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

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1. Introduction

Studies on academia-industry collaboration are relatively rare, and few address the dynamics of collaboration in the context of countries with late economic and technological development, such as Brazil. Compared to technologically developed countries, these countries face complex and significant challenges [1,3,4,5].

This research contributes by filling this gap and providing an original perspective by examining the research collaboration dynamics of the National Nuclear Energy Commission (CNEN), through its Scientific and Technical Units (STUs), over the last three decades. Furthermore, the research offers an empirical contribution by measuring the intensity of research collaboration and its impacts (scientific, economic, and social), at different levels (institutional, national, and international) and for different actors (government, industry, and medical-hospital organizations, in particular).

Aligned with the National Strategy for Science, Technology, and Innovation [2], which highlights the nuclear area as strategic for the country's development, and the Brazilian Nuclear Policy, which advocates academia-industry collaboration as strategic for strengthening the nuclear sector, studying the research collaboration dynamics of the CNEN's STUs becomes necessary, or even indispensable, to guide future collaborations and point out ways to enhance the economic and social impact.

Moreover, given its 'bifrontal' nature, which serves as a public policy instrument – the state aspect, and also provides services in nuclear technology – the market aspect, CNEN is a relevant case and constitutes a differential in the studies of academia-industry collaboration in the country, predominantly concentrated from the perspective of universities, or companies, in isolation.

2. Methodology

In line with the general objective of the research, an exploratory study of descriptive and analytical nature was conducted. Based on the requirements to: (a) measure research collaboration, (b) include informal collaboration arrangements, and (c) considering the availability of existing data, the bibliometric method was chosen. Although used in international literature, this method constitutes a differential in studies within the country - predominantly based on surveys and case studies.

To examine the dynamics of research collaboration, the scientific output affiliated with the CNEN's STUs, indexed internationally in the Scopus database from Elsevier, was used, utilizing the SciVal platform for the period from 1996 to 2023 - the longest data series available.

This choice is justified by the rigorous curation of the databases, indexing journals and publications through peer review, as well as by the breadth of coverage and the provision of reliable, high-quality multidisciplinary bibliographic metadata. Although restricted to subscribers, access to the databases was guaranteed through the Federated Academic Community (CAFe), provided by the National Network for Teaching and Research (RNP), which the Institute of Energy and Nuclear Research (IPEN/CNEN) is part of, and other agreements established by the University of São Paulo (USP).

Finally, it is noted that the information was retrieved on December 30, 2023.

3. Results and Discussion

Despite annual variations and discrepancies among knowledge areas, from 1996 to 2023, the CNEN's STUs indexed 9,270 scientific publications, involving scientific articles published in journals (71%) and conferences (25%), reviews (1.8%), and book chapters (1.7%), totaling approximately 129,000 citations and 232,000 views. The predominance of journal articles underscores the importance placed on original and rigorously reviewed research, while the significant presence of conference articles reflects engagement in prominent debates and networks.

The strong preference for publications in English (96%) aligns with global publishing practices. Although in the minority, publications in Portuguese or Spanish are important for disseminating knowledge in the local and regional context. Furthermore, 2,187 publications, or 24% of the total, are categorized as open access, subdivided into gold, hybrid gold, bronze, and green, highlighting a commitment to open science and a growing trend towards democratizing access to knowledge.

While the volume of publications reflects scientific prolificacy, offering a measure of contribution to the advancement of scientific knowledge, key impact indicators of citation (FWCI) and view (FWVI), weighted by field of knowledge, emerge as distinctive metrics and offer insight into the resonance and reach of the research within the international scientific community.

Considering the citation impact (FWCI), a non-linear trend was observed, indicating that the volume of citations fluctuated year by year, remaining below the global average for similar publications. However, in 2023, there was a significant increase, showing that, in that year, despite a relatively smaller scientific output, the publications had a citation impact 8% higher than the global average for similar publications. As for the view impact (FWVI), a declining trend was observed with fluctuations from year to year. However, notably, it consistently remained above the global average for similar publications. Moreover, in 2023, the publications had a view impact 20% higher than the global average for similar publications, indicating a renewed international interest in the research conducted by the CNEN's STUs.

The prolificacy of the CNEN's STUs in the analyzed period can be decomposed into key aspects that involve, but are not limited to, the expansion of research capabilities, investment in scientific-technological development, growth of the academic body and postgraduate programs, and political-social and commercial conditions.

The following visualization (Table 1) provides a concise representation of the scientific output of the CNEN's STUs, distributed across different levels of collaboration: national, international, institutional, or single authorship, as well as their respective impacts in terms of citations, views, patent citations (knowledge with an innovative profile), and citations by policy bodies, from 1996 to 2023.

Table 1: Scientific Production and Impact, by levels of collaboration (1996-2023)

Co-authorship	*Output*	***Citation** Impact – (FWCI)*	***Views** Impact – (FWCI)*	*Output Cited by **Patents** (%)*	*Output Cited by **Policy** (%)*
UTCs/CNEN	9,270	0.70	1.19	5.3	2.8
International	2,269	1.00	1.47	5.5	5.2
National	5,947	0.62	1.11	5.5	2.1
Institucional	947	0.51	1.05	4.3	1.7
Single Author	107	0.36	0.95	0.9	1.9

Source: Own elaboration from Scival.

It was found that publications are predominantly registered with national collaborators (65%). In total, more than 400 national partner institutions were revealed. However, more than half of the publications with national co-authors refer to public educational and research institutions from the State of São Paulo. Despite a citation impact below the global average, publications with national co-authorship received a level of

attention and interest 11% higher than the global average for similar publications. However, it was found that publications with international co-authorship (24.5%), though relatively less frequent, displayed a higher impact in terms of citations, matching the global average. Moreover, they received a level of attention and interest 47% higher than the global average for similar publications.

The influence on patents and policy bodies, highlighting the practical and political relevance of the research conducted with national, international, or institutional collaborators, stands out. It was observed that 5.3% of the publications influenced patents filed in different patent offices, such as: United States of America (584), World Intellectual Property Organization – WIPO (216), People's Republic of China (148), and European Patent Office (127). In total, 1,190 patents cited the publications of the CNEN's STUs. Among the main applicants are the International Business Machines Corporation (37), Massachusetts Institute of Technology (20), Weber Jan (12), 3M Innovative Properties Company (10), Atanasoska Liliana (10), and Chiang Tony (9). Furthermore, they also influenced policy bodies (governmental, intergovernmental, or think tanks). In total, 461 documents cited the publications of the CNEN's STUs. Among the main ones are the Publications Office of the European Union (46), World Meteorological Organization (34), Joint Research Centre (30), Government Publishing Office – GPO (19), World Health Organization (15), and United Nations Environment Programme (14). In this context, publications with international co-authorship exerted greater influence on patents and policy bodies.

The following visualization (Table 2) provides a concise representation of the scientific output of the CNEN's STUs, from the traditional bilateral relationship (academia-industry) or the triad (academia-industry-government), as well as their respective impacts, from 1996 to 2023.].

Table 2: Scientific Production and Impact, from different actors (1996-2023)

Collaboration	***Citation** Impact - (FWCI)*	***Views** Impact - (FWCI)*	*Output Cited by **Patents*** %	*Output Cited by **Policy*** %	*Co-authorship **International*** %	*Co-authorship **National*** %	***Government** Collaboration* %
UTCs/CNEN	0.70	1.19	5.3	2.8	24.5	64.2	65
Government	0.72	1.20	5.3	3.1	27.3	72.2	100
Coporate	0.86	1.45	6.7	5.2	51.1	48.9	67.4
Medical	0.95	1.64	6.7	10.1	58.0	42.0	70.6

Source: Own elaboration from Scival.

It was found that publications in collaboration with the government or industry are cited less frequently than the global average for similar publications. However, the impact of citations is higher in collaborations with industry and especially with the medical-hospital sector, approaching the global average. In all categories analyzed, the view impact indicator reveals that publications are viewed more than the global average, with the greatest impact in collaborations with industry and the medical-hospital sector.

Meanwhile, it was observed that 65% of the publications were conducted in collaboration with the government, suggesting a strong synergy between the research activities of the CNEN's STUs and national objectives and priorities. Furthermore, 67% and 70% of the publications with industry and the medical-hospital sector, respectively, also involved collaboration with the government and international partners. These, in particular, exhibited a greater impact on citations and views, as well as a greater influence on patents and policy bodies. It was also noted that international co-authorship is more prominent in collaborations with industry and especially with the medical-hospital sector.

Regarding collaboration with industry, it was revealed that most of the publications were co-authored by companies such as DuPont, Studsvik AB, Suzano Group, Vale S.A., 2B Technologies, Inc., ABB Group, and Braskem, with Petrobras and General Motors being notably prominent. As for collaboration with the medical-hospital sector, in particular, most of the publications were co-authored by Hospital Israelita Albert Einstein, Hospital Sirio-Libanes, Tufts Medical Center, Hospital A.C. Camargo, and Hospital Samaritano.

Moreover, publications in collaboration with industry and, in particular, with the medical-hospital sector, exerted a strong influence on policy bodies. Among the main bodies are the Government Publishing Office – GPO, Government of Israel, Guidelines in PubMed, Publications Office of the European Union, Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften, World Health Organization, NHS England, Province of Québec, and Umwelt Bundesamt. Furthermore, they are also frequently cited by patents.

4. Conclusions

This research examined the dynamics of research collaboration of the CNEN's STUs over the last three decades – the longest data series available. Despite annual variations and discrepancies among knowledge areas, in this period, the CNEN's STUs indexed 9,270 scientific publications, accounting for about 129,000 citations and 232,000 views.

Of this total, 65% of the publications were in collaboration with governments, 1.5% with industry, and 1.3% with the medical-hospital sector. Moreover, most of the publications with industry and, in particular, with the medical-hospital sector, involved collaboration with the government and international partnerships.

These publications, stemming from the traditional bilateral relationship (CNEN-industry) and, above all, from the triad (CNEN-industry-government), exhibited a greater impact on citations and views, as well as a greater influence on patents (economic impact) and on policy bodies (social impact) – which underscores the need to promote and facilitate these collaborations further, aiming to expand the impact on science, technology, and society. Future research could explore the intersection of multiple factors that facilitate or hinder the effectiveness of these collaborations.

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