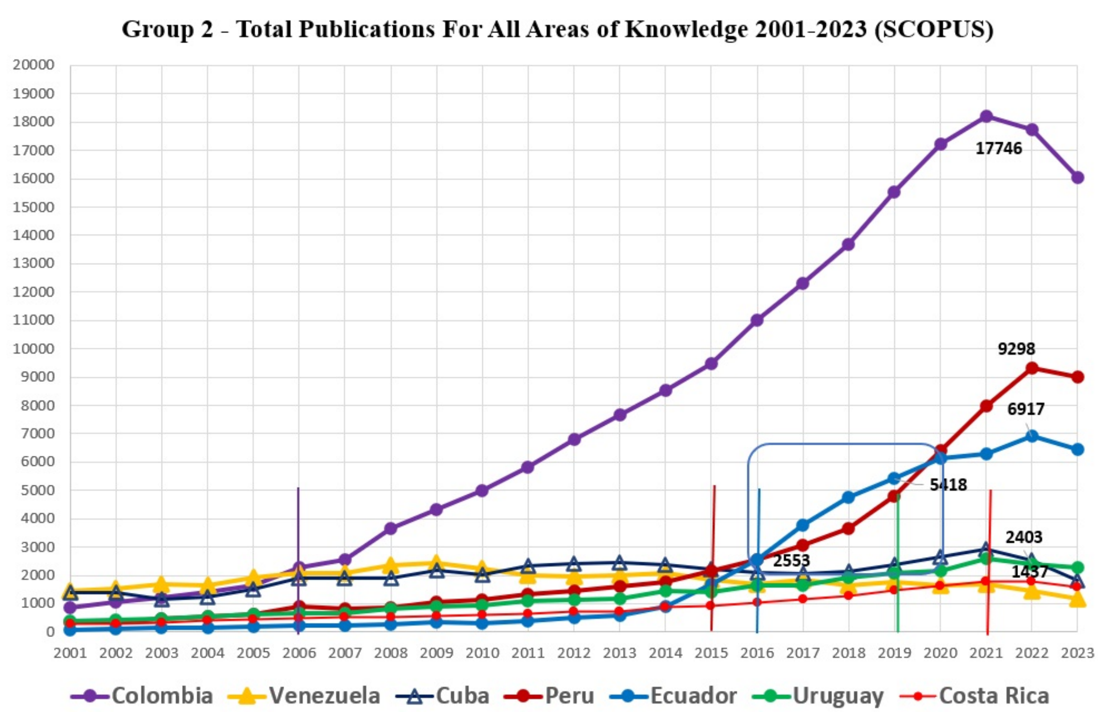

Figure 5. Publication trend in general for group 2.

1. Colombia case:

   (a) In the period 2010-2014 Colombia invested 0.24% of the GDP in R+D+I providing 26,246 scholarships for master's and PhD studies. In Figure 5, an increase in Colombia's scientific production is observed starting in 2006, coinciding with the science and technology law reform of the Uribe term, which increased project funding at universities and businesses helped by foreign investment. In 2008, the bicentennial program was implemented, providing 1000 annual doctoral scholarships for foreign stays. The obligations imposed on scholarship recipients notably influenced the curve's growth from 2009 to 2018 [25,26].

   (b) The Santos term, in 2014, began to decrease the budget for the bicentennial program, leading to a reduction in doctoral scholarships for studies abroad. The government shifted its focus to development plans, particularly emphasizing technology-based companies as alternatives to replace domestic production, given the country's status as a raw material producer and the growth of the service sector. Perhaps the most significant advancement is evident in the improvement of tax benefits for companies investing in science, technology, and innovation [27].

   (c) In 2018, with the Duque government, overseas doctoral scholarship programs were completely discontinued. The beginning of the Ministry of Science marked the definitive end of these programs. In 2020, COLCIENCIA transitioned to the Ministry of Science, Technology, and Innovation.

2. Peru case:

   (a) In the period 2010-2014, Peru increased its investment for R+D+I from 0.11% to 0.3% of GDP [28,29]. Then Peru experienced modest growth in the number of publications starting in 2013; this growth gained momentum with the approval in 2016 of the "National Policy for the Development of Science, Technology, and Technological Innovation – CTI" by CONCYTEC [30].

   (b) CONCYTEC promoted the generation and transfer of scientific and technological knowledge, developing new incentives to stimulate and increase activities in science, technology, and technological innovation.

3. Ecuador case:

   (a) In 2006 the investment in R+D+I in Ecuador was 0.13% of the GDP, but in the period 2006-2014, the investment was increased up to 0.44% by 2014, reaching the maximum investment. It could provide 19,567 scholarships for master's and PhD studies [31].

   (b) In 2012 Ecuador enacted the Higher Education Law, establishing the promotion of research as a fundamental pillar of higher education institutions, offering incentives for scientific and technological research, and supporting the training of researchers [32].

When comparing the top five areas of knowledge that these countries focused on medicine and agriculture are the common areas, as shown in Table 6 in terms of priority positions and percentages. Meanwhile, engineering and computer science are a priority for Ecuador, Colombia, and Peru.

The two main types of publications by country and their percentages are shown in Table 7, where Venezuela shows the highest percentage for articles in journals and Uruguay has a lower percentage for proceedings in conference papers.

For Uruguay, engineering (6th) is not the top priority, and computer science is not the top priority for Venezuela (10th). In the case of international collaboration, Table 8 shows the top 10 collaboration

Table 6. The top five areas of knowledge by country for group 2 (ENG-Engineering, COMP-Computer science).

#	Colombia %	Peru %	Venezuela %	Cuba %	Ecuador %	Uruguay %	Costa Rica %
1	Medic 15.4	Medic 19.1	Medic 17.4	Medic 28.9	COMP. 12.5	Medic 16.9	Agricul 20.8
2	ENG 9.5	Soc Cs 10.5	Agricul 9.7	Agricul 7.1	Medic 10.6	Agricul. 13.0	Medic 14.0
3	Agricul 8.3	Agricul 9.6	ENG 7.6	Biochem 6.1	ENG 10.0	Biochem 9.7	Environ 8.1
4	Soc SC 7.9	ENG. 8.6	Phy&Ast 7.3	Inmuno 5.6	Agricul 9.2	Soc Sc 5.4	Biochem 7.0
5	COMP 6.5	COMP 7.3	Biochem 6.0	Phy&Ast 5.2	Soc Sc 8.0	COMP 5.1	Soc Cs 6.9

Table 7. The top two main types of publications by country for group 2.

Type	Colombia	Peru	Venezuela	Cuba	Ecuador	Uruguay	Costa Rica
Article (A)	74.6%	70.8%	79.4%	80.3%	68.5%	77.4%	78.6%
Conf. paper (CP)	12.8%	15.4%	10.9%	10.7%	20.8%	9.5%	8.5%
A + CP	87.4%	86.2%	90.3%	91.0%	89.3%	86.9%	87.1%

countries for each of the five countries under study; collaboration with the same five countries occurs where Venezuela is the only country collaborating with Colombia (3rd) and Ecuador (8th), but Colombia does not collaborate closely with the compared countries. It is very interesting to note that the seven countries have in common collaboration with the USA, Spain, Mexico, the UK, Brazil and France.

Table 8. The top 10 collaboration countries by country for group 2.

#	Colombia	Peru	Venezuela	Cuba	Ecuador	Uruguay	Costa Rica
1	USA	USA	USA	Spain	Spain	USA	USA
2	Spain	Brazil	Spain	Mexico	USA	Brazil	Spain
3	Brazil	Spain	Colombia	Brazil	Brazil	Argentina	Brazil
4	UK	UK	France	USA	Colombia	Spain	Mexico
5	Mexico	Mexico	Brazil	Germany	Mexico	Chile	Germany
6	France	Chile	Mexico	Italy	UK	France	UK
7	Germany	France	UK	France	Germany	Mexico	France
8	Chile	Colombia	Ecuador	UK	France	UK	Colombia
9	Italy	Germany	Argentina	Ecuador	Chile	Germany	Canada
10	Argentina	Argentina	Chile	Belgium	Argentina	Italy	Chile

3.3.2. Group 2: Contributions to engineering

Figure 6 shows the annual publications contributions to engineering. In this case Colombia, Ecuador, Peru, and Uruguay surpassed Venezuela in 2005, 2014, 2015, and 2019, respectively. It can be seen that Ecuador surpassed Peru in the period 2014 to 2020; then the recovery of Peru occurred when Ecuador began to stagnate:

1. Colombia case: The results obtained by Colombia are remarkable, because in 2013 Colombia overcame Argentina and in 2018 it overcame Chile, countries which belong to the first group. In

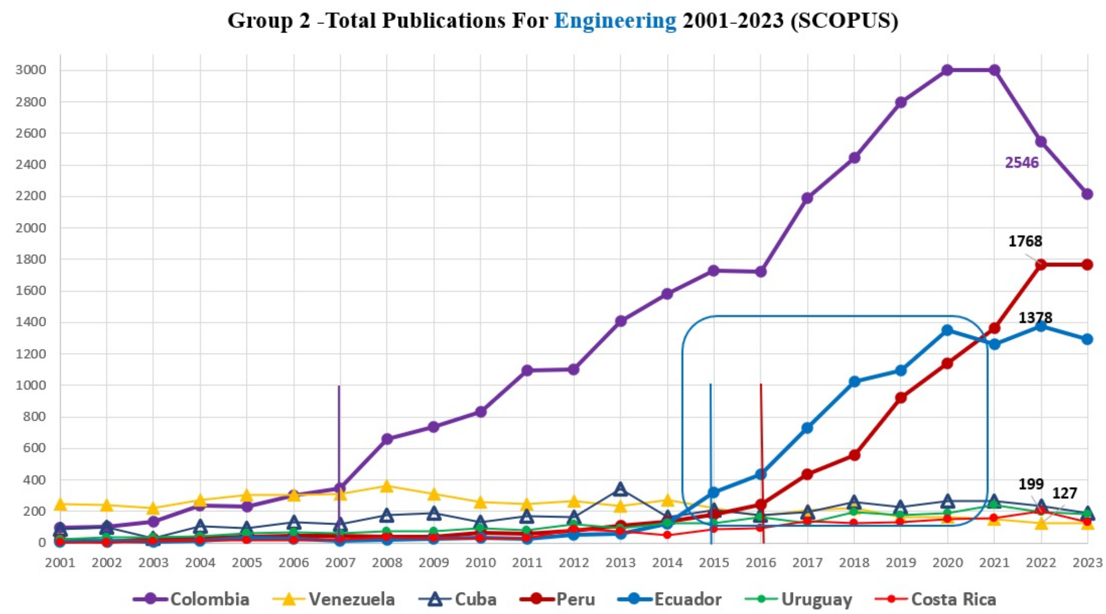

Figure 6. Publications trend in engineering for the group 2.

this way, Colombia is sending a message, even after the tremendous fall in its production of 800 documents between 2021 and 2023.

2. Peru case: In 2021, it overcame Argentinean production.
3. Ecuador case: Its production has been superior to than of the of Argentina since 2019.

3.3.3. Group 2: Contributions to computer science

The annual academic research contributions to computer science are shown in Figure 7 for the group 2 countries. Colombia grew almost exponentially starting in 2007 when it surpassed Venezuela; then, Ecuador and Peru dramatically increased their production in 2014 and 2015, respectively. Again Ecuador stagnated in 2021 but retained the second position of the group:

1. Colombia case: Although its behavior in computer science is similar to the behavior in engineering, in computer since Colombia is remarkable because in 2015, Colombia overcame Argentina and in 2019 it overcame Chile, with both of these countries being part of the first group.
2. Ecuador case: It overcame the production of Argentina in 2017 and is close to that of Chile.
3. Peru case: Peru overcame the production of Argentina in 2021 and is close to that of Chile.

3.4. Group 3 (G3): Ibero-American countries producing between 2,000 and 20,000 documents

3.4.1. Group 3: Contributions to all areas of knowledge

Figure 8 shows the annual distribution of publications in the 21st century for the eight Ibero-American countries producing between 20,000 and 2,000 documents, also referred to as group 3, as shown in Table 9. In this group, Panama has led, followed by Bolivia. In 2012, Guatemala and Paraguay experienced significant growth. The slope of the curve indicates steady growth until 2017, when it is observed that Bolivia, Guatemala, and Paraguay reached a similar number of documents (around 330), while El Salvador,

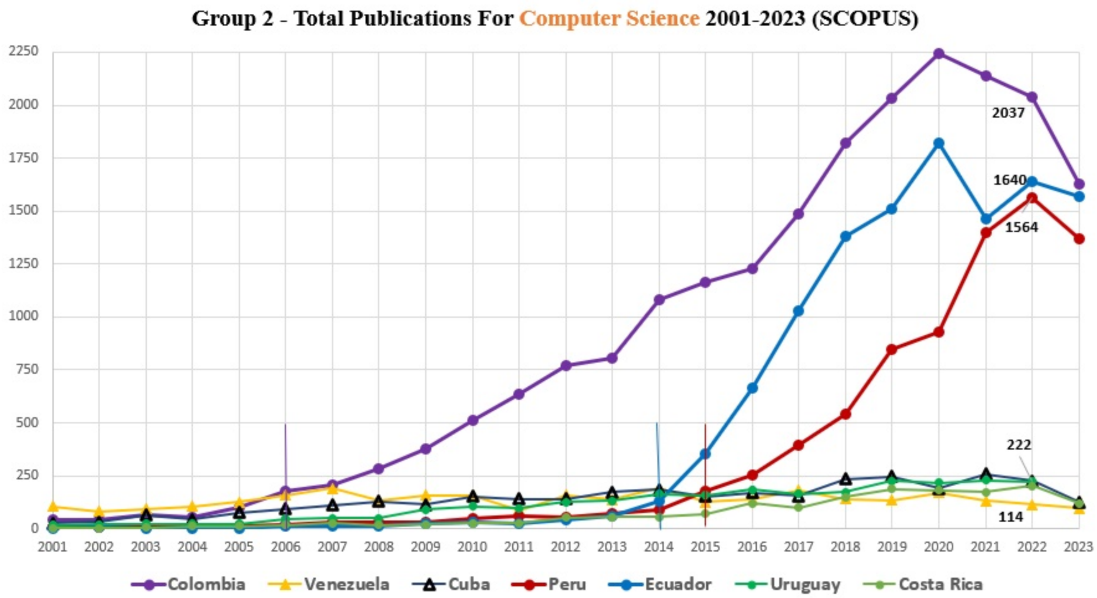

Figure 7. Publication trend in computer science for group 2.

Nicaragua, and Honduras coincided with around 150 documents. From that year onward, Paraguay maintained sustained growth, surpassing Guatemala. This growth could be attributed to the National Science and Technology Policy approved in 2002 [33]. However, Guatemala, Honduras, and the Dominican Republic experienced considerable growth. On the other hand El Salvador and Nicaragua maintained a number below 250 documents per year, which could indicate a lack of budget or a lack of interest from

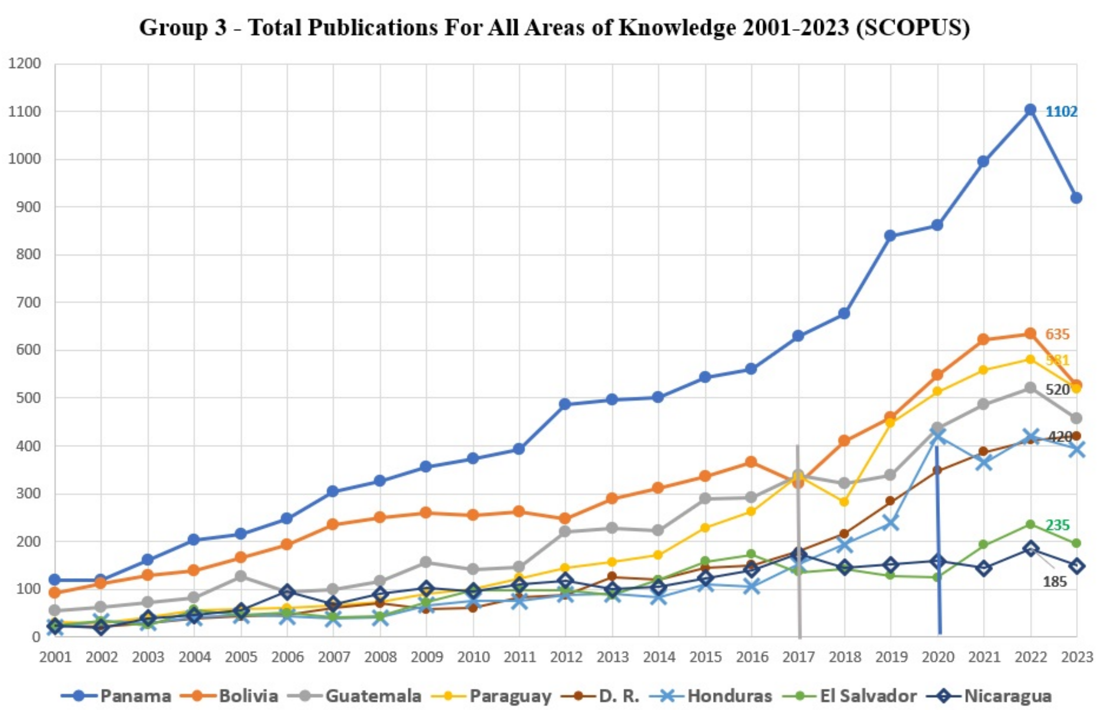

Figure 8. Publication trend in general for group 3.

governments and private entities in research. As shown in Table 9, the eight countries invest no more than 0.16% of the GDP in R+D+I from a reduced GDP, which is worst for EL Salvador, Honduras and Nicaragua. Perhaps the most interesting case is that of the Dominican Republic, which is the only country which did not reduce its general production even in 2023; this could be explained by the fact that the Dominican Republic has the highest GDP. The two main types of publications by country and their percentages are shown in Table 10, where Paraguay shows the highest percentage for articles in journals and proceedings in conference papers, which represent more than 90% of its total publications. When comparing the top five areas of knowledge that these countries focused on, medicine and agriculture are the common areas, as shown in Table 11 in terms of priority positions and percentages. Meanwhile, engineering and computer sciences are only a priority for Paraguay.

Table 12 shows the top 10 collaboration countries for each of the countries under group 3, where the USA, Brazil, Spain, Mexico and Colombia are the countries in common.

Table 9. Academic research production up to 2023 for group 3.

2,000 < # DOCUMENTS < 20,000				
No	Country	Production	GDP position 2023	R+D+I expenditure (%GDP)
14	Panama	13,129	# 77	0.16%
15	Bolivia	8,222	# 95	0.16%
16	Guatemala	6,577	# 70	0.06%
17	Paraguay	5,367	# 98	0.16%
18	Dominican Republic (D.R.)	3,921	# 64	0.12%
19	Honduras	3,579	# 105	0.06%
20	El Salvador	2,856	# 104	0.16%
21	Nicaragua	2,799	# 127	0.11%

Table 10. The top two main types of publications by country for group 3.

Type	Panama	Bolivia	Guatemala	Paraguay	D.R.	Honduras	El Salvador	Nicaragua
Article (A)	79.6%	80.4%	78.7%	68.0%	81.4%	74.0%	76.9%	81.9%
Conf. paper (CP)	6.7%	6.4%	5.2%	22.4%	5.6%	13.4%	9.4%	5.6%
A + CP	86.3%	86.8%	83.9%	90.4%	81.4%	87.4%	86.3 %	87.5 %

Table 11. The top five areas of knowledge by country for group 3 (ENG-Engineering, COMP-Computer sciences).

#	Panama%	Bolivia%	Guatemala%	Paraguay%	D.R.%	Honduras%	El Salvador%	Nicaragua%
1	Agri 28.2	Med 18.6	Med 35.1	Med 27.2	Med 30.8	Med 22.8	Med 26.7	Med 29.2
2	Med 14.0	Agri 17.9	Agri 10.4	Agri 10.8	Agri 8.5	Agri 13.6	Agri 7.9	Agri 13.3
3	Env.10.5	Env. 10.6	SocSc 8.3	COMP 7.2	SocCs 7.3	ENG. 7.9	SocSc 7.9	Env. 8.6
4	Bioche 9.5	SocCs 7.8	Nursin 5.9	ENG. 5.9	Bioche 5.7	SocCs 7.5	ENG. 7.8	SocCs 8.5
5	ENG. 4.1	Bioche 6.3	Bioche 5.3	SocCs 5.4	Env. 4.6	Enviro 5.7	Earth 5.3	Inmun 5.5

Table 12. The top 10 collaboration countries by country for group 3.

#	Panama	Bolivia	Guatemala	Paraguay	D.R.	Honduras	El Salvador	Nicaragua
1	USA	USA	USA	Brazil	USA	USA	USA	USA
2	UK	Brazil	Mexico	USA	Spain	Colombia	Mexico	Mexico
3	Germany	France	Brazil	Spain	Mexico	Brazil	Spain	Sweden
4	Brazil	Spain	UK	Argentina	Brazil	Mexico	Colombia	Spain
5	Spain	Argentina	Spain	Chile	Argentina	Spain	Guatemala	Costa Rica
6	Colombia	Peru	Argentina	Mexico	Colombia	UK	Brazil	Colombia
7	Canada	UK	Colombia	Colombia	UK	Peru	Argentina	UK
8	Mexico	Colombia	Chile	UK	Chile	Chile	Costa Rica	Brazil
9	Australia	Chile	Peru	Peru	Peru	Guatemala	Peru	Honduras
10	Costa Rica	Mexico	Costa Rica	Italy	Cuba	Argentina	Chile	Argentina

3.4.2. Group 3: Contributions to engineering

Figure 9 shows the engineering annual publications for the group 3 countries, where all of them had similar levels of production until 2012, when Panama began to increase its production for engineering, changing the trend. In general the production of the group for engineering is very limited, where just Panama and Honduras surpassed the level of 100 publications per year; this occurred on two occasions for Panama and one for Honduras.

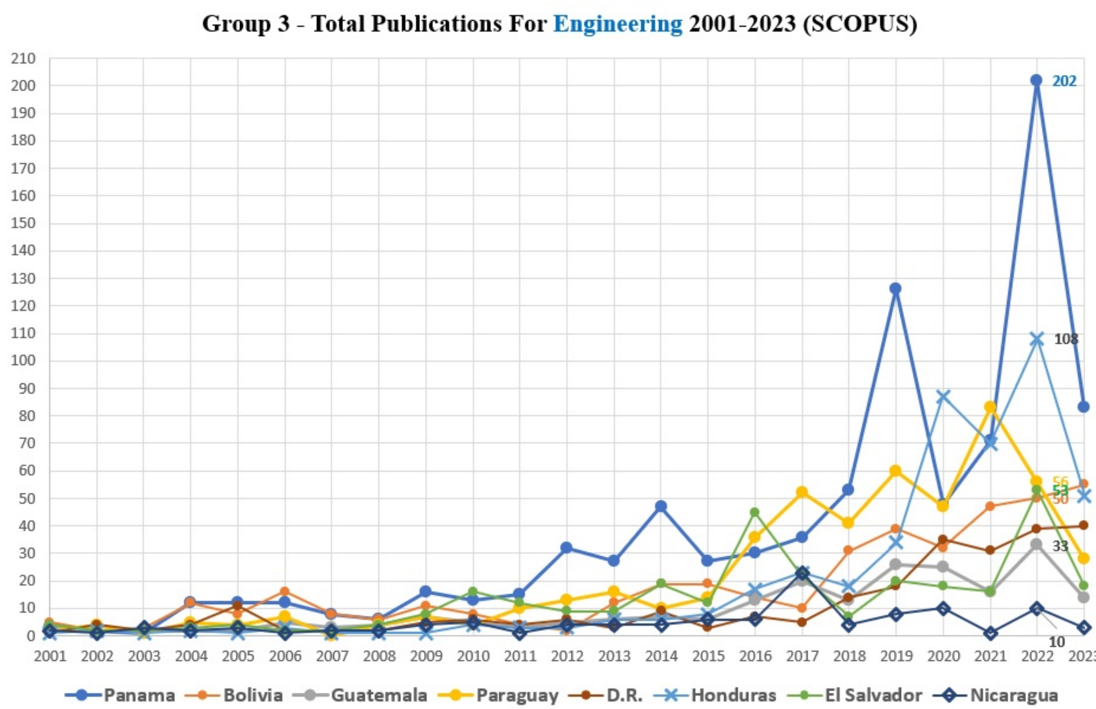

Figure 9. Publication trend in engineering for group 3.

3.4.3. Group 3: Contributions to computer science

Figure 10 shows the computer science annual publications for the group 3 countries, where no country could reach 100 documents per year, and only Paraguay reached 93 documents, the maximum production in a year in 2021. Although all countries decreased their production per year, Paraguay and Honduras saw a huge decrease for 2023, close to the production of the Dominican Republic and Guatemala.

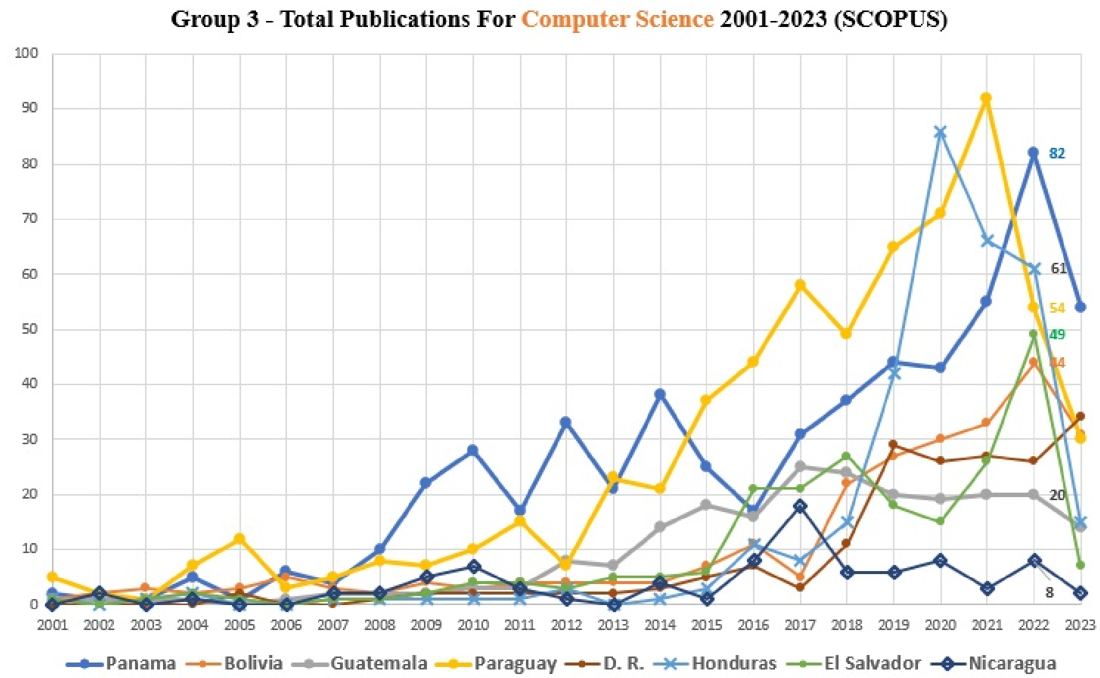

Figure 10. Publication trend in computer sciences for group 2.

4. Conclusions

In this work the 21 Ibero-American countries were analyzed by comparing their scientific contributions in general and also in the specific cases of engineering and computer science, based on the SCOPUS database, using a quantitative description. It was found that the 19 countries can be organized into three groups; the first one includes the six countries that produced more than 200,000 documents. The second group is formed by those five countries that produced between 20,000 and 200,000 documents and the third group is formed by eight countries that produced less than 20,000 documents. In the case of the general academic production behavior, for the first group, three pairs can be identified, Spain and Brazil; Mexico and Portugal, where traditionally Mexico occupied the third position, and although they were very close, in 2011 Portugal surpassed Mexico and the third pair where traditionally Argentina occupied the fifth place, but in 2016 it was surpassed by Chile, indicating a change in the trend for the first group. The second group was led in the past by Venezuela, but it took 17 years for it to be surpassed by Colombia in 2005, Peru in 2014, Ecuador in 2015, and Uruguay in 2018. Finally, the third group was formed by Costa Rica, Bolivia, Paraguay, Panama, Guatemala, Honduras, El Salvador, and Nicaragua; this group was not analyzed in detail due to the fact that these countries' production is below 20,000 documents where Costa Rica led with less than 18,000, followed by Bolivia with 4,154 documents. In this way, the research objective to identify the general position of academic research contributions from Ibero-American countries was achieved, and because of their contributions the title of the work is limited to the top Ibero-American countries.

Also, the research objective to identify if there have been changes in trends in production for countries, showing acceleration or deceleration in the production of knowledge, was achieved. It is very useful for showing win-to-win paths of international collaboration, which could be related to R+D+I policies in the considered countries to potentialize the results of the stakeholders. Also, the objective to determine the level of collaboration among different countries inside and outside Ibero-America was achieved. Specifically, in the case of the first group, in terms of academic research contributions for engineering, Brazil showed stagnation starting 2019, Mexico lost third place to Portugal in 2006, and Argentina lost fifth place to Chile in 2012. Now in terms of the academic research contributions for computer sciences, according to the trend, it could be expected that Brazil could reach Spain in the near future. Portugal obtained the third position in 2006, and Mexico stagnated and then grew slowly; Argentina was surpassed by Chile definitively in 2013. For the first group only Spain, Brazil, Mexico, and Portugal put high importance on engineering, but only Portugal gave high priority to computer science. In the case of the second group, in terms of academic research contributions for engineering, Colombia, Venezuela, Peru, and Ecuador give priority to engineering, but only Colombia, Peru, Ecuador, and Uruguay give priority to computer Science. It is interesting to note that Colombian academic production was reduced in 2020, 2021 and 2022 as in the case of Ecuador in engineering, but not the production for computer science. In this way the research objective to identify if engineering and computer science are subareas of knowledge in the strategic interest of the countries and to determine how these countries contribute to their general production was achieved. Additionally, two more objectives were achieved: tracing the position of academic research contributions from Ibero-American countries to engineering and computer science and to analyzing their trends in production, also showing interesting changes in the positions occupied by countries. The case of Colombia is remarkable due to the fact that its production grew to almost 16 times its initial level in 20 years in general, but most remarkable is that its engineering and computer science production grew to close to 28 times its initial level in the same period. In general, this study is useful for governmental entities making decisions about their policies on science and technology by considering the general policies on those topics followed by neighboring countries, and also considering that contributions from countries are mobile. Changes in positions developed by Portugal, Colombia, Chile and Ecuador indicate that changes in public policies and a huge quantity of money could modify the traditional positions that were maintained for years when funding is well focused, where Ecuador was the only one which received funds from USA and China. Finally, it is important to consider the internal factors and external factors that determine investment in research. For instance, in Figure 2 we saw that Canada increased its research production by 1,000 documents between 2004 and 2005; then, its production grew at a rate of 1,000 in periods of three years. This continued until the period from 2018 to 2023 where in five years Canada could not grow by 1,000 research products. In future works, it could be interesting to explain why and how the 12th-largest economy in the world, Mexico invests much less in research than Portugal, the 50th-largest economy in the world, to get a similar quantity of production. In general the production of a country is directly related to the size of the economy in terms of the GDP and the percentage of the GDP invested in research, development and innovation.

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