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Research Collaboration Dynamics at the National Nuclear Energy Commission (CNEN): Pathways to Enhance Economic and Social Impact

Jordão [a*], A. A.; Arthur [b], V.

[a] Nuclear and Energy Research Institute (IPEN), 05508-000, São Paulo, São Paulo, Brazil
[b] Nuclear and Energy Research Institute (IPEN), 05508-000, São Paulo, São Paulo, Brazil

*Correspondence: jordao@usp.br

Abstract: The growing recognition of university-industry collaborations as a strategic alternative for economic and social development at regional and national levels has fostered a continuous academic (and political) debate. Moreover, university-industry collaboration emerges as a strategic pathway for research production, particularly in developing and emerging countries. However, there is a scarcity of studies on university-industry collaboration oriented towards research production, as well as on its respective impacts, especially economic and social ones. To help fill this gap, this research examined the dynamics of research collaboration of the National Nuclear Energy Commission (CNEN), as well as its respective scientific, economic, and social impacts over the past three decades – the longest available data series, which adds originality and novelty to the research. Based on a descriptive and evaluative informetric analysis of internationally indexed publications in the Scopus (Elsevier) database, accessed through the SciVal platform, it was found that publications co-authored by CNEN with industry, government, and international actors, although less frequent, achieved greater resonance and influence in international knowledge networks, attracted more attention and interest from the international community, significantly exceeding the average expectation for similar publications, and exerted a more significant influence on patentable technologies and public policy formulation. These results may be useful for informing policies, guiding pathways to increase the prolificacy and impact of research.

Keywords: University–industry, Research Collaboration, CNEN, SciVal.

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Dinâmica de Colaboração em Pesquisa da Comissão Nacional de Energia Nuclear (CNEN): Caminhos para Ampliar o Impacto Econômico e Social

Resumo: O crescente reconhecimento das colaborações academia-indústria como alternativa estratégica para o desenvolvimento econômico e social em níveis regional e nacional fomentou um contínuo debate acadêmico (e político). Além disso, a colaboração academia-indústria emerge como um caminho estratégico para a produção de pesquisa, especialmente em países em desenvolvimento e emergentes. Há, no entanto, uma escassez de estudos sobre colaboração academia-indústria orientada à produção de pesquisa, bem como de seus respectivos impactos, sobretudo, econômicos e sociais. Para ajudar a preencher essa lacuna, esta pesquisa examinou a dinâmica da colaboração em pesquisa da Comissão Nacional de Energia Nuclear (CNEN), bem como seus respectivos impactos científico, econômico e social, nas últimas três décadas – a série de dados mais longa disponível, o que confere originalidade, além de um caráter de novidade à pesquisa. A partir de uma análise informétrica, de caráter descritivo e avaliativo, com base em publicações indexadas internacionalmente à base Scopus (Elsevier), através da Plataforma SciVal, constatou-se que as publicações coautoradas pela CNEN com a indústria, o governo e atores internacionais, embora menos frequentes, alcançaram maior ressonância e influência em redes internacionais de conhecimento, atraíram mais atenção e interesse da comunidade internacional, superando significativamente a expectativa média para publicações similares, além de exercerem uma influência mais significativa em tecnologias patenteáveis e na formulação de políticas públicas. Esses resultados podem ser úteis para informar políticas, orientando caminhos para ampliar a prolificidade e o impacto da pesquisa.

Palavras-chave: Universidade-indústria, Colaboração em pesquisa, CNEN, SciVal.

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1. INTRODUCTION

The growing recognition of university-industry collaborations as a strategic alternative for strengthening innovation systems [4, 9, 19, 6], and consequently for regional and national economic and social development [17, 12, 2, 22], has fueled ongoing academic and political debate.

In recent years, the literature on university-industry collaboration has experienced a notable increase. Although marked by multiple distinct and ambiguous perspectives, characterized by highly complex interconnections, recent literature can be synthesized into three central and interconnected perspectives [22]. From the individual perspective, the focus is on human capital, mainly exploring how personal relationships (and emotional bonds) influence collaboration and knowledge transfer between academia and industry [21, 22]. The organizational perspective emphasizes interactions and knowledge transfer between organizations, mainly examining the importance of geographic and cognitive proximity for university-industry collaboration [21, 22]. Finally, the institutional perspective points to the growing importance of political and institutional aspects that facilitate (or hinder) the effectiveness of university-industry collaborations, mainly analyzing how public and institutional policies shape (and encourage) collaborations between academia and industry [21, 22].

Despite a significant increase in the last decade, there is still a lack of studies on university-industry collaboration in the context of late-developing economies [10, 5], such as Brazil. On the one hand, these countries, compared to technologically developed ones, face complex and significant challenges. On the other hand, university-industry collaborations occur in different contexts and are dependent on idiosyncratic factors related to the geographic, political, and historical-cultural aspects in which they evolved. This reinforces the need for studies directed at specific contexts.

Moreover, in developing and emerging countries, given the lack of research infrastructure and the limitation (or instability) of resources for research and development (R&D) [20, 13, 15], university-industry collaboration also represents a strategic path for research production. Some studies have emphasized the importance of research collaboration, especially intersectoral collaborations, arguing that national research policies should focus on promoting collaboration [15, 1].

In this sense, there is also a need for more studies on university-industry collaboration aimed at research production, especially in developing and emerging countries. Some studies have revealed a positive correlation between university-industry collaborations and research production [11, 21], including an increase in research quality [3]. Few studies address the impacts of research resulting from university-industry collaboration, focusing primarily on scientific impacts while neglecting economic and social impacts. Therefore, there is a scarcity of studies on university-industry collaborations that result in scientific publications, as well as the associated scientific, economic, and social impacts, particularly in Brazil.

Aligned with the National Science, Technology, and Innovation Strategy (2016), which highlights the nuclear sector as strategic for the country's development, and the Brazilian Nuclear Policy (2018), which advocates university-industry collaboration for strengthening the nuclear sector in the country, the study of the research collaboration dynamics of the National Nuclear Energy Commission (CNEN), considered the vector of nuclear policy at the national level, becomes necessary, or even indispensable. To help fill this identified gap, this study aimed to examine the research output of the CNEN, considering different levels of geographical and intersectoral collaboration, as well as its respective scientific, economic, and social impacts, over the period from 1996 to 2023 — the longest available data series.

2. MATERIALS AND METHODS

Considering the feasibility of measuring research collaboration—particularly intersectoral collaboration involving universities, industry, and government—as well as the different types of impact resulting from such collaboration (scientific, economic, and social), the informetric method was adopted. Informetrics encompasses three main subfields: bibliometrics, which analyzes the volume of publications and authorship patterns; scientometrics, which assesses scientific and economic impact through citations and patents; and altmetrics, which measures the social reach of research, considering its presence in public policies and digital platforms [7]. The use of the informetric method to examine collaboration at both geographical and sectoral levels, although present in the international literature [8], represents a distinctive approach in the national context, where studies are predominantly based on surveys and case analyses.

To identify, systematize, and subsequently generate recognizable and reproducible information on the research collaboration dynamics of the CNEN, internationally indexed publications in the Scopus database (Elsevier) from 1996 to 2023 were used, via the SciVal platform (Elsevier), a research performance evaluation tool. This choice is justified both by the rigorous curation of the database, which indexes journals and publications through peer review, and by the extensive coverage and availability of reliable, high-quality multidisciplinary bibliographic metadata. Although access to the databases is restricted to subscribers, access was guaranteed through the Federated Academic Community (CAFe), provided by the National Education and Research Network (RNP), of which the Nuclear and Energy Research Institute (IPEN/CNEN) is a member, as well as through other agreements established by the University of São Paulo (USP). It should be noted that the information was retrieved on May 22, 2024.

However, it should be noted that the publications affiliated with the different Technical-Scientific Units (UTCs) of CNEN were considered, namely: the Nuclear

Technology Development Center (CDTN), the Northeast Regional Center for Nuclear Sciences (CRCN-NE), the Institute of Nuclear Engineering (IEN), and the Institute of Radiation Protection and Dosimetry (IRD), in addition to IPEN. Thus, a database containing 9,411 publications was created. The database was then decomposed into multiple interrelated databases, allowing for the examination of the impact of collaborative research at geographic and intersectoral levels.

In terms of scientific prolificacy, research output was considered—that is, the count (volume) of internationally indexed publications and, by extension, the annual growth rate of research production. Accordingly, the growth rate was calculated based on the difference in research output between a given year and the previous year, relative to the research output of the previous year [8]. This choice is justified, on the one hand, by the ability to understand the volume of research production and its evolution over time, and on the other hand, by the ability to normalize and compare entities more equitably.

To provide a comparative assessment and a more equitable understanding of scientific impact—adjusting for the inherent variations across different fields of knowledge, publication year, and document type—the field-weighted citation impact (FWCI) was considered. This metric compares the volume of citations received to the expected citation count—that is, the average number of citations for similar publications. Furthermore, to offer additional insight into citation impact, the count (and percentage) of highly cited publications—those in the top citation quartile—was also considered, with adjustments for the intrinsic differences among fields of knowledge. Additionally, to capture the influence of publications, particularly those with lower citation potential, the field-weighted view impact (FWVI) was used, taking into account the variations related to academic field, year, and document type. The methodology used to calculate the FWCI and FWVI indicators, both developed by Elsevier, has been detailed in previous studies [18].

Considering that innovation is generally defined as the successful implementation of new or significantly improved ideas—whether in the form of products, processes, organizational methods, or business models—that generate economic value, and also that patent filings are often used as a proxy indicator of technological innovation [14], the count (volume) of publications cited in patents was used as a proxy indicator of the innovative profile and influence on patentable technologies—that is, the economic impact of research output.

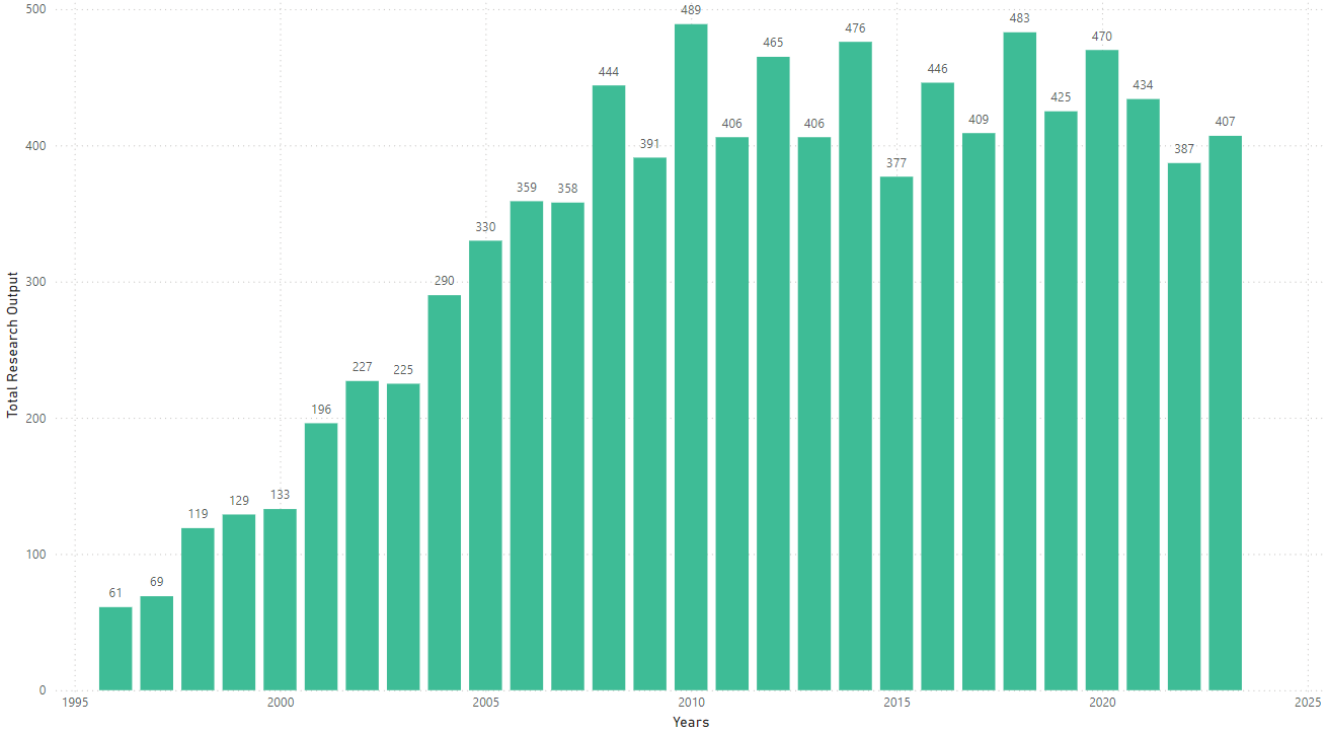
Concerning the social impact of research output, the count (volume) of publications cited in public policies was used as a proxy indicator, reflecting the resonance and influence of publications in public policies—i.e., in direct benefit to society. Additionally, to explore underlying aspects of the capacity to produce research with social impact, the count (volume) of citing policy documents was considered.

3. RESULTS AND DISCUSSIONS

3.1. Scientific Prolificacy of CNEN

Despite annual variations and discrepancies between fields of knowledge, during the period from 1996 to 2023, CNEN recorded 9,411 internationally indexed publications, including journal articles (71%), conference papers (25%), reviews (1.9%), and book chapters (1.8%). This highlights the importance placed on both original, rigorously reviewed research and participation in prominent networks and debates. Figure 1 shows the evolution of research output—i.e., the volume of internationally indexed publications—from 1996 to 2023.

Figure 1: Evolution of research output (1996-2023)



Source: Own elaboration based on Scival (Elsevier).

On average, research output was 336 publications per year. Regarding the evolution of research output, most years saw production slightly above average, suggesting underlying stability in research production capacity. Additionally, some exceptional years saw significantly higher-than-average output, such as 2010 (489), 2014 (476), 2018 (483), and 2020 (470), indicating notable episodes of high scientific prolificacy.

Moreover, over the past three decades, the average growth in research output was approximately 9% per year. Most years had positive growth rates, which can be interpreted as an indicator of consistent and marked growth in research production. Additionally, some atypical years showed exceptionally accelerated growth, such as in 1998 (72%), 2001 (47%), and 2004 (29%). The highlighted years correspond to a phase of expansion in CNEN's educational and research infrastructure, particularly marked by the creation of the CRCN-NO (1996) and the launch of stricto sensu graduate programs both at the IRD (2001) and the CDTN (2002). Moreover, the relative performance can be broken down into key aspects

that include, but are not limited to, the start of operations at the Angra II nuclear power plant in the 2000s; the Regional Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL), signed in 1998; and several other international agreements, such as those with Canada in 1996, the United States in 1997, South Korea in 2001, and France in 2002 [16]. These milestones, when combined with the expansion of CNEN's education and research infrastructure, may have had multiplier effects on research output during the highlighted period and in subsequent years.

In terms of scientific prolificacy, over the past three decades, there has been a trend of marked and consistent growth in research output, despite considerable annual variations. These variations may be associated, at least in part, with the historical context of political-institutional aspects and incentives for research, as well as the conditions of CNEN's educational and research infrastructure, including the dynamics of research collaboration—which warrants further attention.

3.2. Geographic Collaboration

Table 1 displays the percentage of research output, broken down by different levels of geographic collaboration, as well as their respective scientific, economic, and social impacts, during the period from 1996 to 2023.

In terms of geographic collaboration, almost all research output involved some level of geographic collaboration. Only 1.1% of the indexed publications were single-authored, with no collaboration. The publications were predominantly recorded with national collaborators (64.1%), followed by international collaborators (24.6%) and institutional collaborators (10.1%).

Regarding scientific impact, notably the percentage of highly cited publications, those with international collaboration stood out, with 26.8% of these publications falling in the top citation quartile, remaining above the average percentage relative to total research output (18.7%). Additionally, when considering the FWCI, it was observed that publications with

international collaboration (0.97) exhibited greater resonance and influence compared to total research output (0.70), approaching the average expected citation rate for similar publications (1.0). Moreover, considering the FWVI, publications with international collaboration (1.47) exceeded the average expected views for similar publications and achieved greater visibility relative to total research output (1.19). Publications with international collaboration exceeded the expected views for similar publications by 47%, while those with national and institutional collaboration exceeded by 10% and 6%, respectively, attracting greater interest and attention from the international community.

Table 1: Research output, by level of geographic collaboration (1996 a 2023)

Geographic Collaboration	Output	Highly Cited	Citation Impact (FWCI)	Views Impact (FWVI)	Economic Impact	Social Impact
International	24.6%	26.8%	0.97	1.47	5.6%	5.6%
National	64.1%	16.6%	0.61	1.10	5.8%	2.6%
Institutional	10.1%	13.3%	0.51	1.06	4.5%	2.1%
Single Author	1.1%	9.3%	0.36	0.95	0.9%	1.9%
Total Research Output	100%	18.7%	0.70	1.19	5.6%	3.3%

Source: Own elaboration based on Scival (Elsevier).

Concerning economic impact, reflecting the resonance and impact of publications on patentable technologies, it was observed that 5.8% of publications with national collaboration were cited in patents, garnering 776 citations across 739 distinct patents, while 5.6% of publications with international collaboration were cited in patents, garnering 488 citations across 473 patents. Additionally, 4.5% of publications with institutional collaboration and 0.9% of single-authored publications were cited in patents, with 70 and 1 citations across 68 and 1 distinct patents, respectively. However, when considering the volume of patent citations relative to the volume of publications, publications with international collaboration stood out. Specifically, for every 100 publications with international collaboration, there were 21 patent citations, whereas for every 100 publications

with national collaboration, there were 13 patent citations. Thus, publications with international collaboration showed a greater propensity to be cited in patents, indicating a higher economic impact.

Regarding social impact, reflecting the resonance and impact of publications on policy-guiding documents, it was observed that 5.6% of publications with international collaboration were cited in 304 distinct policy documents, while 2.6% of publications with national collaboration were cited in 211 distinct policy documents. Additionally, 2.1% and 1.9% of publications with institutional collaboration and without collaboration (single authorship), respectively, were cited in policy documents. Thus, it can be inferred that publications with international collaboration have a greater propensity to influence public policies, being more frequently cited in guiding policy documents, indicating a more significant social impact.

3.3. Intersectoral Collaboration

Table 2 displays the percentage of research output, broken down by different levels of intersectoral collaboration, as well as their respective scientific, economic, and social impacts, during the period from 1996 to 2023.

In terms of sectoral collaboration, 97.6% of research output involved some level of sectoral collaboration. Publications were predominantly registered in collaboration with governments (64.9%), followed by bipartite collaborations with academia (27.5%) and industry (3.0%). Only 2.1% of publications were related to tripartite collaborations, involving CNEN, industry, and government simultaneously.

Regarding scientific impact, particularly the percentage of highly cited publications, tripartite collaborations involving CNEN, industry, and government stood out, with 30.6% of these publications in the top citation quartile, surpassing the average percentage relative to total research output (18.7%) and other forms of sectoral collaboration. Publications in collaboration only with industry (28.6%) and only with government (19%) also stood out.

Table 2: Research output, by level of sector collaboration (1996 a 2023)

Sector Collaboration	Output	Highly Cited	Citation Impact (FWCI)	Views Impact (FWVI)	Economic Impact	Social Impact
Academic	27.5%	18.4%	0.67	1.22	6.0%	2.4%
Government	64.9%	19%	0.71	1.19	5.6%	3.5%
Industry	3.0%	28.6%	1.06	1.65	8.7%	6.6%
Industry – Government	2.1%	30.6%	1.19	1.83	9.3%	8.3%
Total Research Output	100%	18.7%	0.70	1.19	5.6%	3.3%

Source: Own elaboration based on Scival (Elsevier).

Furthermore, when considering the Field-Weighted Citation Impact (FWCI), it was observed that tripartite collaborations (1.19) exhibited greater resonance and influence in international knowledge networks, surpassing the average expected citation rate for similar publications by 19%, while publications in collaboration only with industry surpassed by 6%. It is noteworthy, however, that publications in collaboration only with academia and only with government did not meet the average expected citation rate for similar publications.

Additionally, considering the FWVI, it was observed that tripartite collaborations exceeded the average expected views for similar publications and achieved greater visibility relative to other forms of sectoral collaboration. Tripartite collaborations exceeded expected views for similar publications by 83%, attracting greater interest and attention from the international community, while bipartite collaborations with industry, academia, and government exceeded by 65%, 22%, and 19%, respectively.

Regarding economic impact, it was observed that 9.3% of publications in tripartite collaboration (CNEN-industry-government) were cited in patents, garnering 123 citations across 112 distinct patents. In comparison, 8.7% of publications in exclusive collaboration with industry were cited in patents, garnering 143 citations across 132 distinct patents. Exclusive collaborations with academia and government had a lower percentage of publications cited in patents, despite having a higher volume of publications.

Thus, considering the volume of patent citations relative to the volume of publications, tripartite collaborations (CNEN-industry-government) stood out. Specifically, for every 100 publications in collaboration with both industry and government, there were 64 patent citations, while for every 100 publications in collaboration with industry and government separately, there were 50 and 16 patent citations, respectively. Therefore, it can be inferred that publications in collaboration with both industry and government simultaneously have a greater propensity to influence patentable technologies, being more frequently cited in patents, indicating a more significant economic impact. This underscores the importance of integrating science, industry, and government to promote innovation and economic growth.

Regarding social impact, it was observed that 8.3% of publications in tripartite collaboration (CNEN-industry-government) were cited in 21 distinct policy documents, while 6.6% of publications in collaboration with industry were cited in 25 distinct policy documents. Additionally, 2.4% and 3.5% of publications with exclusive collaboration with academia and government, respectively, were cited in policy documents.

Thus, it can be inferred that publications in tripartite collaboration, involving both industry and government, have a greater propensity to influence public policies, being more frequently cited in guiding policy documents, indicating a more significant social impact.

In summary, the results reveal that intersectoral collaboration—especially when it simultaneously involves CNEN, industry, and government—although less frequent, is associated with the highest scientific, economic, and social impacts of research output. Publications resulting from these tripartite partnerships showed: (i) greater scientific resonance, with 30.6% of articles among the most cited and a FWCI of 1.19; (ii) higher international visibility, with a FWVI of 1.83 (83% above the expected average); (iii) greater influence on patentable technologies, with 9.3% of articles cited in patents; and (iv) greater social impact, with 8.3% cited in public policy documents.

3.4. Intersectoral and Geographic Collaboration: Triangulation

Table 3 displays the percentage of research output, broken down by different levels of intersectoral and geographic collaboration, as well as their respective scientific, economic, and social impacts, during the period from 1996 to 2023.

In terms of intersectoral and geographic collaboration, it was found that publications were predominantly registered in collaboration with government and national actors (49.9%), followed by collaborations with government and international actors (17.9%). Only 1.8% of publications involved collaborations with industry and international actors, and 1.3% involved industry and national actors. The proportion of publications involving collaboration with industry, government, and international actors (1.2%), or industry, government, and national actors (0.9%) is relatively smaller.

However, despite being less frequent, publications involving collaboration with industry, government, and international actors simultaneously tend to generate publications with greater impact across all dimensions (scientific, economic, and social). Regarding scientific impact, it was observed that publications involving collaboration with industry, government, and international actors simultaneously exhibited greater resonance and influence in international knowledge networks, surpassing the average expected citation rate for similar publications (FWCI) by 56%, and attracting greater international attention and interest, surpassing the average expected views for similar publications (FWVI) by 122%. Notably, 40.5% of publications involving collaboration with industry, government, and international actors are in the top citation quartile.

Table 3: Research output, by level of sector and geographic collaboration (1996 a 2023)

Setorial	Geographic	Output	Highly Cited	Citation Impact (FWCI)	Views Impact (FWVI)	Economic Impact	Social Impact
Government	National	46.9%	16%	0.61	1.08	5.5%	2.4%
	International	17.9%	27.1%	0.97	1.49	5.8%	6.4%
Industry	National	1.3%	20%	0.66	1.34	6.7%	4.2%
	International	1.8%	34.7%	1.34	1.87	10.2%	8.4%
Industry – Government	National	0.9%	17.1%	0.69	1.30	6.1%	4.9%
	International	1.2%	40.5%	1.56	2.22	11.7%	10.8%
Total Research Output		100%	18.7%	0.70	1.19	5.6%	3.3%

Source: Own elaboration based on Scival (Elsevier).

Additionally, concerning economic impact, it was observed that 11.7% of publications involving collaboration with industry, government, and international actors simultaneously were cited in patents, garnering 118 citations across 108 distinct patents. Moreover, for every 100 publications in collaboration with industry, government, and international actors simultaneously, there were 106 patent citations, suggesting that some publications influenced multiple patentable technologies. Furthermore, regarding social impact, it was observed that 10.8% of publications involving collaboration with industry, government, and international actors simultaneously were cited in 16 distinct policy documents, indicating a more significant social impact.

Thus, the results indicate that intersectoral and international collaboration—involving CNEN, industry, government, and foreign partners—generates the highest impacts across all evaluated dimensions. Although intersectoral and international publications represent only 1.2% of the total, they concentrate: (i) high scientific influence, with 40.5% among the most cited articles and a FWCI of 1.56; (ii) high international

visibility, with a FWVI of 2.22 (122% above the expected average); (iii) significant economic impact, with 11.7% of articles cited in patents; and (iv) substantial social impact, with 10.8% of articles cited in public policy documents.

Although the count of citations in patents represents a robust indicator of the economic and technological impact of scientific output, it is necessary to highlight an important limitation: this metric essentially reflects external recognition of the relevance of CNEN's publications in developing patentable technologies—predominantly cited in patents deposited by third parties in international patent offices—and does not necessarily translate into CNEN's effective innovative capacity, that is, its direct ability for technological generation and appropriation. Thus, to explicitly assess CNEN's innovative capacity, it is recommended, as a future research agenda, to complement this analysis with the counting of own patents filed and granted in national and international patent offices. This approach would clearly highlight the techno-economic impact of CNEN's publications as well as its innovative prominence. Therefore, as an institutional strategic policy, strengthening systematic efforts towards the filing of CNEN's own patents is recommended, demonstrating technological autonomy, ensuring effective protection of generated intellectual property, and enabling full appropriation of the economic benefits. This strategy aligns with national innovation policies and strengthens CNEN's role as a technological anchor in Brazil.

4. CONCLUSIONS

This research examined the dynamics of research collaboration within the CNEN, as well as its respective scientific, economic, and social impacts over the past three decades – the longest available data series, which lends originality and novelty to the study. In terms of scientific prolificacy, there has been a marked and consistent growth in research output over

the last three decades, despite considerable annual variations. Additionally, the proportion of co-authored publications was higher compared to single-authored publications, with a notable emphasis on national-level collaborations. However, the proportion of intersectoral publications, particularly those involving industry, is relatively and significantly lower.

Despite this, in terms of research output impact, it was found that intersectoral publications, especially those co-authored by CNEN with industry, government, and international actors, though less frequent, exhibited greater impact across all evaluated dimensions (scientific, economic, and social). These publications achieved greater resonance and influence in international knowledge networks, attracted more attention and interest from the international community, significantly exceeding the average expectations for similar publications. Additionally, they exerted a more significant influence on patentable technologies and in public policy formulation. Thus, it was revealed that promoting research internationalization combined with encouraging intersectoral collaboration, particularly with both industry and government simultaneously, may represent a fruitful path to maximize the scientific, economic, and social impacts of research output.

These findings can be useful for informing policies, guiding pathways to enhance the prolificacy and impact of collaborative research. Future research could examine the prolificacy and differential impact of geographic and intersectoral collaborations across different fields of knowledge, explore collaboration between organizations with a focus on geographic and cognitive proximity, or investigate the political-institutional aspects that facilitate (or hinder) the effectiveness of collaborations, focusing on public and institutional policies that shape (and encourage) intersectoral collaborations.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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