Science diplomacy and foreign affairs:

S&T cooperation from India-Germany and India-Japan

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Abstract

In the globalized world, diplomatic relations have a crucial role to play. Such relations have evolved over the years between countries and various forms of diplomacy have emerged, Science Diplomacy being one of them which is envisaged to enhance relations between countries, by addressing global challenges and facilitating the exchange of resources in science, technology, and innovation (STI). India's foreign policy prioritises the utilisation of Science & Technology (S&T) to foster international cooperation. The country had established science counsellors in the Indian embassies at USA, Japan, Germany and Russia to foster scientific relations. In this paper we take the case of two countries amongst the four, Germany and Japan to understand how India had undertaken scientific relations with the respective countries. Along with the development of the several schemes to foster R&D in the countries for joint R&D, student visits, etc., bibliometric analysis with indicators to measure the productivity performance was implied to assess the progress of collaborative research among the countries in the study for the period 2001-2022.

1. Background

The concept of Science Diplomacy is emerging as an inseparable part of Science Technology and Innovation policy since the last decade as it tries to interconnect between Science and Politics bringing in a new rhetorical that stresses on novel policies to bridge the gap between the drivers of insular fields. Science diplomacy (SD) refers to the process and practises that occur at the intersection of two domains, namely science and diplomacy. It encompasses a set of practices in which science and technology intersect with foreign affairs and international relations (Ruffini, 2020). This term, coined lately, encompasses the interaction between these two fields (S4D4C, 2019) "Science and Technology Diplomacy" (Scientific Diplomacy) has emerged as a new mechanism for developing, shaping, and reshaping international relations across the world (Lloyd & Patman, 2014). In "Scientific Diplomacy", science and knowledge are at the core of a country's power and the seductiveness of its ideas, and therefore who will shape and direct it is very important (Degelsegger & Blasy, 2011). In addition, the influence and effectiveness of diplomats and international civil servants is increasingly dependent upon the extent to which they can mobilize scientific and technical expertise in their work (United Nation, 2003). Science diplomacy highlights how science may bridge the gap between flawed politics driven by national self-interests. It emphasises the need to promote scientific diplomacy as a means to facilitate

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this process (Rungius and Flink 2020). As scientific and technological issues become increasingly dominant in global affairs, and in order to build and form a consensus on scientific issues, ways must be found to identify the key players in science and technology as well as how to mobilize them. This is where the roles of those key players, as a powerful engine for the progress and development of "Scientific Diplomacy" becomes significant (Ghanbari & Ideris, 2018).

2. Scope of S&T diplomacy policy / strategy

Despite having many traditional types of diplomacy (such as political, cultural and media diplomacy), rapid changes in science, knowledge, and technology resulted in the development of a new strategy. Science diplomacy is recognised to enhance relations between countries, by addressing global issues and facilitating the exchange of resources, where science, technology, and innovation (STI) are acknowledged as catalysts for social and economic advancement, as well as drivers of globalisation. To promote such diplomatic relations, cooperation is required between the government departments involved in diplomacy and science and technology. Such cooperation includes the identification of the strengths and weaknesses of the partner countries and the exploration of international joint research topics (RTs) in close relationship with the scientific community. RTs for science and technology diplomacy are generally selected by a bottom-up approach driven by scientists and researchers or a top-down approach defined by government agencies in pursuit of top-down strategic priorities (Ceballos, et.al. 2017; The Royal Society, 2010). The problems include the bias arising from the subjective judgment of scientists, the attribution of the halo effect to famous researchers, and the use of different criteria for different experts (Chubin and Hackett, 1990; Kostoff , 1994). It may be difficult for an expert in a particular field to judge the suitability of an interdisciplinary topic beyond his or her domain or compare topics from different fields. The process of selecting an RT requires knowledge of a wide range of subjects, time, and effort. In the case of a top-down approach to science diplomacy, there may be complaints arising from scientists being asked to conduct collaborative research.

India's foreign policy prioritises the utilisation of Science & Technology (S&T) to foster international cooperation. It is responsible for identifying, facilitating, and promoting India's collaboration with other countries in cutting-edge and emerging areas of STI through bilateral, regional, and multilateral programmes governed by the Transaction of Business Rules & the Cabinet Business Rules. In its pursuit of promoting scientific cooperation and collaboration, India has established bilateral and multilateral collaborations with several countries. Understanding the primary role of the Science Attaché or Counsellor of Scientific and Technological Affairs at an Embassy as practitioners of Science Diplomacy to analyse and assess the influence of scientific and technological advancements on policy issues relevant to the State and thereafter to propose suitable courses of action based on their findings, India has established science counsellors in USA, Japan, Germany and Russia. In this paper we take the case of two countries amongst the four, namely Germany and Japan to understand how India had undertaken scientific relations with the respective countries.

3. India–Germany Science Diplomacy

India had established diplomatic relations with Germany in the aftermath of the Second World War, making it one of the earliest countries to do so. However, the Indo-German Science & Technology cooperation commenced with the ratification of the Intergovernmental S&T Cooperation Agreement in 1971 and 1974. In May 1974, an Inter-governmental Agreement on "Cooperation in Scientific Research and Technological Development" was signed based on which the Indo-German Science & Technology (S&T) cooperative programme was carried. In 1994, an apex Indo-German Committee on Science and Technology (S&T) was formed to oversee the implementation of cooperation between India and Germany which includes coordination with various Indian organisations such as the Department of Science and Technology (DST), Department of Biotechnology (DBT), Ministry of Earth Sciences (MOES), Council of Scientific and Industrial Research (CSIR), Indian Council of Medical Research (ICMR), and Department of Atomic Energy (DAE).

Eleven sessions of the S&T Joint Committee was held, with the most recent one being held in Berlin in 2017. The Indian delegation is led by the Secretary, DST, while the German delegation is led by the State Secretary of the Federal Ministry of Education and Research (BMBF). Through this cooperation

There exist over 150 collaborative scientific and technological research initiatives and 70 direct alliances between the Universities of both nations. India's scientific institutes have strong collaborations with leading German research and development organisations, such as the Max Planck Society, Fraunhofer Laboratories, and Alexander von Humboldt Foundation as a result of research programs like DST-Max Planck Gessellschaft (MPG) and others which were launched during 1998 onwards as found in Table 1. India has made significant investments in prominent scientific endeavours in Germany, including the Facility for Anti-Proton and Ion Research (FAIR) located in Darmstadt, as well as the Deutsche Elektronen Synchrotron (DESY), which is dedicated to conducting studies in the fields of innovative materials and particle physics. The cumulative amount of bilateral Technical and Financial Cooperation since its inception in 1958 is €10.91 billion. Development cooperation focuses on prioritising energy, sustainable economic development, and the management of natural resources in order to promote environmental sustainability. German firms also provide scholarships for Indian students to pursue postgraduate studies at German universities. Germany has agreed to offer concessional loans of up to € 1 billion for the funding of Green Energy Corridors through German development cooperation. In November 2019, during Chancellor Merkel's visit to Delhi, Germany and India agreed to establish a joint research programme in Artificial Intelligence. They also decided on the extension of the Indo-German Partnership in Higher Education for another four years, with contributions of 3.5 Million Euros each.

Germany is now hosting around 9,000 Indian students who are enrolled in different academic programmes, whereas India is accommodating approximately 800 German students. A growing number of Indian students are choosing to pursue Engineering and Management programmes at German universities. The exchange of students and young researchers has considerably grown over the past years. Since 2008, the number of Indian students in Germany has quadrupled making Indian students the second largest foreign student group in the German university system.

India and Germany have established multiple mechanisms to facilitate and enhance cooperation and collaborative effort in science and technology. The collaborations encompass the following:

- Collaborative research initiatives involving institutions and scientists
- Joint projects in the 2+2 format, involving research and development institutions and industries from both countries, facilitated by the Indo-German Science and Technology Centre (IGSTC)

Figure 1 India–Germany Trade Statistics, 2018–2022 (US$ Billion)

Source: https://www.india-briefing.com/news/profiling-india-germany-trade-and-investment-relations-26995.html/

- A project-oriented people exchange initiative focused on the exchange of young PhD scientists.
- Indian students, researchers, and scientists will visit Germany to engage with Nobel Laureates.
- Collaborative workshops, seminars, symposia, schools, and trainings will be conducted.
- Research groups will be connected through networking.
- Frontiers of Engineering symposia will be organized. • Participation in large-scale science projects such as FAIR and DESY will be encouraged.
- Establishment of Indo-German Max Planck Centres.
- The Indo-German Centre for Sustainability (IGCS)

Additionally, Germany is the ninth largest investor in India, with cumulative foreign direct investment (FDI) inflows of US$13.8 billion during the April 2000–September 2022 period. Key areas of German investment in India have been transportation, electrical equipment, and metallurgical industries, chemicals, construction activity, trading, and automobiles. Germany's total foreign direct investment in India from 2000 until 2016 amounted to approx. EUR 9 billion. There are more than 1600 Indo-German collaborations and over 600 Indo-German Joint Ventures in operation. Indian corporate entities have invested over EUR 6.5 billion in Germany, especially in sectors of IT, automotive, pharma and biotech. Today, there are more than 200 Indian companies operating in Germany. In the period from 2021 to 2022 (up until October 2021), the total value of bilateral trade between the two countries amounted to USD 13.83 billion, representing a 16% growth compared to the same period in the previous fiscal year, 2020-2021. Indian exports to the US reached $5.4 billion during this period, representing a growth of almost 27%.

Table 1 Time–line of evolution of Indo–German cooperation of S&T development

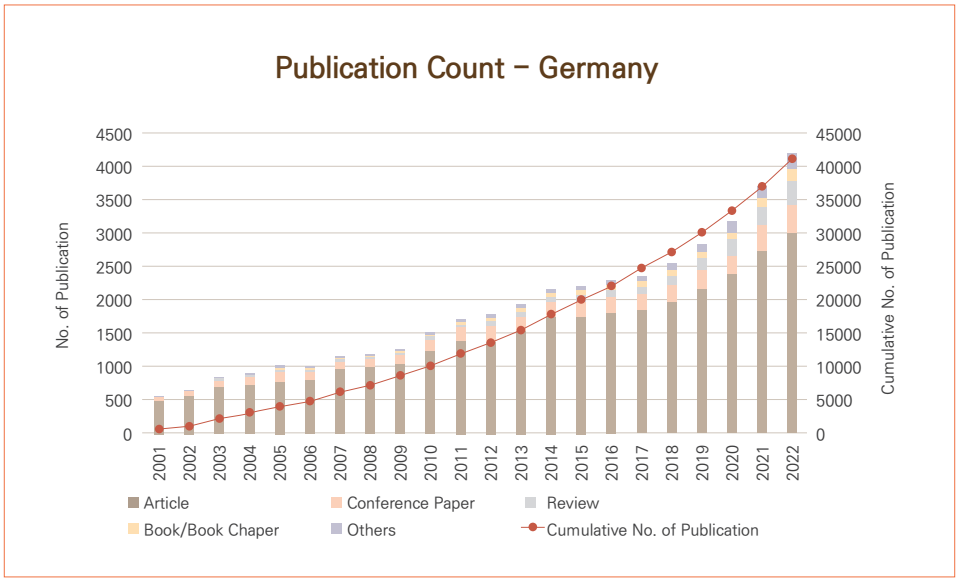
Year	Events/Programs	Objectives/Thrust Areas
May, 1974	Inter–governmental Agreement on "Cooperation in Scientific Research and Technological Development"	▸ Department of Science & Technology (DST) from Indian side and the Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung – BMBF) from Germany are the nodal agencies for overall coordination of the programme
1994	An apex Indo–German Committee on S&T established	▸ to coordinate the implementation of the cooperation through joint review of the activities and suggesting measures towards enhancement of cooperation
1998	DST– Deutscher Akademischer Austauschdienst (DAAD) Program	▸ Project based Personnel Exchange Programme (PPP) ▸ More than 600 researchers from both countries have been promoted
2004	DST–Max Planck Gessellschaft (MPG) Program	▸ Thrust areas – Partner Group Programmes, Mobility Grants, Kick–off Workshops
2005	DST–Deutsche Forschungsgemeinschaft (DFG) Program	▸ Aims to support joint research projects; use major of facilities in Germany and India; establishment of International Research Training Groups (IRTG) and Collaborative Research Centers
2008	DST–Alexander von Humboldt (AvH) Program on Frontiers of Engineering	▸ inter–disciplinary seminars ▸ IGSTC and AvH jointly launched the IGSTC–CONNECT Plus Programme in 2018

2010	Establishment of Indo-German Science and Technology Centre (IGSTC)	▸ To cultivate and advance research collaborations that are pertinent to industry, jointly supported by the Governments of India and Germany ▸ 2+2 paradigm – involvement of one academic institution and one industry partner from each country ▸ A total of 40 projects have received funding in national priority areas, including Advance Manufacturing (Make in India), Embedded System and ICT (Digital India), Sustainable Energy/ Environment, Biotechnology / Bio-economy (Food Security), Bio-Medical Technology (Healthy India)/ Water and Wastewater Technology (Clean India), Smart Cities, and more ▸ 21 projects completed and 19 are currently ongoing
2010	Indian participation in Facility for Antiproton and Ion Research (FAIR) project of Germany	▸ Alongwith UK, Finland, France, Germany, India, Poland, Romania, Russia, Slovenia, and Sweden, India signed the FAIR Convention and Act under which shareholders from India joined one of the world's largest construction projects for research being realized in international cooperation ▸ Funding is jointly by the Department of Science and Technology and the Department of Atomic Energy on 50:50 basis ▸ Indo-FAIR Coordination Centre (IFCC) has been established at the Bose Institute to coordinate the implementation of this project in India ▸ Presently 22 institutions and 1 industry are participating; 5 DAE institutions, 17 universities and non-DAE institutions (like Bose Institute, Kolkata, Delhi University, Panjab University, Chandigarh, Jammu University, Rajasthan University, Jaipur, etc.); and the Electronics Corporation of India Limited (ECIL), Hyderabad
2011	Indian National Science Academy (INSA) – DFG Program	▸ Joint funding to increase bilateral scientific cooperation through workshops or mobility funding to initiate joint projects ▸ INSA nominates approx. 25 – 30 Indian researchers every year to visit Germany in order to initiate collaborative projects
2011	India – Germany cooperation in Synchrotron research (DESY) Hamburg	▸ Saha Institute of Nuclear Physics (SINP), Kolkata and DESY, Germany signed one of the four major Cooperation Agreements, DST giving funding support for this program ▸ More than 750 scientists from India visited DESY for experiments from 50 different institutes and performed 260 experiments ▸ Over 180 publications till May 2020
2012	DBT-German Research Foundation (DFG) Program	▸ The Programme of Cooperation (POC) aims to foster research collaborations and facilitate bilateral research projects through various means such as Research Grants (one-to-one basis), Mobility Grants, and Workshops/ Seminars. Focus areas – Medical Biotechnology, Agricultural Biotechnology, Innovative Food & Nutrition technology, Medical devices and bioengineering, and Environmental biotechnology ▸ Indo-German International Research Training Groups (ITRGs) and Collaborative Research Centres (CRCs)
2013	Indo-German Centre for Sustainability (IGCS) under DST-DAAD	▸ The collaboration was formed between Indian Institute of Technology (IIT) Madras, Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University, Technische Universität 9 group (TU-9), and Christian-Albrechts-Universität (CAU), Kiel from Germany ▸ Conducting comprehensive research on sustainable practises related to renewable energies, water and waste management, as well as rural and urban development. The second phase of the Centre at the Inter-Governmental Consultations (IGC) in 2017 has a specific focus on the topic of 'climate change and its impact on coastal infrastructure'
2013	Indo-German Programme (IGP) on Higher Education	▸ MoU between UGC and DAAD for Cooperation in Field of Higher Education ▸ UGC funded IIT Bombay, IIT Delhi, IIT Madras, IISc Bangalore, Delhi University, and Jawaharlal Nehru University in India for the first part of the programme. DAAD funded Freie Universitat Berlin, RWTH Aachen, Friedrich-Alexander Universitat Erlangen-Nuremberg, University of Potsdam, Julius Maximilian Universitat Würzburg, Heidelberg University, and Technical University Clausthal in Germany ▸ New schools from both countries also joined later
2017	ICMR – Helmholtz program	▸ MoU to promote research in the area of Anti-Microbial Resistance (AMR)

4. Research outcome of India Germany collaborative research

To assess the progress of collaborative research, bibliometric analysis with indicators more suitable to measure the productivity performance was undertaken as such studies we can identify that there are numbers of research areas that emerge and evolve over time (Tang and Hsiao, 2013). The expectation to identify a good productivity in publication is high as in every year, funding bodies and government bodies spends huge number on research (Mutz, Bornmann and Daniel, 2012; Ahmad, Farley and Kim Soon, 2014). When the numbers of publication is increasing by year, certainly shows that the allocation money is spend well towards the research and development. It also shows that the researchers are progressively moving ahead in their fields.

Figure 2 Year–wise research growth in terms of Total papers for Indo–German joint research



A total of 40977 articles researching on the India-Germany joint research from 2001 to 2022 were collected from the Web Of Science (WOS) database. The year wise research growth in terms of TP (Total papers) are given in figure 2, shows that no. of research papers are increasing. The number of annual publication and the cumulative growth of the publications are shown in figure 2. We categorize letters, note, short survey, editorial and others in Others publication categories for this study. In the 2001, 88% of publication were article, in 2012 the % share of article category reduced to 77% which further reduced to 71% in 2022 whereas, the share of conference paper increased over the year. As the joint conferences provide the platform to share the research ides and the provides opportunities to address the common problem in collaboration, the rise in the conference paper is a passive indicator of the strength among the country.

Figure-3 shows that the research output covered in this study during 2001-2022 as various subjects as defined by Scopus database. In the last 22 years, 2001-2022, the maximum contribution are from the Physics and Astronomy subject domain followed by Material Science, Chemistry, Medicine and Engineering as shown in figure 3. Top 10 most productive subjects for the Indo-German joint research are Physics and Astronomy, Materials Science, Chemistry, Medicine, Engineering, Biochemistry, Genetics and Molecular Biology, Earth and Planetary Sciences, Computer Science, Agricultural and Biological Sciences and Mathematics. Out of these subjects Physics and Astronomy attracts the maximum attention in their joint research publication (fig 4). Materials Science and Chemistry subject category are the next most productive subject for the joint research.

Figure 3 Discipline wise distribution of Indo–Germany Joint research outcome

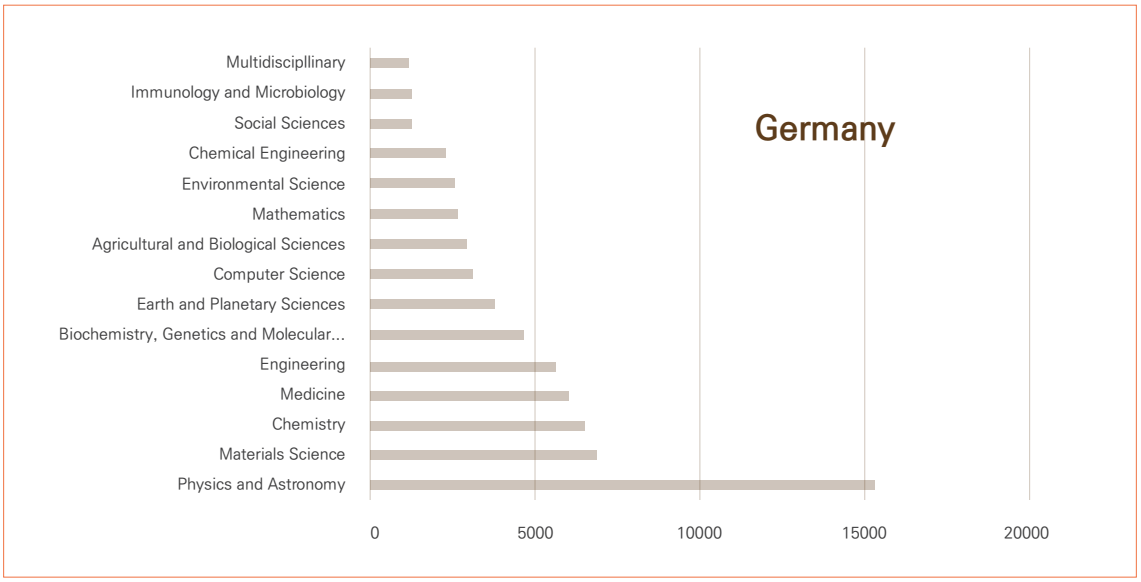


Figure 4 Decadal growth in Scopus discipline of Indo–German Joint research

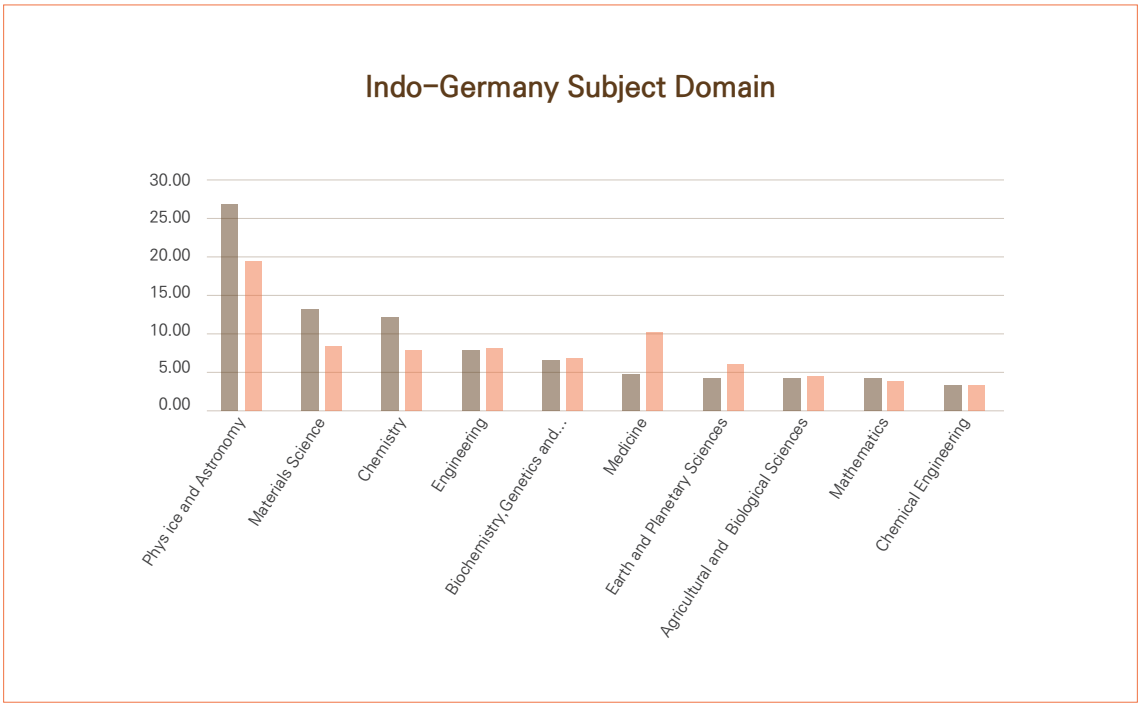


Figure 4 shows the preference of the Indo-German collaborative research publication in which their research domain lies. In both the decade 2001-2011 and 2012-2022, Physical & Astronomy is most preferred subject domain for the India Germany joint research. Research in medicine and Earth and Planetary Sciences shows the growth in the number joint research publication are the area.

Figure 5 Annual growth of top-12 Scopus discipline in Indi-German joint research

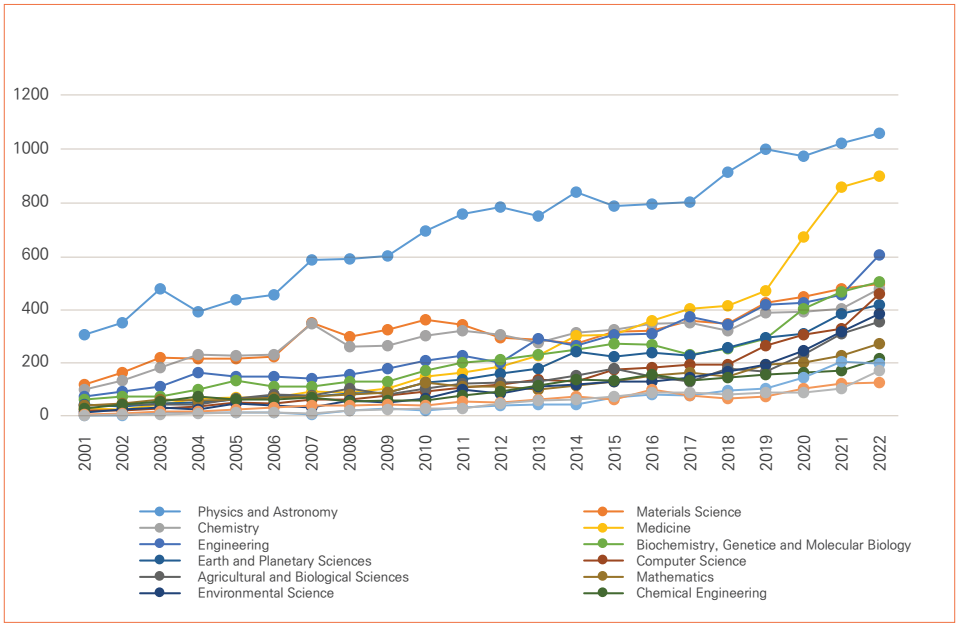
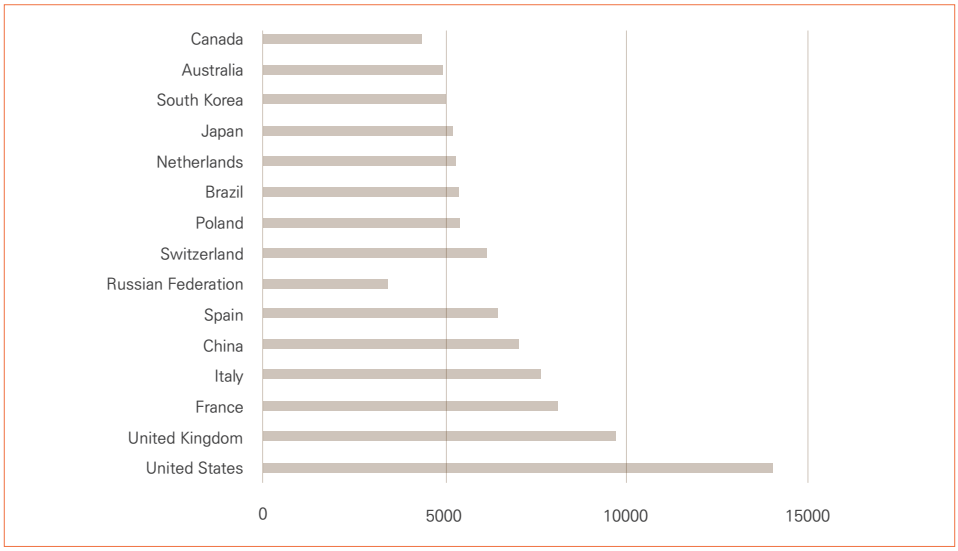


Figure 6 Top-15 collaborating countries in Indo-German Joint research



Scientific collaboration has a different effect on participants depending on collaboration type (Leahey 2016). Expectedly, the impact of international collaboration on a country's publication output also depends on the type of collaboration and the role of the country in this collaboration. It is analyzed on the basis of contributions of the authors from different countries. In the period from 2001-2022 United State is the major contributor to the Indo-German joint research with the contribution of 14011 joint publication with India and Germany followed by United Kingdom with 9677 shared publication and France with 8072, Italy with 7643 and China with 7016 number of publication (figure 6). The contribution of United States increases from 148 paper in 2001 to 1628 papers in 2022 (figure 7) and contribution of United Kingdom increases from 38 in 2001 to 1175 in 2022.

Figure 7 Annual growth in participation from different countries in Indo-German joint research
Publication distribution by funding source

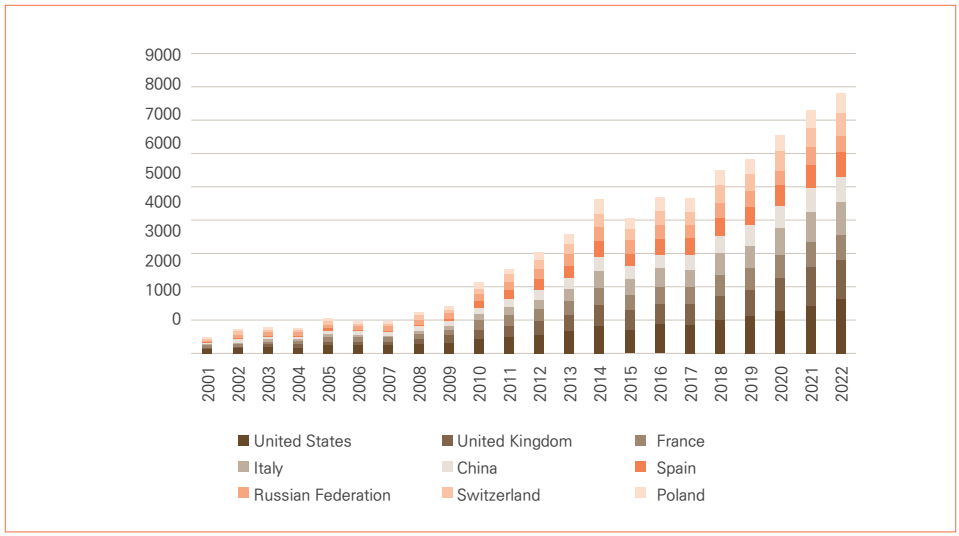
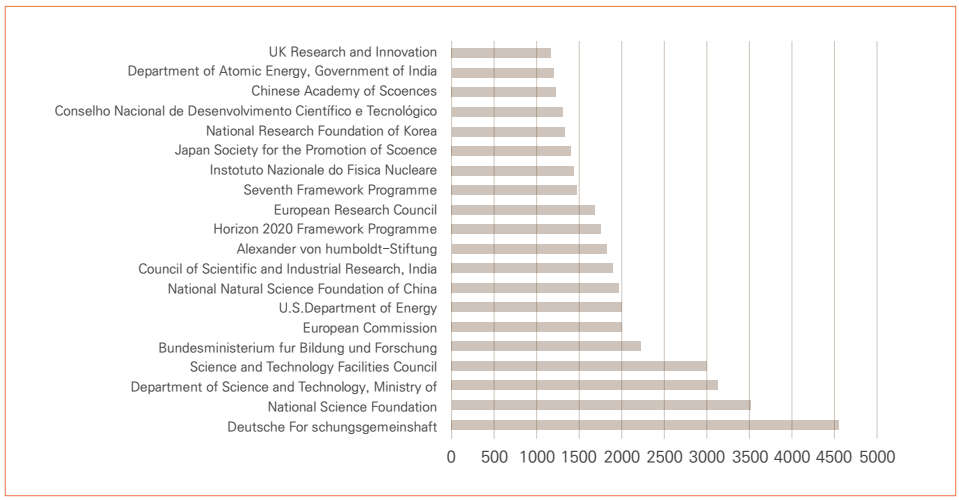


Figure 8 Top-20 funding agencies of Indo-German joint research



The investment in R&D is significant for the global economies to develop new products and services that drive growth, create jobs, and improve the collaboration among the countries However, scientific research is becoming very expensive due to the interdependence of each branch with other disciplines. Many countries are striving for their economies to be knowledge-based and so spending a vital part of their Gross Domestic Product (GDP) on R&D. Several studies examine the relationship between funding and research output at the level of the university or department; some examine international scientific knowledge flows and the scholarly impact of countries and institutions (Waheed, et.al, 2016; Hassan, Visvizi and Waheed, 2019; Gyorffy, Herman and Szabó, 2020). Studying the impacts of funding schemes has become more common in such a way that it makes funding authorities more curious and keener to make sure that these grants have intended positive impacts on research performance and scientific quality (Liv, Bloch and Sivertsen, 2015).

In this study, it is found Deutsche Forschungsgemeinschaft has funded maximum publication, 4550 joint research

paper has been funded by the German agency. Among the German funding agencies Bundesministerium für Bildung und Forschung and Alexander von Humboldt-Stiftung are in the top funding agencies for the Indo-German collaborative research publication. From the Indian agencies, Department of Science and Technology, Ministry of Science and Technology, India and Council of Scientific and Industrial Research, India has funded 3100 and 1900 research publication respectively. There are several other agencies who has funded the Indo-German joint research publication are National Science Foundation, Science and Technology Facilities Council, U.S. Department of Energy, National Natural Science Foundation of China and Other European funding agencies.

5. Institution wise Distribution of Publications

The below figure 8 indicates Institution-wise research productivity of Indo-German collaborative research. 78% of total publication output from the top-10 publishing institutes. The leading participation institute in Indo-German collaborative research are from CNRS France, India, Germany, Russia, USA and other European countries. Tata Institute of Fundamental Research, Mumbai from India has the maximum (3773) contribution in the collaborative research followed by Panjab University (3220), from the Germany side IN2P3 - Institut National de Physique Nucléaire et de Physique Des Particules has the maximum contribution to the Indi-German collaborative research, Figure 9 shows the top participating institutions in collaboration with Indo-German joint research. It is find that authors/ contributors this joint research were collaborating with many other institutions across the globe to publish their papers, It has been found that within top 10 institutions CNRS found in in Top Position with more than 4500 papers, followed by Tata Institute of Fundamental Research, India more than 3700 Publications & CNRS Institut national de physique nucléaire et de physique des particules with 3400 Publications found in second and third position respectively.

Figure 10 shows the year wise contribution of Indian, German and others collaborating institutes among the top publishing institutes.

Figure 9 Top–25 collaborating research institute/universities/industries in Indo–German joint research (2001–2022)

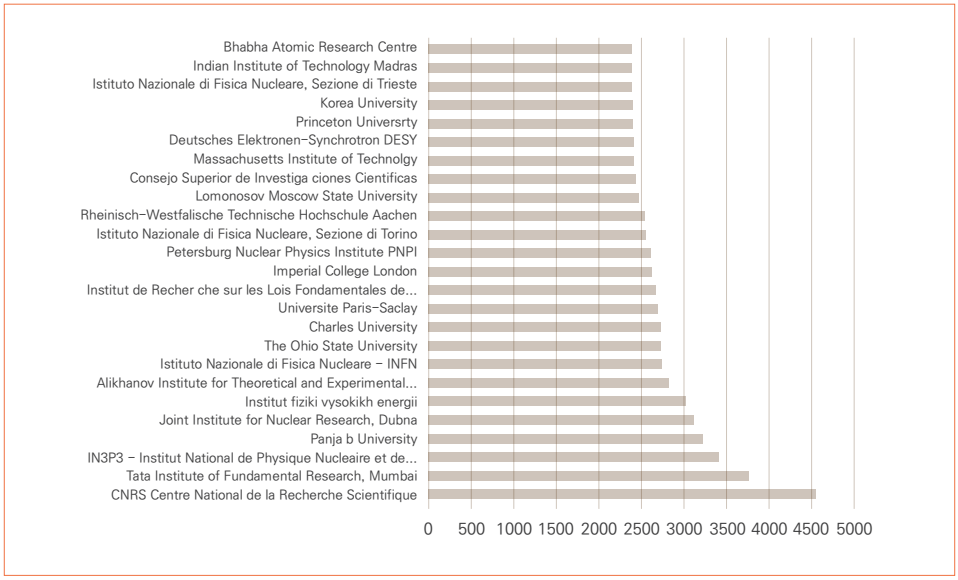
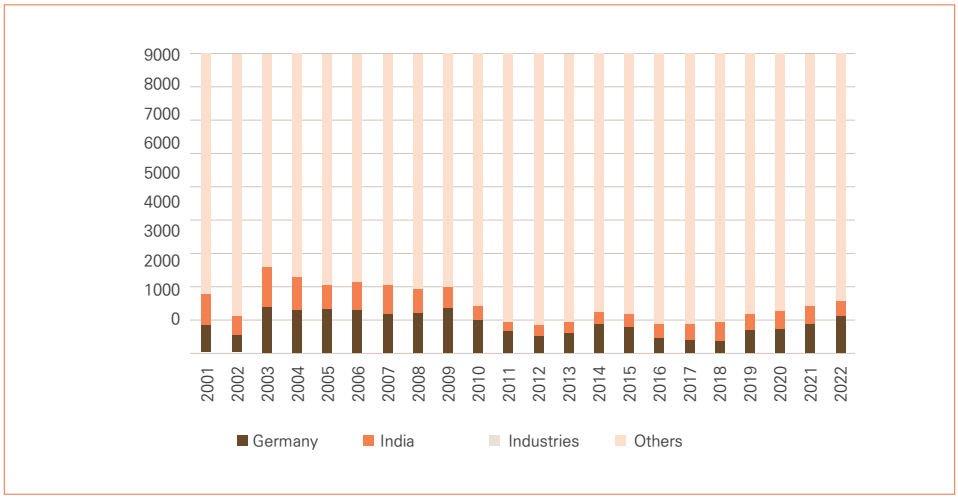


Figure 10 % share of institutes/universities/Industries in top160 publishing institutes in Indo-German joint research.



6. India-Japan Science Diplomacy Strategies

On April 28, 1952, Japan and India formally agreed to a peace treaty and established diplomatic relations. This treaty was among the initial peace treaties that Japan ratified subsequent to World War II. India and Japan have maintained a calm and effective partnership for the past 70 years. In 1985, the Ministry of External Affairs (MEA) of India and the Ministry of Education, Culture, Sports, Science, and Technology (MECSST) of the Government of Japan entered into a bilateral agreement to collaborate on scientific and technological endeavours. The Indo-Japan Joint Science and Technology Committee was established by the DST in India and the Ministry of Foreign Affairs (MOFA) in Japan, to provide guidance for collaborative scientific and technological endeavours. The inaugural joint committee meeting took place in New Delhi in September 1986, following the signing of a science and technology cooperation agreement with India in August 1985. The Japanese working group consisted of individuals from the Ministry of Economy, Trade, and Industry, Ministry of Foreign Affairs, Ministry of Education, Culture, Sports, Science and Technology, as well as other corporate delegates.

The time-line of evolution of Indo-Japan collaboration framework is in Table 2 which explains how both countries have collaborated through agreements that prioritise shared values, reciprocity, and co-funding. Recently, both nations are also interested in collaborating to formulate a strategy for achieving sustainable development goals (SDGs) in the fields of science, technology, and innovation.

The Japan Science Council has been established for a period of 21 years and has proven to be a highly effective platform for facilitating collaboration between the two nations in the field of science and technology. By facilitating collaborative initiatives like as research projects, seminars, scientist exchanges, RONPAKU Fellowships, and Asia Academic Seminars, it has effectively fostered a tighter and more robust relationship between the scientific communities of India and Japan.

The scientific diplomacy gained momentum in the recent years during Prime Minister Modi's visit to in 2016 and 2018 with the signing of Memorandum of Cooperation (MOC) between the Ministry of Earth Sciences (MoES) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and another on the India-Japan Digital Partnership (IJDP) between the Ministry of IT & Electronics of India (MeitY) and the Ministry of Economy, Trade, and Industry of Japan (METI) in respective years. The Indian government's think tank, NITI Aayog, has recognised Japan as a potential partner for the development of artificial intelligence (AI). The AI Research Centre (AIRC) at the National Institute of Advanced Science and Technology (AIST) in Japan and the Indian Institute of Technology (IIT) in Hyderabad

have entered into a memorandum of understanding (MoU) to enhance collaboration in the field of artificial intelligence (AI).

Recent initiatives involve the establishment of three India-Japan Joint Laboratories focusing on Information and Communication Technology (ICT), specifically Artificial Intelligence (AI), Internet of Things (IoT), and Big Data. Additionally, the DST-JSPS Fellowship Programme has been launched to support young researchers. An MoU has been signed for the second phase of the Indian Beam Line at KEKT Sukuba, which would facilitate advanced materials research. The DBT-AIST Advanced International Laboratory for Advanced Biomedicine (DAILAB) is being established in Tsukuba, Japan. Additionally, Six SISTERs (Satellite International Institutes for Special Training, Education, and Research) are being set up in India for the purpose of drug development and therapeutic illnesses.

The India-Japan Cyber Cooperation, which is a recent agreement signed by the two countries in January 2021 to enhance their cooperation in the field of cybersecurity. The agreement covers areas such as cyber threat intelligence sharing, capacity building, joint research and development, and promotion of norms and rules for responsible state behavior in cyberspace.

The India-Japan Semiconductor Collaboration, which is a pioneering partnership announced by the two countries in August 2023 to strengthen their semiconductor industries and drive joint innovation in semiconductor design, manufacturing, equipment research, supply chain resilience, and talent development. The collaboration involves setting up a joint semiconductor fabrication facility (fab) in India, as well as establishing a joint research center for semiconductor technologies.

With regards to investment in India, from 2000 to 2019, around US$ 32.058 billion was allocated for India. Currently, Japan ranks as the third most significant investor, following the United States and China. The majority of Japanese foreign direct investment (FDI) in India has been in sectors such as automobile, electrical equipment, telecommunications, chemical, financial (insurance), and pharmaceutical industries. The foreign direct investment (FDI) from Japan into India increased from $2.61 billion to $4.7 billion from 2015-16 to 2016-17. The FDI for the fiscal year 2019-20, covering the period from April to November, has reached a total of $3.99 billion.

7. India–Japan Trade

The trade relation of India with Japan is growing continuously, in 2014 the trade from India to Japan was 739 billion yen which increased to 833 billion yen in 2022 with an increment of 11% with respect to 2014. The trade from Japan was 861 billion yen in 2014 which increased to 2014 billion Yen (figure 11).

India has been the largest recipient of Japanese ODA Loan for the past decades. Delhi Metro is one of the most successful examples of Japanese cooperation through the utilization of ODA. Japan continues to cooperate in supporting strategic connectivity linking South Asia to Southeast Asia through the synergy between "Act East" policy and "Partnership for Quality Infrastructure."

Figure 11 Annual Trade with Japan from India

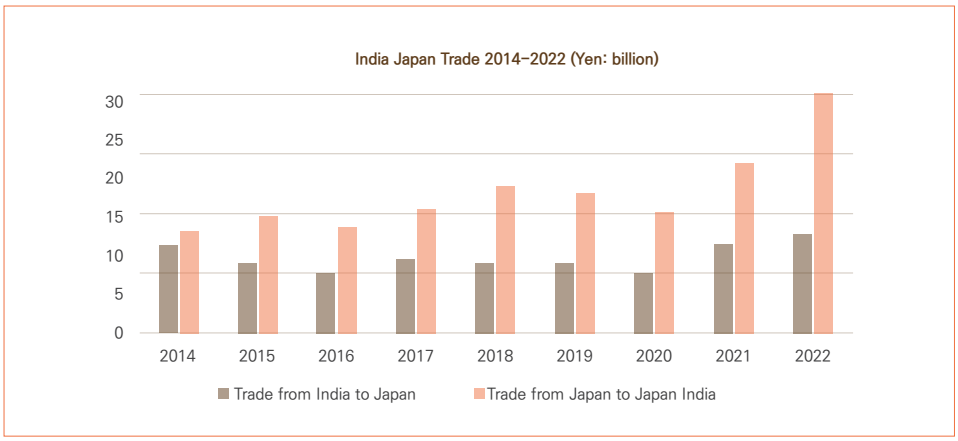
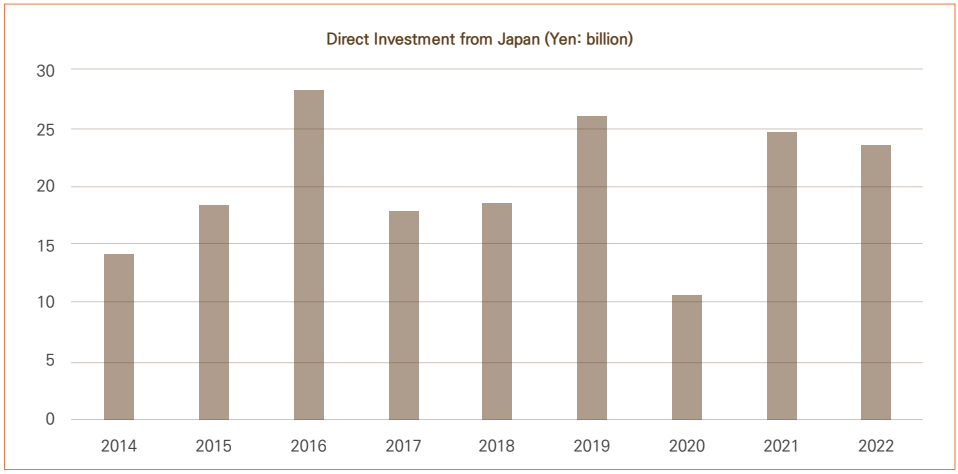


Figure 12 Year wise FDI in India from Japan



Source: Japanese government documents

Table 2 Time-line of evolution of India-Japan cooperation of S&T development

Year	Events/Programs	Objectives/Thrust Areas
1960	Japan Space Exploration Agency (JAXA) and Indian Space Research Organization (ISRO)	
1985	Inter-Governmental Agreement	MECSST (Japan) and MEA (India)
1993	India-Japan Cooperative Science Program	Physical and Chemical Systems; Fundamental Science, Engineered Materials Systems; Engineering and Processes, Natural Systems; Biology and Life Sciences, Global Systems are among the joint project and workshop priorities. Environment, Marine, and Earth-Space Sciences, as well as Mathematics and Computational Science
2005	ISRO and JAXA signed an arrangement on the potential future cooperation in field of outer space	
2006	MoU	DST-Japan Science and Technology Agency (JST)
2007	MOU was signed between Directorate General of Hydrocarbons (DGH) & Japan Oil, Gas and Metals National Corporation (JOGMEC)	Objective was to establish R&D collaboration on Gas hydrates
2013	MoU between Indian Nuclear Society (INS) and Japan Atomic Energy Society (JAES)	To promote peaceful uses of nuclear science & technology
2014	Implementation Arrangement (IA) between DST, India and the Ministry of Education, Culture, Sports, Science & Technology (MEXT), Japan	To provide vision and direction to the cooperative S&T activities
2014	MoC between Govt of India and Govt of Japan in the field of Healthcare followed by a MoU between AIIMS and Osaka University	To pursue Research and Academic Cooperation

2015	MoC for Medical Products Regulation between PMDA, Japan and CDSCO	
2015	Letter of Intent on the Strategic International Cooperative Program between DST– JST	Aims to promote collaborative activities for functional applications of Physical Sciences in Information and Communication Technology (including Internet of Things, Artificial Intelligence and Big Data Analysis)
2015	SAKURA Science Programme	JST and MHRD
2015	MOC between Ministry of Agriculture, Forestry and Fisheries, (MAFF) Govt of India and Ministry of Environment, Forestry and Climate Change (MoEF&CC) Govt of Japan	Focus areas: human resource development, sustainable forest management, improvement of forest conservation and prevention of forest disasters, preservation of biodiversity, efficient utilisation of forest resources, enhancement of policies related to forests, forestry, and technologies, and research and development in the forestry sector
2016	MoU between ISRO and JAXA to pursue future cooperative activities in the use and exploration of outer space exclusively for peaceful purposes	
2016	3 India–Japan Joint Laboratories at IIT–Delhi, IIT–Bombay and IIT–Hyderabad from India and the University of Tokyo and Kyushu University from Japanese side	Focus area "Architecting Intelligent Dependable Cyber Physical Systems Targeting IoT and Mobile Big Data Analysis", "Security in the Internet of Things Space", and "Data Science–based Farming Support System for Sustainable Crop Production under Climatic Change"
2016	MoC between the Ministry of Earth Sciences (MoES) and JAMSTEC	▸ The objective of MoC is to foster collaboration in the realm of marine and earth science and technology, with a focus on reciprocal fairness and advantages achieved through shared investigations, expeditions, and research and development endeavours, among other activities. Ministry of Education and Science (MoES) ▸ JAMSTEC has identified three collaborative projects in the fields of climate modelling for monsoon prediction, deep–sea exploration, and earthquake and tsunami warning research in the Andaman Sea
2017	Young Researcher Fellowship Program	DST – JSPS
2017	Japan–India joint statement signed at the Japan–India Summit on Cooperation in Nuclear Science and Technology	An Indo–Japanese project was initiated during F.Y.2019 to reconstruct past–climate, relative sea–level changes and ice–sheet dynamics from the lake sediments of Schirmacher Oasis (SO), Central Dronning Maud Land
2017	Implementation arrangement (IA) signed between ISRO and JAXA concerning collaboration activities on the radio occultation experiment in JAXA's Venus orbiter mission Akatsuki (Planet–C)	
2018	ISRO and JAXA signed an IA for cooperation on validations, improvement, and applications of rainfall products using satellite images and ground measurements	
2018	MoU between National Center for Polar and Ocean Research (RCPOR), India and National Institute of Polar Research (NIPR), Japan	
2018	Roadmap for India–Japan forest and forestry cooperation" from 2018 to 2022	
2018	MOC on India–Japan Digital Partnership (IJDP) between Ministry of IT & Electronics, India (MeitY) and Ministry of Economy, Trade and Industry (METI), Japan	It envisaged cooperation in five sub–areas: 1) Start–up Initiative, 2) Corporate Partnership, 3) ESDM promotion, 4) Digital talent exchange, 5) R&D Cooperation and 6) Security related strategic collaboration

2018	Synergies between the goals and objectives of India's AYUSHMAN Bharat Programme and Japan's AHWIN led to a MoC to formalize cooperation under the overall MoC in the field of Healthcare	MoC was signed between Ministry of Health and Family Welfare, India and Cabinet Secretariat, Government of Japan and Ministry of Health, Labour and Welfare of Japan
2018	MoU signed between Indian Council of Agricultural Research (ICAR) and Japan International Research Center for Agricultural Sciences (JIRCAS)	First meeting discussed cooperation on development of low-cost subsurface drainage and irrigation technology in salt-affected fields for sustainable agricultural production, and development of regionally-adopted salt-tolerant crop
2018	MoU signed Ministry of the Environment (MOEJ), Japan and the Ministry of Environment, Forest and Climate Change (MoEFCC), India	Discussion Meetings on environmental issues such as solid waste management, climate change and air pollution
2019	ISRO and JAXA signed IA on "Collaborative activities on APRSAF/SAFE Agromet project"	
2020	"India-Japan Digital Partnership" Reviewed	
2020	Meeting on Japan-India civil nuclear cooperation	Strengthening of bilateral cooperation in the peaceful uses of nuclear energy
2020	4th India-Japan Medical Products Regulatory Symposium	To share the best practices in the regulation of pharmaceuticals and medical devices
2020	Roadmap on STI-SDGs	Workshop on "Developing STI Partnerships for Sustainable Development: Accelerating International co-operation and actions through global pilot programme on STI for SDGs roadmaps
2021	India-Japan celebration of the 6th Ayurveda Day	"Finding Ayurveda in Japan- Perceptions, People, and Practice in Nutrition, and control of Lifestyle Disorders" was organized in association with the Ministry of Ayurveda, Yoga & Naturopathy, Unani, Siddha and Homoeopathy (M/o AYUSH), GoI
2021	IA between ISRO and JAXA	Collaborative activities on rice crop area and air quality monitoring using satellite data
2021	Meeting of the Japan-India Space Dialogue	
2021	MoC on comprehensive ICT cooperation between MOC (Ministry of Communication, India) and MIC, Japan	Issues covered - development of technologies related to 5G and submarine cables, Telecom Security including relevant human resources development
2021	First India-Japan High Level Policy Dialogue on the Environment between MOEJ, Japan and MoEFCC, India	Discussion on JCM (Joint Crediting Mechanism) and decision to organizing JCM training workshops on technology transfer, success stories, accounting standards, emission crediting schemes in Japan
2021	Meeting on civil nuclear cooperation between DAE and METI	Discussion on hydrogen thermo power, India's nuclear energy policy, small and modular reactors (SMRs), CLND Act, Rare Earths Minerals and GCNEP
2022	Workshop on Policy Dialogue on Article 6 and avenues of Japan-India Technology cooperation by The Energy and Resources Institute (TERI), India and Institute for Global Environmental Strategies (IGES), Japan	Workshop focused on commercialized hydrogen technologies, district cooling systems (DCS) and agrivoltaic practices

8. Research outcome of Indo–Japan collaborative research

A total of 27849 articles researching on the India-Japan joint research from 2001 to 2022 were collected from the WOS core database. The year wise research growth in terms of total papers published are given in figure 13, it shows that no. of research paper are increasing year wise form 2001 to 2022. The number of annual publication and the cumulative growth of the publications are shown in Figure 13. In the 2001, 90% of publication were article, in 2012 the percentage (%) share of article category reduced to 77% which further reduced to 70% in 2022. Whereas, the share of conference paper increases over the year.

Figure-14 shows that the research output covered in this study during 2001-2022 as various subjects as defined by Scopus. The list of Top subjects for which the authors of India Japan joint research, mostly contributed papers. In the last 22 years, 2001-2022, the maximum contribution are from the Physics and Astronomy subject domain followed by Material Science, Chemistry, Medicine and Engineering as shown in figure 14. Top 10 most productive subjects for the India Japan joint research are Physics and Astronomy, Materials Science, Engineering, Medicine, Chemistry, Biochemistry, Genetics and Molecular Biology, Earth and Planetary Sciences, Computer Science, Agricultural and Biological Sciences, and Chemical Engineering. Out of these subjects Physics and Astronomy attracts the maximum attention in their joint research publication. Physics and Astronomy has continuous growth in joint research publication (fig 14). Materials Science and Chemistry subject category are the next most productive subject for the joint research.

Figure 13 Year–wise research growth in terms of Total papers for India–Japan joint research

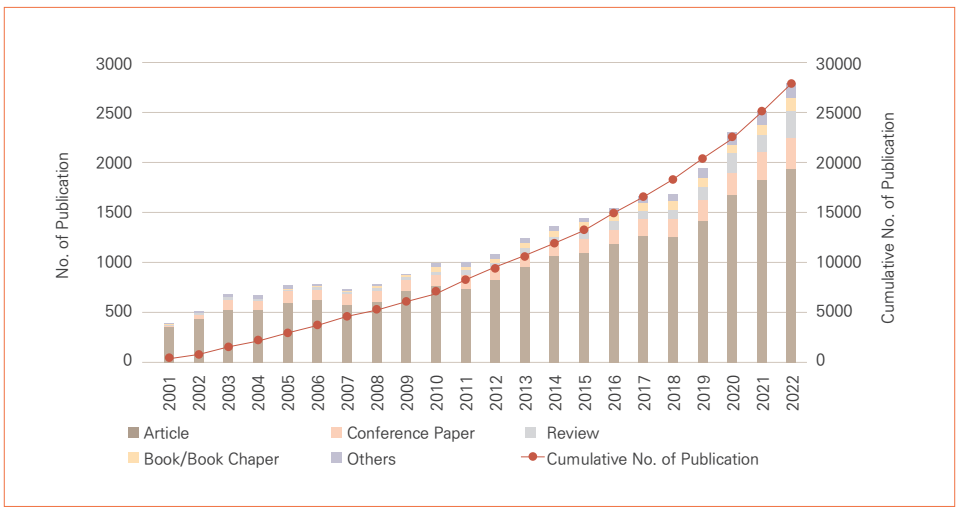


Figure 14 Discipline wise distribution of India–Japan Joint research outcome

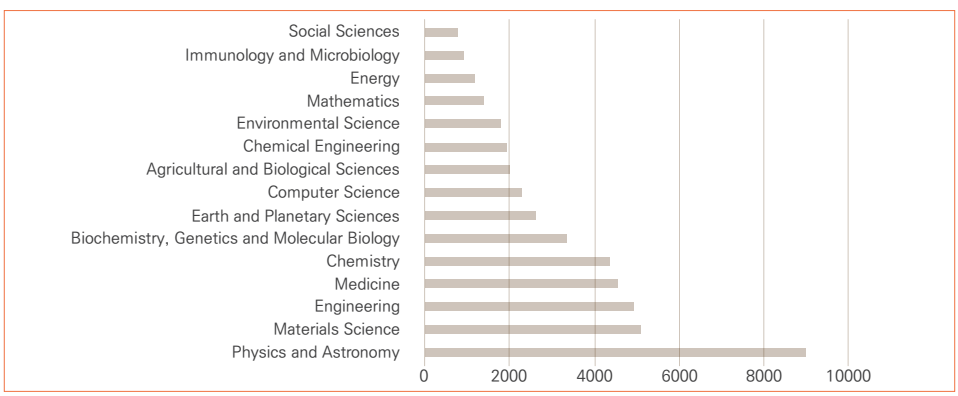


Figure 15 shows the preference of the Indo-Japan collaborative research publication in which their research domain lies. In both the decade 2001-2011 and 2012-2022, Physical & Astronomy is most preferred subject domain for the India Japan joint research. Research in Material Science and Chemistry shows the growth in the number joint research publication are the area during the period of 2001-2011, whereas during the period 2012-2022 Medicine bags the second position and Engineering subject domain placed at the third position.

Figure 15 Decadal growth in Scopus discipline of India Japan Joint research

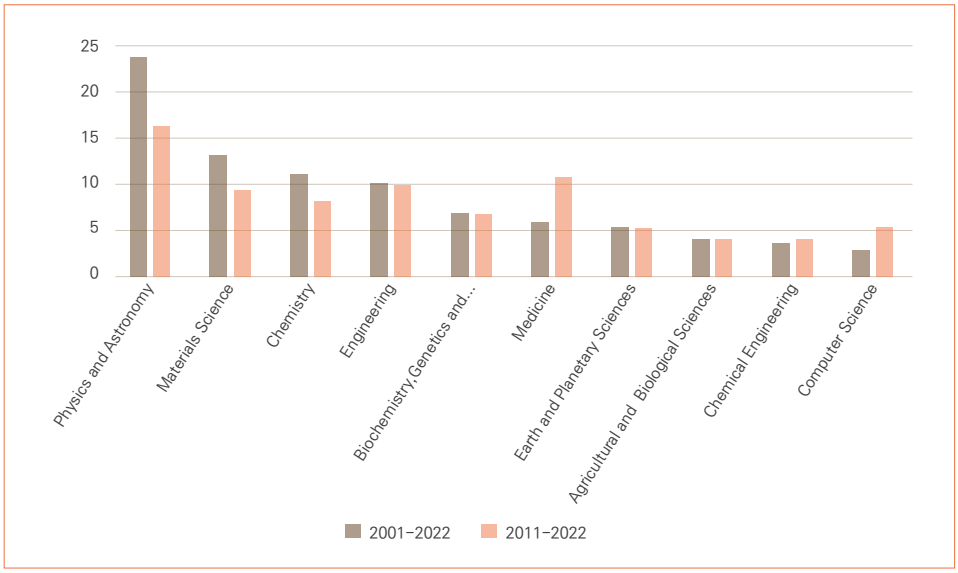
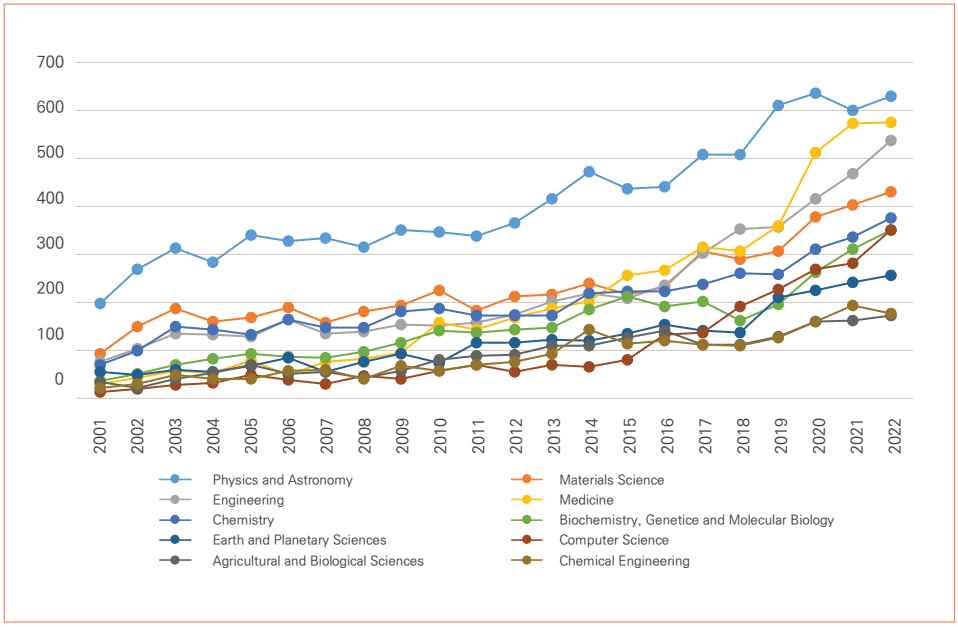


Figure 16 Annual growth of top-12 Scopus discipline in India-Japan joint research



Engaging in collaboration with other institutions or countries is a prevalent practise in research publications. Collaboration is a common occurrence among researchers, particularly in the fields of science and engineering, with the aim of enhancing productivity in publishing (Sidone, et.al., 2017; Sooryamoorthy, 2014). In the realm of science and engineering, it is customary to have multiple individuals comprising a team for research and development (Janius, Abdan, & Zulkaflli, 2017; Sedah et al., 2017). This chance frequently entices international experts to collaborate on ongoing research. Consequently, a partnership was established with other nations. Each team member has the opportunity to learn and contribute the knowledge and expertise they have gained from past research or studies. The number of collaborations with countries globally is currently increasing. It is analyzed on the basis of contributions of the authors from different countries. In the period from 2001-2022 United State is the major contributor to the Indo-German joint research with the contribution of 8101 joint publication with India and Japan followed by China with 5285 shared publication and Germany with 5218, United Kingdom with 4483 and South Korea with 4163 number of publication (figure 17). The

Figure 17 Top-15 collaborating countries in India-Japan Joint research

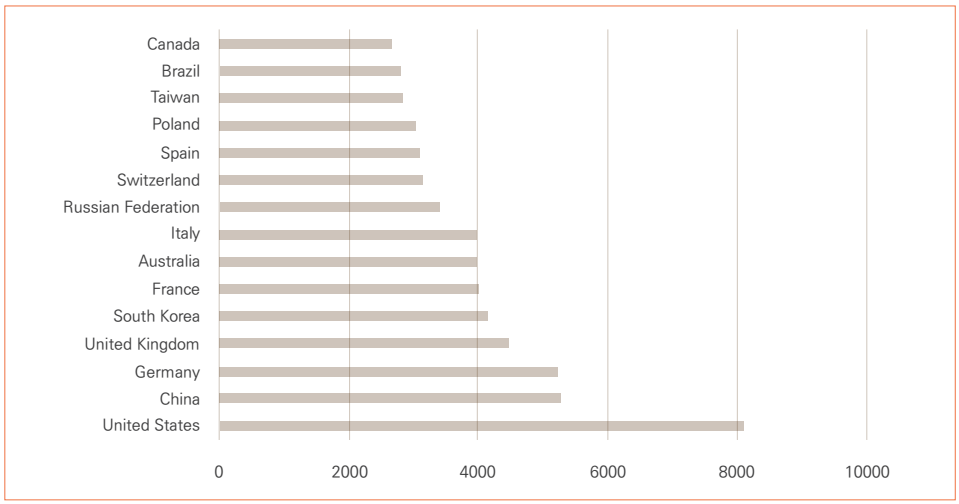
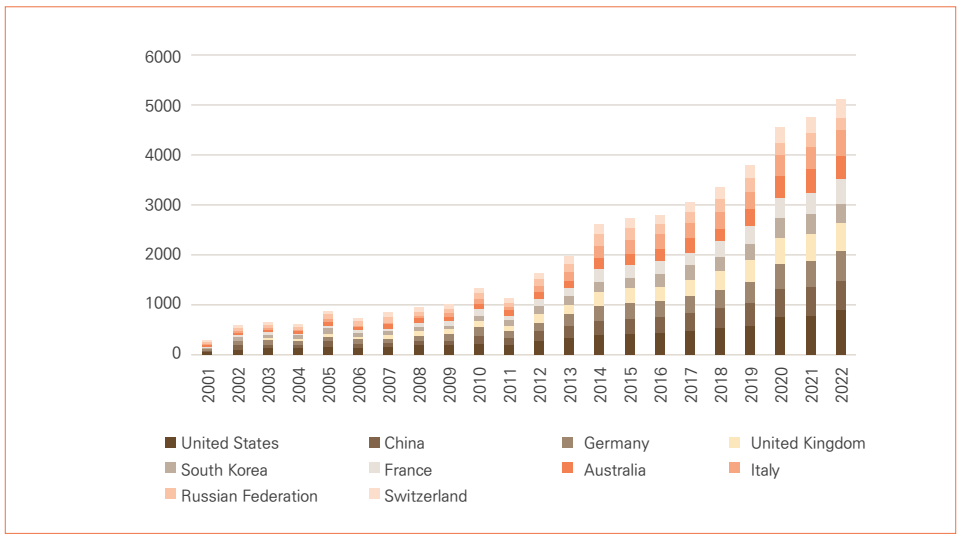


Figure 18 Annual growth in participation from different countries in India-Japan joint research



contribution of United States increases from 81 paper in 2001 to 907 papers in 2022 (figure 18) and contribution of China increases from 25 in 2001 to 604 in 2022.

Many countries want knowledge-based economies and invest a large portion of their GDP on R&D. Public research policy relies on R&D financing programmes to improve research quality. These programmes' main objective is to ensure competitive funding improve research performance and maximise it. Studying the effects of such funding schemes has grown more widespread, making funding bodies more curious and keener to ensure that these investments in R&D have expected positive benefits on research performance and scientific quality. Japan Society for the Promotion of Science has supported 5340 number of Indo-Japan joint publication which is highest among the others funding agencies during the period. Ministry of Education, Culture, Sports, Science and Technology, Japan is second highest in funding Indo-Japan joint research publication in the last 22 years with 2047 publications. Department of Science and Technology, Ministry of Science and Technology, India has supported 1906 number of joint publications and Council of Scientific and Industrial Research, India has supported through funding 1034 number of research publications. Apart from the Japan and India several agencies of other countries had also supported the India-Japan joint publications, some of the agencies are National Science Foundation (1610) publication and National Natural Science Foundation of China (1102) publications among the top funding agencies for India-Japan Collaborative research.

The figure 20 shows Institution-wise research productivity of Indo-Japan collaborative research. 73% of total publication output from the top-10 publishing institutes. The leading participation institute in Indo-Japan collaborative research are from Japan, India, Germany, China, USA and other European countries. The University of Tokyo from Japan has the maximum (4124) contribution in the collaborative research followed by Kyoto University (2227), from the India side Tata Institute of Fundamental Research, Mumbai has the maximum (1523) contribution to the India-Japan collaborative research.

Figure 21 shows the year wise contribution of Indian, Japanese and others collaborating institutes among the top publishing institutes.

Figure 21 shows the year wise contribution of Indian, Japanese and others collaborating institutes among the top publishing institutes.

Figure 19 Top–20 funding agencies of India–Japan joint research

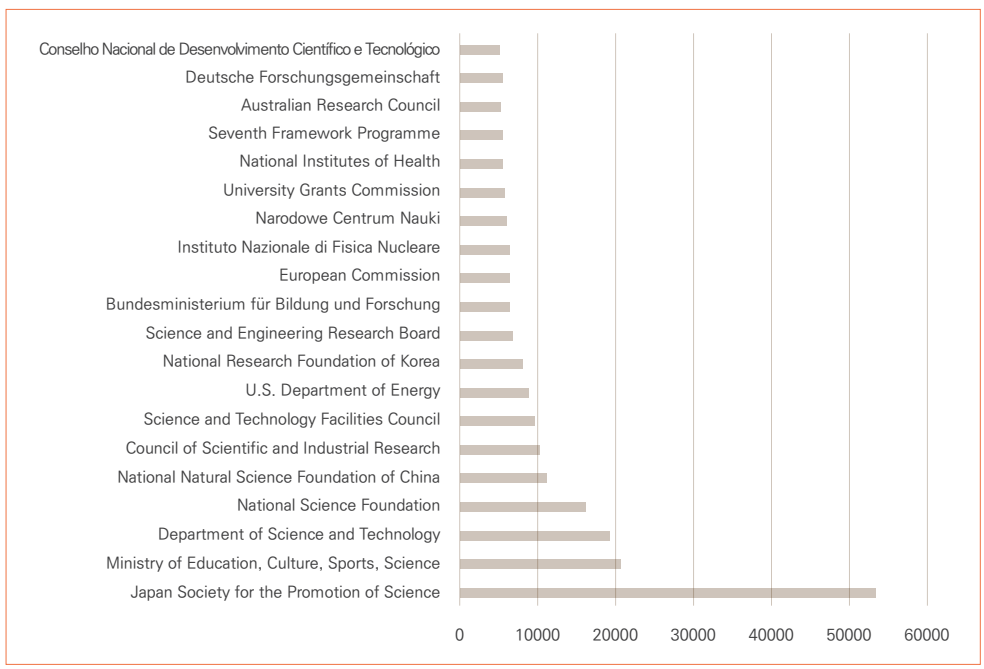


Figure 20 Top-25 collaborating research institute/universities/industries in India-Japan joint research (2001-2022)

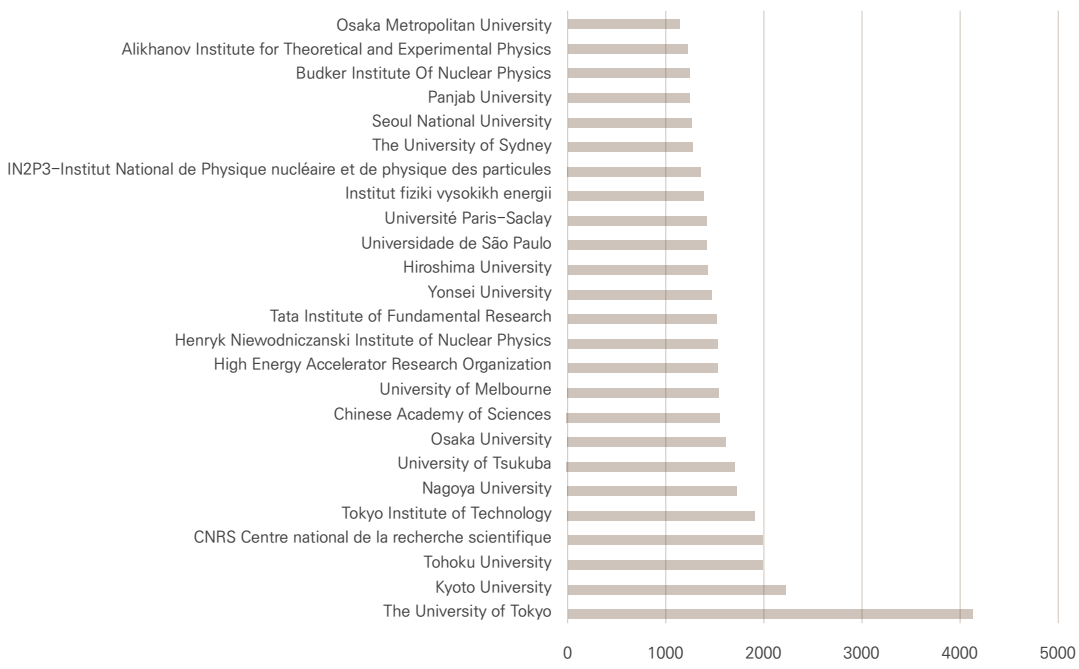
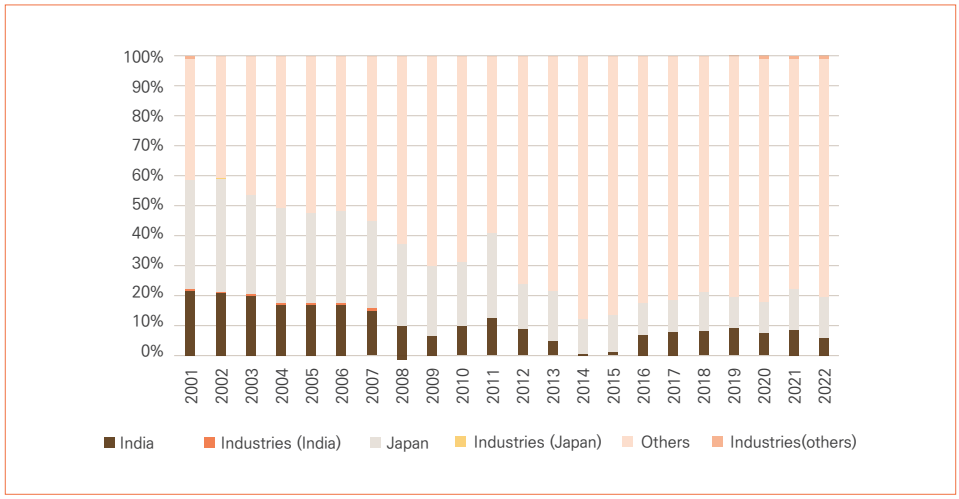


Figure 21 % share of institutes/universities/Industries in top160 publishing institutes in India-Japan joint research



9. Discussion and Conclusion

There is a target of five trillion yen in investment and financing from Japan to India over the next five years, and Japanese companies operating in India are being assessed in relation to this target. During the trip that Prime Minister Kishida took to India in March of 2022, this objective was decided upon. Additionally, the two leaders have pledged to move forward with the "Clean Energy Partnership" that was declared during Prime Minister Kishida's trip to India in March of 2022. Attaining carbon neutrality and ensuring energy security on a global scale are the goals of this endeavour. Additionally, through the "Japan-India Energy Ministerial Dialogue" and other initiatives that are relevant to this topic, they intend to encourage tangible collaboration in the domains of hydrogen, ammonia, and LNG

The cumulative amount of foreign direct investment (FDI) from Germany to India during the period of April 2000–September 2022 amounts to $13.8 billion, making it the ninth largest investor in IndiaThe total amount of foreign direct investment that Germany made in India from the year 2000 till the year 2016 was around 9 billion Euros. Over one thousand and six hundred Indo-German collaborations and over six hundred Indo-German joint ventures are currently actively operating. Over 6.5 billion euros have been invested in Germany by Indian corporate companies, particularly in the fields of information technology, automotive, pharmaceuticals, and biotechnology. At the present time, there are around two hundred Indian businesses having operations in Germany.

During Chancellor Merkel's visit to Delhi in November 2019, Germany and India reached an agreement to create a bilateral research programme in the field of artificial intelligence. Additionally, they came to the conclusion that the Indo-German Partnership in Higher Education should be extended for an additional four years, with each partner contributing 3.5 million Euros respectively. According to our bibliometric research, the proportion of conference papers that contributed to the publication is insignificant. Small researcher groups, however, may suffer overlap within the scope of a collaboration network when their members participate in diverse research-related activities, such as conferences, colloquia, and other field-related activities. As a result, external funding organisations and research administrators in a country like India should advocate for a policy that favours cluster development in order to ease the formation of new research collaborations among prospective scientists. Physics and astronomy, materials science, engineering, medicine, and chemistry were the top chosen topic domains in which Germany and Japan interacted the most during the period. However, the field of medicine has seen the most development in terms of publication for both the research collaboration India-Germany and India-Japan collaboration research. However, in the Indo-German joint study, the United States and other European countries were found to be significantly involved, while in the Indo-Japanese collaboration, the United States, China, South Korea, and other European countries were involved.

Furthermore, it is noteworthy that the cooperative research endeavours between India and Germany, as well as India and Japan, are funded supported by agencies from countries other than India, Germany, and Japan. These collaborations aim to tackle global concerns. Science diplomacy has been significant throughout history, but it is now more pertinent due to the emergence of global concerns that were not prevalent in prior centuries. These challenges encompass growing urbanisation, population growth, climate change, disease, ageing populations, and poverty alleviation. Each of these difficulties possesses a scientific aspect, and equally significantly, necessitates collective and coordinated international efforts. Evidently, no individual nation possesses the capability to independently resolve these issues. When it comes to addressing global issues, it is becoming increasingly important for nations to combine scientific research with diplomatic efforts.

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