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RESEARCH ARTICLE

Benefits of International Collaboration in Computer Science: A Case Study of China, the European Union, and the United States

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Abstract

Co-authored publications can bring positive results for those who participated, such as accessing more funding or increasing the publication impact. China, the European Union, and the United States have been collaborating between them throughout the years in the field of Computer Science. These collaborations have been varying over time, as well as they have impacted the regions in different ways. In this paper, we obtained the publications from these territories across 31 years on the topic of Computer Science and studied them focusing on how the regions have approached co-authorship. In particular, we have analyzed the number of collaborations during that period, the impact of those papers measured as number of citations, and the topics that have been studied in those associations. We have concluded that China's focus on STEM has led it to be the most productive region in recent years; plus, it has benefited from the US and European impact. On the other hand, the EU and the US have benefited from Chinese funding and workload, increasing the number of publications together.

KEYWORDS:
computer science, co-authorship, collaboration, citation

1 | INTRODUCTION

The proportion of internationally co-authored scientific papers has significantly increased since the turn of the century, representing a growing share of all scientific cooperation, while in-home collaboration has been falling (Adams, 2013; Choi, Yang, & Park, 2015; Wagner, Park, & Leydesdorff, 2015).

This growth is mainly attributed to the participation of scientifically advanced countries such as the US or some of the countries in the European Union, with scientific emerging countries such as China also increasing their involvement through increased spending on research and development, resulting in their increased appearance as partners in internationally co-authored scientific papers Wagner, Park, and Leydesdorff (2015). International collaboration can bring positive results in general to the countries that participated in it. For example, papers co-authored by individuals from multiple nations receive higher citation rates compared to those authored by individuals from a single nation (Glänzel & Schubert, 2001; Kwiek, 2021; Levitt & Thelwall, 2010). Another positive trend observed is that co-authored publications receive higher citation rates compared to single-authored papers (Ronda-Pupo, 2022; Shen, Xie, Li, & Cheng, 2021). But apart from general benefits, international coauthoring can also bring specific advantages for a country depending on the other countries it is collaborating with, such as access to more funding opportunities, more R&D activity, and local knowledge (Harhoff, Mueller, & Van Reenen, 2014; Lee & Haupt, 2020). The top 3 most scientific works producers are China, the European Union (EU), and the United States (US), also they

are their major collaborators, as well as the ones that received more citations (Burke, Okrent, Hale, & Gough, 2022; Wang, Wang, & Philipsen, 2017; Zhang, Rollins, & Lipitakis, 2018). Although the scientific collaborations between China and the US have been increasing during previous decades, recent studies suggest that this tendency has stopped (Cai, Fry, & Wagner, 2021; Lacey, 2021; Schüller & Schüler-Zhou, 2020; L. Zhao & Yin, 2019). This rivalry leaves the EU in the middle of a crossfire, in which it is not clear yet if it will follow the anti-China approach proposed by the US or will follow another path keeping the positive collaboration tendency (Schüller & Schüler-Zhou, 2020; Ullah, Aria, & Akhter, 2020). It is in this context that we want to contribute to the current literature by providing a long-term analysis of these territories. In this paper, we examine the collaboration tendencies between China, the US, and the UE during 31 years in the field of computer science, observing the impact on publications considering the aim of the institutions that work on the co-authorship. Therefore, we contribute to the current literature in 3 ways. First, we conduct an analysis of how the regions have been collaborating between them over time, as well as providing insights based on the type of institutions that collaborated. Second, we investigate the impact of those collaborations on the article's outcomes in both academic and privately owned papers. Third, we analyze how the different countries have been prioritizing the different fields of computer science over time, and how they have been sharing their interest between them.

The subsequent sections of this paper are organized as follows: In Section 2 we discuss related work of research collaborations, as well as provide current literature about the relations between China, the EU, and the US in scientific co-authorship. In Section 3, we provide the details about our dataset and explain the process we followed to collect and analyze it. Section 4 shows the results we obtained when investigating the data. Finally, draw a conclusion with the findings we got and outline potential future research in Section 5.

2 | RELATED WORK

2.1 | Scientific copublication

Publication co-authorship has been thoroughly examined within the field of bibliometrics, which is a quantitative branch of information and library science that studies the publication of research accomplishments (Broadus, 1987). Different studies suggest that collaborating can bring different advantages, such as higher productivity, higher impact, and higher quality. However, it may also bring about certain drawbacks, such as a potential lack of comprehension and cohesion between collaborators, as well as the potential for disputes over authorship credit (Besancenot, Huynh, & Serranito, 2017; Biscaro & Giupponi, 2014; Franceschet & Costantini, 2010). Despite the possible disadvantages, cooperation in research continues to grow in most academic disciplines (Chinchilla-Rodríguez, Sugimoto, & Larivière, 2019; Wagner, Bornmann, & Leydesdorff, 2015; Wagner, Whetsell, & Leydesdorff, 2017). However, this tendency, as well as the collaboration outcomes, might vary within disciplines and whether the collaboration has been national or international (Franceschet & Costantini, 2010; Puuska, Muhonen, & Leino, 2014). Focusing on collaboration within the different areas of science, previous literature suggests that international collaborations have been increasing in recent years, as measured by the number of co-authored papers, with global collaboration continuing to grow as a share of all scientific cooperation (Larivière, Ni, Gingras, Cronin, & Sugimoto, 2013). Different studies have examined the citation impact of international and domestic co-publishing in different scientific disciplines, and they have found that international collaboration has a higher citation impact than domestic collaboration in sciences (Lancho-Barrantes, Guerrero-Bote, & Moya-Anegón, 2010; Newman, 2004; Puuska et al., 2014). Finally, in the field of computer science, it has been also found that its research networks are widely connected, allowing new collaborations to be created between scientists from different institutes, countries, or sub-disciplines (Franceschet, 2011).

2.2 | Chinese - American collaborations

The United States and China have been the two leading countries in global research and development (R&D) performance during the last decades (Burke et al., 2022). Although the number of collaborations between these countries, measured as the number of scientific papers co-published, has constantly increased, their positioning is as global adversaries instead of allies (Lee & Haupt, 2020; Lewis, 2021; Wagner, Bornmann, & Leydesdorff, 2015; B. Zhao, Gu, Forde, & Saphra, 2022). This can be seen in recent findings suggesting that the collaboration between these countries has been slightly decreasing, even when the relationship between the two countries can bring advantages to both (Cai et al., 2021; Wagner & Cai, 2022; WAGNER & CAI, 2022). Previous studies suggest that the collaborations between the US and China bring more citations than only those authored

by Chinese researchers (Tang & Shapira, 2011). On the other hand, the US benefit from collaborating with China by obtaining funds for research, as well as increasing their scholarly output (Lee & Haupt, 2020).

2.3 | European - American collaborations

Although the global concentration of R&D performance continues shifting from the United States and Europe to countries in East-Southeast Asia and South Asia, scientific publications made by the EU and the US are more relevant than those that these regions published collaborating with China (Burke et al., 2022; Leydesdorff, Wagner, & Bornmann, 2014). Apart from this higher impact, the US and the EU benefit from each other's specializations in the different scientific fields (Burke et al., 2022). In addition to this, European countries have also benefited from the rivalry between China and the US, attracting more collaborations between the US and the EU (Cai et al., 2021; Schüller & Schüler-Zhou, 2020; WAGNER & CAI, 2022).

2.4 | Chinese - European collaborations

The EU and China are the countries where more Science and Engineering articles are produced respectively (Burke et al., 2022). In recent years, the collaboration between them has grown fast, turning the European Union into the second biggest partner of China in science and technology research (Li & Chang, 2014). This collaboration tendency between the EU and China varies among the EU former countries. However, it represents more than 20% of total Chinese collaborations (Wang et al., 2017; Yuan et al., 2018). Previous findings indicate that the proportion of Chinese scientists living abroad is significantly higher in the USA compared to the EU. However, the flow of researchers from these destinations coming back to China has been more pronounced from the EU than the USA, which can increase international collaboration with their previous locations (Cao, Baas, Wagner, & Jonkers, 2020). That trend, summed with political reasons can be the cause of that Chinese researchers still want to collaborate with EU institutions instead of US institutions (Schüller & Schüler-Zhou, 2020; Silver, van Noorden, & Subbaraman, 2020; WAGNER & CAI, 2022).

3 | DATA SET

3.1 | Dataset

For our analysis, we used OpenAlex as data source, a fully open scientific knowledge graph (SKG) that replaces the previously discontinued Microsoft Academic Graph (MAG) (Priem, Piwowar, & Orr, 2022). On 15th of April of 2023, the OpenAlex dataset had 245M works, which include journal articles, books, datasets, and theses. OpenAlex allows using filters in advance, setting thresholds to the search, and therefore reducing the processing time.

3.2 | Data collection

In the following section, we discuss the process we followed for the data collection.

We gathered information on the works by utilizing OpenAlex API, using various filters. First, we filtered works by the "computer science" concept, considering only journal articles, and limiting the publication year from 1990 to 2021, both inclusive. In addition to this, we filtered retracted publications.

3.3 | Data preprocessing

Before starting to work with the data, we had to pre-process the raw data. As the scope of this research paper is to analyze the collaboration patterns between different countries and regions, papers written by just one author were removed, and we only considered publications whose all authors were affiliated with an educational or company institution. There were works that did not have their DOI code attached, nor either the number of citations that were also removed. To categorize the publications, we added a tag to mark each work based on the institutions' type that participated in the collaboration. Therefore, works where all participants were affiliated with educational institutions, such as universities, were categorized as "educational", works where all participants came from profit-oriented private corporations were categorized as "company", and those works done by both were

Collaboration type	CN-only	EU-Only	US-Only	CN-EU	CN-US	EU-US	CN-EU-US	Total
All	692924	727151	835456	26267	73420	84701	3277	2443196
Education	672256	678427	748132	24024	65978	68861	2648	2260326
Company	4064	16015	31420	92	153	1375	9	53128
Mixed	16604	32709	55904	2151	7289	14465	620	129742

TABLE 1 Number of publications per collaboration type

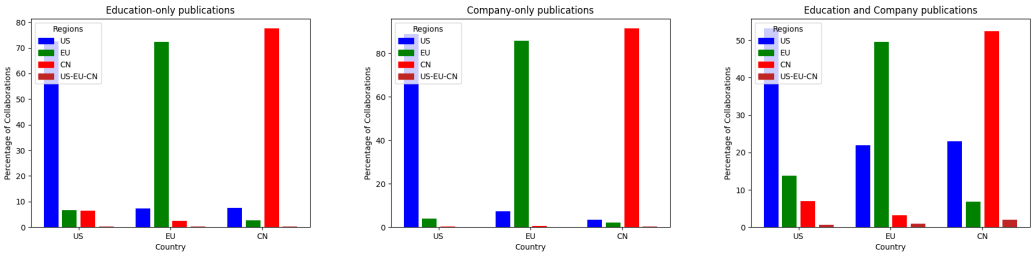

FIGURE 1 Collaboration percentage by collaboration type

marked as "mixed". In this experiment, we considered EU publications published by the EU27 as well as the UK to simplify, and China publications published by "China Mainland". It resulted in a dataset composed of 2.443.196 research papers.

4 | RESULTS

In this section, we present the results of the different statistical methods we applied in our our dataset (Section 3). We have divided our findings in three different subsections for better understanding: *Number of collaborations*, *Impact in research outcomes* and *Researched Topics*.

4.1 | Results for the Number of collaborations

As we can see in Table *1* , the nation that published the highest number of publications was the US (835.456) followed by the EU (727.151) and lastly China (692.924). If we look into the number of journal articles written as a result of a collaboration between the regions, we can see that the EU and the US were the territories that collaborated the most, having a total of 84.701 publications done together. It is followed by the number of collaborations between the US and China (73420), China and the EU (26267), and finally, the least common collaboration was between the 3 regions (3277).

In all the cases, the co-authorship between authors from the same region represents more than 70% of their total co-authored articles as shown in Table *2* . However, China has the highest rate, with a 76.75% of their collaborations only within the country. It is followed by the US with 71.33% of self-collaboration and finally the EU with 71.15%. These results suggest that China has been more isolated in terms of collaboration opportunities than the others. It can also be observed in the importance the different countries have given to the others. Both the EU and the US have prioritized each other. Thus, the number of co-authored papers published between the EU and the US represents 8.29% of the total published papers for the EU, and 7.23% for the US, while collaborations with China represent 2.57% of the total for the EU and 6.27% for the US. It also suggests that China has prioritized collaborating with the US. Collaborations between the three regions have been minoritarian for all of them, with rates between the 0.28% for the US the 0.36% for China. We have analyzed the impact of the collaboration type, that is if the collaboration was between educational institutions, companies, or both. Although the collaboration patterns remain equal in all cases, when collaboration is done between public and private institutions, the internationalization rate is higher.

In in Figure 1 , we can observe how the countries go from 77.56%, 72.38%, and 72.58% of self-collaboration for China, the EU, and the US respectively in the case of education-only co-authorship to a rate of 52.48%, 49.52%, and 53.17% in the case of collaborations between mixed institution types. In addition to this, the percentage of papers published in collaboration with

Country	With CN	With EU	With US	All 3 regions
CN	76,75%	2,91%	8,13%	0,36%
EU	2,57%	71,15%	8,29%	0,32%
US	6,27%	7,23%	71,33%	0,28%

TABLE 2 Relative collaboration rates per country

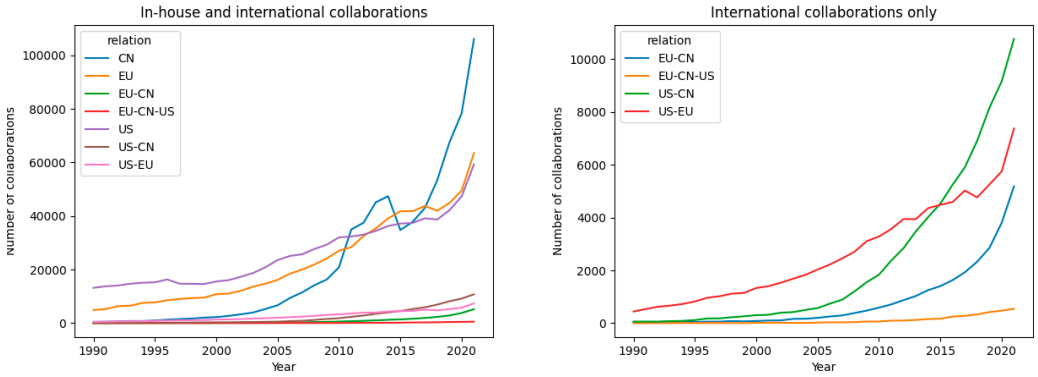

FIGURE 2 Collaboration percentage by collaboration type

Collaboration type	CN-only	EU-Only	US-Only	CN-EU	CN-US	EU-US	CN-EU-US	AVG
All	13,32	21,64	37,24	24,14	27,89	38,12	32,88	27,89
Education	13,41	21,84	37,41	24,44	27,83	38,86	32,66	28,06
Company	6,41	15,4	31,95	19,59	15,87	17,8	11,11	16,88
Mixed	11,43	20,56	38,04	21,04	28,64	36,53	34,12	27,19

TABLE 3 Average number of citations per collaboration type

institutions from the US increased either for China or the EU, going from 7.61% and 7.35% for China and the EU in the case of educational institutions only, to 23.04% and 21.90% in the cases of mixed institution types.

Although in a long-term perspective the EU and the US were the most productive regions in terms of the number of papers published, in Figure 2 we can observe that China became the most published country in 2017, followed by the EU and the US. Regarding the articles published in collaboration, the EU and the US used to be the most productive duple, but in 2014, China and the US surpassed the previous couple, becoming the two most productive publishers as we can see in Figure 2 . The number of co-authored articles between China and the EU has been also increasing, having a positive tendency, similar to the one noted during the last 5 years between China and the US. Finally, we can observe that the number of collaborations between the three territories has been also increasing, especially since 2015.

4.2 | Results for the Impact in research outcomes

Apart from the articles themselves, we have measured the number of citations as the outcome of the published articles. In an overall comparison, we found that the papers published through the collaboration between the EU and the US obtained the highest citation rate with an average of 38.12 citations per paper as we can see in Table **??**. It´s followed by publications done by the US only with a 37.24 citation average, and by the publications where the three regions worked together with 32.88 average citations. The rest of the results are below an average of 30 citations per research paper, the least cited papers were those published only by Chinese institutions, with an average of 13.32 citations per paper, far from the second least cited publications, the EU only with an average of 21.64. However, China increased its rates by collaborating with the US and the EU, which also

	CN		EU		US	
Collaboration type	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*
Education	-0,18	<.05	-0,06	<.05	-0,01	<.05
Company	-0,14	<.05	0	0,63	0,07	<.05
Mixed	-0,19	<.05	0,01	0,04	0,08	<.05
All	-0,18	<.05	-0,06	<.05	0	<.05

TABLE 4 Spearman Correlation Test results for the number of citations and the participation ratio per collaboration type

helped the EU to increase its own rates. Therefore, the collaboration between China and the US brought an average of 27.89 citations, as well as the collaboration between China and the EU brought an average of 24.14 citations, increasing their country-only rates for both regions, China and the EU. If we take a deeper look at the average number of citations between the actors across the different collaboration types, we see that those papers written by authors belonging to private companies had the least number of citations, with an average of 16.88, being China especially disadvantaged, with an average of 6,41 citations per paper, suggesting that publications from Chinese companies do not get relevance in academic research.

We also analyzed how the number of participants from each region affect the final number of citations. To measure it, we compute the number of participants from a region over the total number of participants in the paper, obtaining a participation ratio. Then we used the Spearman Correlation Rank test to analyze if there is a correlation between the country participation ratios and the number of citations obtained. In Table **??**, we can see that the number of institutions from the US participating in the research article may not have an impact on the total number of citations. On the other hand, results suggest that there might be a weak negative correlation between the number of Chinese or European institutions participating in the research and the final number of citations. While for the UE, Spearman's rank correlation between the two variables is -0.06 with a corresponding p-value of <0.05, for China this coefficient is three times higher, with a corresponding p-value of <0.05. Focusing on the different co-authorship types, we found that China had negative correlation values in all cases, the highest of those occurring in collaborations between Chinese companies and public institutions, where there was a negative correlation between the two variables, r (31641) = -0.19, p = <0.05. On the other hand, the EU had no significative correlation results in all cases but education, where it obtained a negative correlation of -0.06 with a corresponding p-value of <0.05. Finally, the US obtained positive correlation results in the collaborations between companies and between companies and public institutions, obtaining a positive correlation of -0.07 with a corresponding p-value of <0.05 and a positive correlation of -0.08 with a corresponding p-value of <0.05 respectively.

4.3 | Results for Researched Topics

We have obtained the keywords of every publication, and we have listed the overall top 10 most used terms for every collaboration type between the regions. As we can see in Figure 3 , in China and the UE, as well as in their collaborations between them and the US, some topics have grown more than others. China seems to be prioritizing "Artificial Intelligence", "Physics", "Mathematics", and "Engineering" over the others. Therefore, these topics have become the most published in internal collaborations, but China is also pushing these topics when working with international colleagues, raising these 4 topics in their collaborations with the EU and the US. Within these topics, the results suggest that China is particularly focusing on "Artificial Intelligence", which is a topic that is being more researched in the last few years. Internal collaborations within the EU also have those 4 topics as the most researched. However, the EU is not only focusing on artificial intelligence. In contrast to the Chinese case, the EU patterns are not repeated when collaborating with the US, being in this case less grouped. The US does not have the clustering tendency we observed in the others. Although they are also researching more in "Artificial Intelligence", it seems that they are also working on other fields such as "Psychology" or "Medicine", relating them to the topic "Computer Science". These topics are also observed when the US works with the EU, but not with China, suggesting that these are fields that may be more interesting for both.

5 | CONCLUSION

In this study, we aimed to analyze the collaboration patterns and tendencies in the field of Computer Science for a long time, with special emphasis on China, the EU, and the US to provide a context on the status, benefits, and pitfalls for those collaborations.

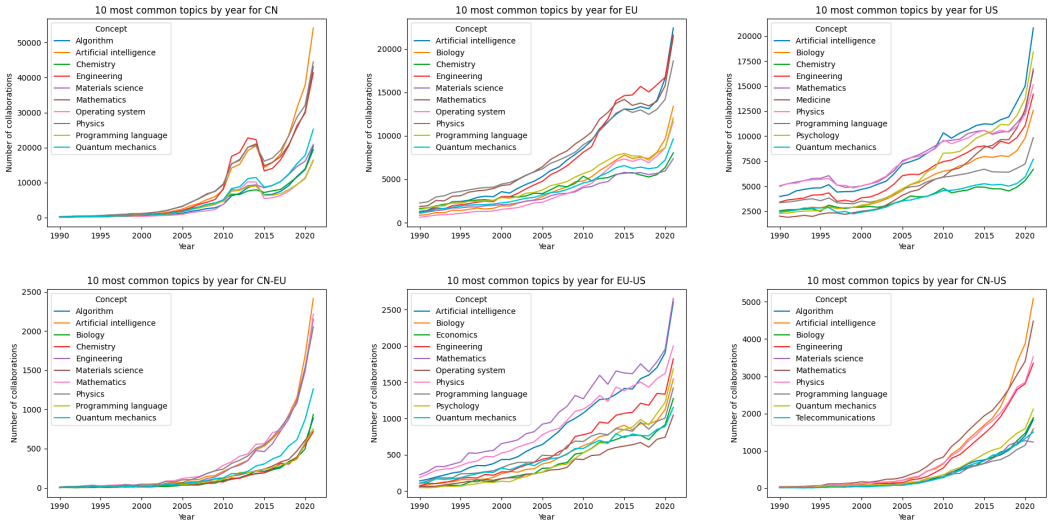

FIGURE 3 Most researched topics by collaborating regions

First, we found that the US has been leading the research efforts in the field of Computer Science in the long term. However, it changed in recent years, when first China surpassed the US in 2011, only being exceeded by the US again in 2015, and second when the EU also surpassed the US in 2013. These results confirm the findings shared by the National Science Foundation placing China and the EU as the topmost productive regions in terms of number of publications in Science and Engineering (Burke et al., 2022). Because of this increase in Chinese publications, the number of co-authored articles between China and the US surpassed the previous leading collaborator partners, the EU and the US, in 2014. This change leaves China and the US as the top collaborators in Computer Science. Taking a deeper look into the different results obtained when analyzing the data based on the institution's type that worked together, we observed that companies-only collaborations tend to be more internationalized, decreasing the number of self-collaborations only. This can be explained because the locations of headquarters or offices around the territories may help to increase the internationalization rate. Second, we study the impact of the different regions when publishing their investigations, we found that those co-authored by the EU and the US tend to have the highest number of citations, suggesting that their findings tend to be more relevant than the others. In addition to this, results suggest that collaborating with the US also brings more citations for Chinese publications, obtaining twice as many as citations than the country obtains when publishing alone. These results, added that US-only papers obtained the second-highest average number of citations, indicate that the US has a big impact on their publications, either when the publication is alone or with institutions from other countries, which can be an important reason for the other countries to collaborate with the US. On the other hand, China and the EU benefit from collaboration between them too, both increasing their publication share when collaborating, compared to their works published when working within their countries only. Our results also indicate that articles published by Chinese companies were the least cited, suggesting that they might not be as relevant to other researchers as those published by colleagues from the EU or the US. In private sector collaborations, the US is clearly the most relevant, obtaining 39% more citations on average than the second most cited, being those papers published by China and the EU. Lastly, we found that China and the EU have been prioritizing "Artificial Intelligence", "Physics", "Mathematics", and "Engineering" over others. This can also be seen when they have collaborated between themselves and the US. In contrast, the US has had not such a clear aim. Its research topics have been broader, including topics such as "Psychology" and "Medicine". The EU has benefited from this wider approach by also collaborating with the US on these topics, bringing them more knowledge in the fields. We can draw different conclusions for the three regions. First, while China produces the greatest number of scientific articles about Computer Science, their impact is relatively low. Hence, as observed in our study, China can benefit from collaborating with the EU and the US by obtaining more relevance in the scientific community and getting more quality in their publications. Its collaboration with the EU, whose interests seem to be aligned with China's, can bring more, better, and more diversified studies for both partners. Apart from this, the EU can also take advantage of co-authorship with China by accessing the most productive region, in terms of the number of published papers. On the other hand, collaborating with the US can bring the EU high-quality knowledge about different topics, gaining more relevance in other fields. Lastly, the US can take advantage of collaborating with both

China and the EU by accessing highly specialized research institutions, and in particular with the EU by creating high-impact publications, increasing the relevance of their institutions. Despite all these benefits for all the actors, politics can play a big role in collaborations between countries. Therefore, in future years, we will see which steps they decide to follow.

6 | LIMITATIONS AND FUTURE WORK

In this study, only papers from OpenAlex were analyzed. Although is one of the largest databases, different results can be obtained when analyzing other sources. Studying the status of funding and politics has not been the main aim of this study, although it has been reviewed. We know they play a main role in the relationship between countries, especially in partnerships. In future research, we would like to contribute current literature by these factors into current analysis and conclusions.

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