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EDITORIAL

In times of growing geopolitical tensions, global cooperation is increasingly tested by competing national interests. With complex and interconnected challenges that we face today, it is difficult for any one country to tackle these issues solely on its own. Such transnational challenges require coordinated and integrated responses. Science remains one of the most promising bridges across borders. Scientific and technological advancements and informed decision-making and negotiations are key to planetary crises like climate change, biodiversity loss, disease outbreaks, pollution, etc. Similarly, governance of new and emerging technologies, and shared resources and global commons such as high seas, outer space, etc., equally require science-based decision-making. In this context, science diplomacy emerges as an important tool for fostering international cooperation. But, the current times are marred by rising geopolitical tensions, global inequities, technological sovereignty, 'competitiveness' vs 'collaboration', focused on national interests, misinformation/disinformation, institutional fragmentation and challenges in mobility. Thus, for science diplomacy to be effective, it has to be pragmatic, inclusive and context-specific.

This issue of Science Diplomacy Review emphasises the role science can play in building bridges. It brings together diverse papers, perspectives and case studies that highlight the essential role of science diplomacy in navigating shared challenges, from heritage genomics to clean energy and transnational scientific research. Across all these contributions, a common thread emerges that science diplomacy remains a powerful tool for dialogue.

The paper Protecting South Asia's Genomic Heritage through Regional Cooperation, is a timely intervention in a region rich in biodiversity and cultural complexity. Genomic data demands cross-border governance frameworks that respect ethical, legal, and scientific standards. It underlines science diplomacy as a powerful tool to overcome challenges posed by varied regulatory frameworks, diverse research capabilities and ongoing geopolitical tensions. Thus, it advocates for its role as a catalyst for regional cooperation to safeguard this vital resource. As CERN marks its 70th anniversary, the paper focusing on CERN reflects on its remarkable journey as both a hub of scientific excellence and a long-standing model of science diplomacy. The paper gives a historical account of the role of CERN in international cooperation and science diplomacy during the Cold War and beyond. Looking ahead, the transition to clean energy forms a central pillar of global climate diplomacy. As green hydrogen gains traction, international partnerships, especially among the Global South, will be crucial in preventing a new kind of energy divide. In the perspective on Green Hydrogen, the author discusses the future of Green Hydrogen, emphasising the role of India, together with the need for international partnerships to realise its full potential. The second perspective focuses on emerging bilateral ties with India-Taiwan S&T Cooperation. As both economies pivot towards knowledge-driven growth, the perspective traces growing academic and technological engagements between India and Taiwan. It highlights that the strategic convergence between the two countries represents a significant development in the Indo-Pacific.

This issue's event report covers the Global Ministerial Dialogue on Science Diplomacy organised by UNESCO during 25-26 March 2025 in Paris, France. It provides an overview of the outcomes from the ministerial, highlighting key commitments and future directions for science diplomacy. Finally, in our book review, we revisit Pierre-Bruno Ruffini's work, *Science and Diplomacy: A New Dimension of International Relations*.

As in the past, we remain committed to advancing our efforts through the Science Diplomacy Programme at RIS, which continues to serve as a vital platform for the exchange of research, ideas, and perspectives on diverse dimensions of science diplomacy. Particular emphasis is placed on its critical role in addressing global challenges, including those related to sustainable development. We warmly welcome your feedback and reflections, and encourage all stakeholders to contribute actively to the Science Diplomacy Review.

PAPER

Protecting South Asian Genomics Heritage through Regional Collaboration

Pragya Chaube*

Pragya Chaube

Introduction

Genomics and genetics research hold the promise of revolutionising healthcare by enabling precision medicine, where treatments and preventive strategies are tailored to an individual's genetic makeup, environment, and lifestyle (Mattick *et al.*, 2014; Rehm *et al.*, 2021). By decoding the human genome, researchers can unearth the underlying genetic causes of diseases and conditions. This detailed genetic information empowers clinicians to predict disease risks, initiate early interventions, and customise treatments (Rehm *et al.*, 2021). For example, pharmacogenomics optimises drug dosing and selection based on genetic profiles, leading to safer and more effective therapies. Moreover, genomic research deepens our understanding of disease mechanisms and uncovers novel therapeutic targets; identifying specific mutations in tumours, for instance, has led to targeted cancer therapies that significantly improve patient outcomes (Rehm *et al.*, 2021). In the realm of rare disease research, aggregating genomic data across diverse populations overcomes the limitations posed by small patient numbers in individual regions, facilitating breakthroughs in diagnosis and treatment that would otherwise remain elusive (Rehm *et al.*, 2021; The GUaRDIAN Consortium *et al.*, 2019).

For everyone to benefit from this transformative healthcare, it is essential that all populations are represented in foundational genomics research (Lemke *et al.*, 2022). Human genomics research has leveraged genetic diversity to identify variants that contribute to disease susceptibility and resistance, making it critical for reference genome databases

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to include multiple populations to capture population-specific variations (Lemke *et al.*, 2022). Historically, genomic studies have predominantly focused on populations of European descent, leading to biased findings and limiting the applicability of genomic medicine across different ethnic groups (Fatumo *et al.*, 2022). To address this disparity, several global initiatives have been undertaken to incorporate non-European populations into the knowledge base. Initiatives like H3Africa for African populations and projects such as BioBank Japan and the China Kadoorie Biobank for Korean, Japanese, and Chinese populations are accelerating disease association discoveries in underrepresented groups (Rehm *et al.*, 2021). However, a stark gap remains: South Asian populations are severely underrepresented. South Asia, which comprises eight countries, accounts for 25.29 per cent of the global population (Dokuru *et al.*, 2024), yet its representation in genome-wide association studies (GWAS) is minimal—only about 0.8 per cent, compared to 86.3 per cent for individuals of European descent, 5.9 per cent for East Asians, and 1.1 per cent for Africans (Fatumo *et al.*, 2022).

To address this gap, several genomics projects have been launched in South Asia. India, for instance, is currently undertaking massive genomics initiatives at a national scale, and regional projects like GenomeAsia 100K (GenomeAsia100K Consortium *et al.*, 2019) have been established to address these discrepancies. However, an economical and logistically manageable approach to enhance representation would be through data pooling and sharing across South Asian countries. This paper explores the challenges, opportunities, and policy recommendations for genomic data sharing in South Asia. Despite the transformative potential of genomic data, regional research efforts are often hampered by fragmented regulatory frameworks, ethical concerns, and infrastructural limitations that impede cross-border collaboration. The paper examines these barriers and discusses how harmonised legal and ethical guidelines, modelled on global best practices, could facilitate a more integrated approach to genomic research in the region. By aligning regulatory standards and fostering collaborative networks, South Asia can not only enhance its capacity to tackle region-specific health challenges but also contribute to the global body of genomic knowledge.

The Case for South Asian Genomic and Genetic Research and Data Sharing

South Asia is exceptionally diverse in culture, language, and genetics. Home to over 4,500 distinct anthropological groups with hundreds of languages and multiple major religions(Dokuru *et al.*, 2024), this diversity is rooted in a complex history of ancient migrations and localised practices such as endogamy (Dokuru *et al.*, 2024; Majumder, 2010). Modern South Asians exhibit genetic signatures shaped by key migrations: an initial out-of-Africa movement around 60,000 to 50,000 years ago; a subsequent migration from the Iranian plateau about 12,000 years ago; and a significant influx from Steppe pastoralists roughly 5,000 years ago (Majumder, 2010; Narasimhan *et al.*, 2019). These events have resulted in distinct ancestral components, notably Ancestral North Indians (ANI) and Ancestral South Indians (ASI), along with contributions from Austro-Asiatic and Tibeto-Burman groups (Narasimhan *et al.*, 2019).

Despite modern national boundaries, overlapping genetic signatures are evident across South Asian populations and align closely with linguistic and cultural divisions. For instance, genetic clusters often mirror language families such as Indo-European, Dravidian, Austro-Asiatic, and Tibeto-Burman (Majumder, 2010; Narasimhan *et al.*, 2019). Additionally, long-standing practices like endogamy and caste systems have led to strong founder effects and increased genetic similarity within certain groups, influencing both common and rare genetic variants (Majumder, 2010; The GUaRDIAN Consortium *et al.*, 2019).

This overlapping genetic heritage presents significant opportunities for collaborative research. In the realm of rare diseases, where individual national datasets may be too limited, pooling data across borders can greatly improve the detection of rare variants and enhance our understanding of their impact on health (Rehm *et al.*, 2021). Similarly, a regional approach can advance research into common disorders like type 2 diabetes, cardiovascular diseases, and cancers, which are highly prevalent in South Asia (Jain *et al.*, 2024; Patel, 2021; Ranasinghe *et al.*, 2024).

A comprehensive genomic database that truly represents South Asia's genetic diversity is crucial for developing precision medicine and population-specific healthcare solutions. Such a resource would deepen our understanding of how genes interact with environmental factors, such as diet, socioeconomic conditions, and local climates, leading to more targeted treatments and accurate risk prediction models. Yet, despite its vast genetic diversity, South Asia remains underrepresented in global genomic studies, with most available datasets focusing primarily on a few groups from India, Pakistan, and Bangladesh (Dokuru *et al.*, 2024).

To address this gap, several initiatives have emerged. Projects like GenomeAsia100K aim to capture a broader range of genetic variation across Asia (GenomeAsia100K Consortium *et al.*, 2019), while national efforts such as the Genome India Project are sequencing 10,000 genomes from India's diverse populations to build a comprehensive catalogue of genetic variation. Similarly, India's Cancer Atlas is working to map the genomic, clinical, and epidemiological landscape of cancer across the nation, offering critical insights for targeted prevention and treatment strategies.

Ultimately, pooling genomic data across borders is essential for enhancing the statistical power of studies and developing risk models that reflect South Asia's unique genetic makeup. Overcoming local challenges and the inherent complexities of genomic data sharing can pave the way for more effective and equitable healthcare solutions across the region.

Challenges in Cross-Border Genomic Data Sharing

Genomic and genetic data sharing, however, is inherently challenging due to the nature of genomics data. This is further compounded by the political differences, heterogeneous data regulatory laws, and different socioeconomic situations and differences in technical capabilities.

Complexity of Genomics Data

Genomic data presents unique challenges that set it apart from conventional digital or administrative data. Its inherent sensitivity and complexity require specialised handling, robust governance, and adaptive frameworks. The following points highlight the key aspects of these challenges:

- **Dual Nature**
  - **Individual Information:** Genomic data reveals personal traits, disease risks, ancestry, and even behavioural tendencies. This predictive nature makes it vulnerable to misuse, such as genetic discrimination in employment or insurance (Lemke *et al.*, 2022; World Health Organisation, n.d.).
  - **Collective Information:** Genomic data contains insights about biological relatives, ethnic groups, and entire populations. Decisions made regarding one individual's genomic data can inadvertently affect the privacy and rights of their family members and communities, raising complex ethical questions about data ownership and consent (Lemke *et al.*, 2022; World Health Organisation, n.d.).
- **Long-Term Relevance**

  Genomic data remains relevant throughout an individual's lifetime and can impact future generations. This permanence raises significant concerns regarding how the data is stored, used, and protected over extended periods. In addition, it complicates the informed consent process because explaining the potential future uses of genomic data is challenging when many applications may be unknown at the time of data collection.
- **Ethical and Cultural Dimensions**

  Genomic data intersects with cultural beliefs, ancestry, and identity, which can lead to conflicts with traditional narratives or even legal implications regarding land or resource claims, especially among indigenous communities (Lemke *et al.*, 2022). Moreover, the misuse of genomic data can result in stigmatisation or exploitation of entire communities, particularly those that are marginalised or indigenous. This potential for group harm further complicates governance efforts (Lemke *et al.*, 2022).
- **Complex Consent Dynamics**

  Obtaining informed consent for genomic data is particularly challenging because the data affects not only the individual but also their family and community. Consent must encompass potential future uses of the data, which are often unknown at the time of collection. This complexity makes it difficult to secure truly informed consent that addresses both individual and collective implications (World Health Organisation, n.d.).
- **Global and Technical Implications**
  - **Global Data Sharing:** Genomic data transcends national borders, contributing to international research efforts. This global nature raises important questions about data sovereignty, equitable benefit-sharing, and the ethical use of data in various contexts (Rehm *et al.*, 2021).
  - **Technical and Infrastructure Challenges:** The massive volume and intricate complexity of genomic datasets require advanced computational tools and secure infrastructures, resources that many South Asian countries are still developing. India has taken the lead with the recently formed centralised Indian Biological Data Centre, while Bangladesh is investing in federal genomic centres in research centres, and Sri Lanka has recently come up with a national genomics policy stating the need for genomics data centres. Standardising data formats, ensuring quality control,

and achieving interoperability between different databases are ongoing challenges (Rehm *et al.*, 2021). Moreover, the dynamic nature of genomic information, where new discoveries can change the interpretation of previously collected data, necessitates continuous updates to regulatory frameworks and ethical guidelines.

Political and Regulatory Complexities

One of the primary obstacles in cross-border genomic data sharing in South Asia is the divergence in national policies and regulatory frameworks governing data protection, privacy, and ethical standards. Countries in the region operate under varied legal systems, creating a patchwork of rules that complicates collaborative research efforts. These regulatory discrepancies are further compounded by the absence of specific legal frameworks designed for genomic data sharing. Many South Asian nations are forced to rely on general data protection laws that do not fully address the complexities of genomic information. For example, in 2021, the Department of Biotechnology, Government of India, released Biotech-PRIDE guidelines to encourage biological data sharing (Department of Biotechnology, 2021). Further, India implemented the Digital Personal Data Protection Act of 2023 with a robust regulatory framework on the protection of personal data, however, with biological personal data oversight (Ministry of Electronics and Information Technology, 2023). Similarly, Sri Lanka has implemented a comprehensive Personal Data Protection Act that sets robust guidelines for personal information (Personal Data Protection Act, 2022); and Nepal has its own individual data protection framework (The Privacy Act, 2075 (2018), 2018).

However, these frameworks lack provisions that are tailored to the unique nature of genomic data. The personal data protection bill is under consideration in Pakistan; while Bangladesh, Bhutan and Maldives are still in the process of evolving their legal landscape. Global benchmarks like the European Union's GDPRoffer valuable guidance, but adapting these models to the local context remains a significant challenge.

These varied regulatory practices create a fragmented legal environment that makes it difficult to establish common protocols for pooling and sharing genomic datasets. For example, India's data protection law imposes strict data localisation requirements that mandate sensitive databe stored within national borders (Ministry of Electronics and Information Technology, 2023). Such requirements, firstly in contrast with the country's open science stance and existing research data guidelines, can hinder the seamless transfer of data across borders, thereby complicating collaborative genomic research initiatives. The disparities not only stem from different approaches to data localisation and storage but also from the uneven development of laws specifically addressing the sensitive and enduring nature of genomic information. When each country enforces its own distinct data protection requirements, researchers face significant challenges in aligning standards, ensuring data interoperability, and maintaining ethical oversight across borders.

In addition to regulatory differences, regional geopolitical tensions and historical conflicts among neighbouring nations hinder the development of trust and the willingness to engage in collaborative agreements. These factors, when combined with the regulatory fragmentation, stall initiatives that could otherwise benefit from pooled genomic resources and hinder the establishment of common protocols for data sharing across South Asia.

Data Privacy and Sovereignty Concerns

Ensuring the privacy and security of genomic data is paramount given its highly sensitive nature. The current fragmented regulatory environment in South Asia exacerbates these risks. Moreover, challenges in uniformly enforcing existing regulations across jurisdictions further complicate this issue.

A key aspect of this challenge is the concept of genomic sovereignty. Genomic sovereignty is the principle that national genetic resources should be studied primarily by and for the nation. This concept, first introduced in Mexico through the Genomic Sovereignty Act of 2008 (Rojas-Martínez, 2015) and echoed in discussions in India (Mathur and Swaminathan, 2018), is viewed by many non-Western societies as a necessary measure to correct historical injustices and resist ongoing exploitation (such as biopiracy or unfair benefit sharing by pharmaceutical companies) (Zhang, 2023). Lack of informed consent, unfair benefit sharing, irreversible environmental degradation, and violation of human rights and indigenous culture are just some of the widely acknowledged historical harms that have been caused (Zhang, 2023). However, in the context of ethnic communities, genomic sovereignty goes beyond national borders and encompasses the rights of communities—especially indigenous populations—to govern their own genetic resources.

Genomic sovereignty empowers local groups to control how their data is collected, stored, and used, ensuring that research initiatives respect cultural values and promote equitable benefit sharing (Carroll *et al.*, 2020). Without dedicated biological data sharing laws, these communities may lack the legal tools necessary to assert their control, potentially leading to exploitation or misrepresentation in genomic studies (Carroll *et al.*, 2020; Lemke *et al.*, 2022).

Adaptive governance models, that cater to national sovereignty across borders, and community governance (or indigenous sovereignty) within the borders, are required for a balanced approach that protects local genetic resources while still enabling open scientific inquiry, ensuring fair benefit-sharing and community engagement (Lumaka *et al.*, 2022). Such models require both, innovative regulatory and technological approaches. Advanced computational techniques, such as federated learning and differential privacy, can provide technological solutions that secure genomic data without impeding research progress (Boscarino *et al.*, 2022)

Global Good Practices in Genomics Data Collection and Sharing

Global good practices for genomic data collection and sharing are built on a foundation of ethical, legal, and technical standards that protect individual rights while promoting scientific advancement. International frameworks such as those from the Global Alliance for Genomics and Health (GA4GH) and the World Health Organisation (WHO) have established core principles—focusing on informed consent, data privacy, controlled access, benefit sharing, and robust governance—which serve as guiding models for responsible data stewardship. These principles ensure that genomic data, given its deeply personal and enduring nature, is collected and shared in ways that are transparent, equitable, and respectful of cultural diversity.

- **Informed Consent and Participant Empowerment**

  Consent processes must be clear, accessible, and tailored to local languages and cultural contexts. Dynamic consent models, which allow participants to modify or withdraw consent as research needs evolve, are essential to maintaining trust and ensuring ongoing engagement.

- **Data Privacy and Confidentiality**

  Advanced security measures—such as encryption, strict access controls, and regular security audits—are required to safeguard the highly sensitive nature of genomic data. Protocols for data de-identification and anonymisation must be rigorously applied to minimise risks of re-identification and potential misuse.

- **Controlled Data Access**

  Genomic data should be shared via controlled environments like data access committees and secure cloud-based platforms. Transparent access protocols define who can access data, under what conditions, and for which purposes, thereby striking a balance between open research and privacy protection.

- **Equitable Benefit Sharing**

  The benefits derived from genomic research must be shared fairly with the individuals and communities providing the data. These include both monetary and non-monetary benefits, such as improved diagnostics, enhanced healthcare services, and capacity building. Involving community representatives in benefit-sharing negotiations is critical to ensuring that outcomes are aligned with local needs.

- **Robust Governance and Accountability**

  Establishing clear governance structures is crucial for monitoring data use and ensuring compliance with ethical and legal standards. This involves defining roles for researchers, data custodians, policy-makers, and community representatives, and incorporating mechanisms for regular audits, oversight, and accountability.

- **Collaborative and Inclusive Approaches**

  International and multistakeholder collaborations help harmonise standards across diverse regulatory environments. Adaptation of global frameworks must respect local cultural norms and address unique community concerns, ensuring that policies are both universally informed and locally relevant.

Aside from theoretical frameworks, there are global models of collaborative genomics research and data sharing that can serve as examples for the South Asian model to evolve.

H3Africa Framework

H3Africa (Human Heredity and Health in Africa), launched in 2010, is a collaborative initiative to advance genomic research across the African continent. Launched to address the historical underrepresentation of African populations in genomic research, H3Africa aims to build local capacity through training, infrastructure development, and ethical governance. The project facilitates the collection, analysis, and sharing of genomic data in a culturally sensitive and ethically responsible manner, ensuring that research outcomes directly benefit African communities by informing precision medicine and public health strategies.The H3Africa initiative, involving researchers and institutions across 30 African countries, provides a practical example of how genomic data collection and sharing can be conducted in a manner that is ethically robust and culturally sensitive(H3Africa, 2018). Key features of the H3Africa framework include:

- **Ethical Principles and Community Engagement**

  H3Africa emphasises the importance of involving local communities at every stage of the research process. Consent is obtained in culturally appropriate ways, often incorporating broad consent models with clearly defined limitations and ongoing community consultation. This ensures that participants are fully informed about the potential future uses of their data and that their cultural values are respected.

- **Social Justice and Solidarity**

  A core tenet of H3Africa is to promote social justice by ensuring that the benefits of genomic research are shared equitably. The framework stresses that the communities providing data should also receive tangible benefits, such as improved healthcare services and capacity building, thereby addressing historical imbalances in research collaborations.

- **Equitable Access and Benefit Sharing**

  The H3Africa framework calls for clear benefit-sharing mechanisms that include both monetary and non-monetary returns. It also advocates for the strengthening of local research infrastructure and the empowerment of African scientists through inclusive governance and capacity-building initiatives.

- **Governance and Accountability**

  Good governance in the H3Africa framework is achieved through independent oversight committees that include local experts. These committees ensure transparency, monitor ethical compliance, and hold all stakeholders accountable for the responsible use of genomic data.

European Genomic Data Infrastructure (EGDI)

Launched in 2019 and adopted widely by the members of the European Union, the European Genomic Data Infrastructure (EGDI) offers a contrasting yet complementary model that demonstrates how federated data systems can facilitate cross-border genomic research while maintaining rigorous data protection standards(Pascucci *et al.*, 2024).Key characteristics of EGDI include:

- **Strict Data Protection Regulations**

  EGDI is governed by the European Union's General Data Protection Regulation (GDPR), which sets high standards for privacy, consent, and data security. These regulations ensure that genomic data is processed lawfully and transparently, with explicit consent from participants.

- **Adherence to FAIR Principles**

  The EGDI model emphasises the FAIR (Findable, Accessible, Interoperable, Reusable) principles. Standardised data formats, metadata protocols, and secure access mechanisms are implemented to ensure that genomic data is easily discoverable and usable for research while safeguarding privacy.

- **Federated Data Model**

  Rather than centralising data in one

repository, EGDI employs a federated model where data remains stored at local or national institutions. Harmonised standards enable cross-border queries and collaborative analyses without compromising national sovereignty, thus balancing openness with security.

- **Robust Ethical Oversight**

  Independent ethics committees and institutional review boards provide oversight, ensuring that data sharing adheres to ethical guidelines and that benefits are equitably distributed. This oversight is critical for maintaining public trust and ensuring that data use aligns with both individual rights and collective interests.

Science Diplomacy for Genomics Research

Science diplomacy offers a powerful tool to overcome the challenges posed by diverse regulatory environments, geopolitical tensions, and varying research capacities across South Asia.Given the region's deep genetic interconnections and its diverse cultural, linguistic, and legal landscapes, science diplomacy can serve as a catalyst for regional integration in genomic research. However, how such collaborations are carried out needs to be treated carefully; as the openness for genomics data and knowledge exchange, along with principles of genomic data sovereignty and data security, need to be balanced.

In addition to ensuring data sovereignty, genomic data collection in South Asia must prioritise local needs and contexts. This requires implementing dynamic informed consent processes in local languages and establishing local genomic data governance structures, especially to include indigenous and marginalised communities. Given the region's vast diversity, it is more feasible to develop multiple centres for genomic data collection and management, each accountable for fair benefit sharing and ethical oversight. A federated data management and governance model is therefore more suitable than a centralised approach.

Moreover, the management and analysis of genomic data demand significant technical infrastructure and skilled human resources—capabilities that vary widely across South Asia. Here, science diplomacy can play a major role by facilitating knowledge exchange, organising joint capacity-building workshops, and securing collaborative funding to establish regional genomic centres. These centres can support local data hubs within a federated system and offer joint ethical oversight for the region, while ensuring adherence to global standards such as the FAIR and CARE principles.

Ultimately, one of the key roles of science diplomacy is to balance local needs with harmonised legal and ethical frameworks across borders. South Asian countries currently operate under diverse data protection laws and ethical guidelines, which complicate the sharing of sensitive genomic data. Through multilateral discussions and bilateral agreements, science diplomacy can help develop a regional regulatory framework that supports a federated data governance model. This model enables data to remain locally managed yet accessible for collaborative research, thereby overcoming techno-nationalism and addressing genomic sovereignty concerns. Such an overarching framework would foster capacity building, create secure and interoperable systems, and ensure equitable participation in advancing genomic research across South Asia.

Recommendations for South Asian Countries

Building on the frameworks of GA4GH, WHO, H3Africa, and EGDI, the following recommendations are proposed for South Asian countries to advance genomic data collection and sharing:

1. **Establish a Harmonised Legal Framework**
    - Develop a regional legal framework that standardises policies on genomic data collection, access, use, and sharing across South Asia.
    - Adapt international best practices (e.g. GDPR, GA4GH guidelines) to local contexts while creating specific provisions for the unique aspects of genomic data.
2. **Implement Inclusive Governance Structures**
    - Create multi-stakeholder oversight bodies that include government representatives, local scientists, community leaders, and civil society.
    - Establish independent Data Access Committees and ethics review boards to ensure transparency, accountability, and cultural sensitivity.
3. **Ensure Robust Data Privacy and Security**
    - Mandate the use of advanced security protocols (encryption, access controls, regular audits) to protect genomic data.
    - Develop clear guidelines for de-identification and anonymisation to prevent re-identification risks while balancing the need for data utility.
4. **Promote Equitable Benefit Sharing and Capacity Building**
    - Design benefit-sharing agreements that include both monetary and non-monetary returns, ensuring that local communities receive tangible benefits.
    - Invest in local infrastructure and training programmes to build research capacity and empower South Asian scientists.
5. **Foster Cross-Border Collaboration**
    - Develop bilateral and multilateral agreements to harmonise regulatory practices and facilitate the pooling of genomic data across borders.
    - Leverage models like EGDI to create federated data systems, within communities and countries that respect national and indigenous sovereignty while enabling collaborative research.
6. **Integrate Ethical Principles into Data Governance**
    - Embed principles of informed consent, social justice, solidarity, transparency, and accountability into all aspects of genomic data governance.
    - Ensure ongoing community engagement through the involvement of civil societies and social scientists to continuously adapt policies to evolving ethical, cultural, and scientific landscapes.

Conclusion

The integration of genomic data collection and sharing into the health and research landscape of South Asia represents a transformative opportunity for advancing precision medicine and public health. By drawing on global frameworks and learning from practical models like the European Genomic Data Infrastructure (EGDI) and the H3Africa framework, South Asian countries can adapt and develop robust, harmonised policies that address the unique challenges posed by genomic data.

These recommendations emphasise the need for a cohesive legal framework, inclusive governance structures, stringent data privacy and security measures, equitable benefit sharing, and enhanced cross-border collaboration. Adapting these principles to local contexts will not only empower communities and local researchers but also ensure that genomic advancements benefit all populations while safeguarding individual and collective rights. Ultimately, this comprehensive framework promises to foster an environment where genomic research can thrive ethically and effectively, paving the way for improved health outcomes and greater equity across the region.

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PAPER

CERN at 70: Where Science Meets Diplomacy

Chetna Krishna* and Rüdiger Voss**

Chetna Krishna

Rüdiger Voss

Introduction

Nestled on the border of France and Switzerland, CERN—the European Organization for Nuclear Research—stands as the world's largest particle physics laboratory and a symbol of international collaboration. The Laboratory has more than 17,500 people from across the globe working together to push the limits of knowledge (CERN, 2025). India is an Associate Member of CERN. The Laboratory is home to some of the most advanced and sophisticated scientific instruments, such as the Large Hadron Collider (LHC), and hosts a gigantic complex of other particle accelerators. The first collisions in the LHC took place in 2009, followed by the observation of a new Standard Model particle known as the Higgs boson in 2012, witnessing a day in physics like no other (Rao, 2022). The discovery of the Higgs boson led to the Nobel Prize in Physics immediately the following year. The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider" (Nobel Prize Outreach 2025, 2025).

The construction of the LHC in the early 2000s was not an easy feat, to say the least, both technologically and diplomatically. Building the world's most powerful accelerator was an ambitious mega-science project of the time, with the need for international funding, worldwide cooperation, and

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integration in the local environment. Fast forward to 16 years after the operation of the LHC, the lab is eyeing the major LHC upgrade known as High-Luminosity LHC, aimed to operate from the 2030s and developing accelerator studies for beyond 2040, such as the Future Circular Collider (FCC), the Compact Linear Collider (CLIC) and the Muon Collider. The future of particle physics is built upon and passed from generation to generation, with the need for established and early-career researchers to take part in the decision–making process. But to truly appreciate what lies 70 years ahead of CERN, we must go back to its origins and the role it plays in science diplomacy today.

Origin of CERN

In 1947, while the Indian subcontinent was celebrating Independence along with its own challenges from the remnants of colonial rule, Europe was also recovering from World War II. Many eminent scientists from Europe had left for the United States. In order to rebuild science in Europe and bring it to a world-class level, a handful of visionary scientists imagined creating a European atomic physics laboratory. Raoul Dautry, Pierre Auger, and Lew Kowarski in France, Edoardo Amaldi in Italy, and Niels Bohr in Denmark were among these pioneers. Such a laboratory would not only unite European scientists but also allow them to share the costs of nuclear physics facilities. French physicist and Nobel Prize winner Louis de Broglie proposed the creation of a European laboratory that would be both a centre of excellence in physics and a motto for peace. His idea was taken up by American Nobel Prize winner Isidor Rabi, who convinced UNESCO to adopt this process and tabled a resolution to "assist and encourage the formation of regional research laboratories in order to increase international scientific collaboration…".

At an intergovernmental meeting of UNESCO in Paris in December 1951, the first resolution concerning the establishment of a European Council for Nuclear Research was adopted. Two months later, 11 countries signed an agreement establishing the provisional Council – the acronym CERN was born. At the provisional Council's third session in October 1952, Geneva was chosen as the site of the future Laboratory because of its central location in Europe and its international tradition. The CERN Convention, established in July 1953, defined CERN's goals, stating that its research will have no concern with military requirements and that all its results should be made public (CERN, 2025). The convention was gradually ratified by the 12 founding Member States: Belgium, Denmark, France, the Federal Republic of Germany, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and Yugoslavia. On 29 September 1954, following the ratification by France and Germany, the European Organization for Nuclear Research officially came into being. The provisional CERN was dissolved, but the acronym remained, and CERN was born.

The seeds of CERN's creation, however, were sown much earlierin the United States by the notable French diplomat, François de Rose, and his close friendship with physicist Robert Oppenheimer. François de Rose recalls the first discussions that ultimately led to the birth of the Organization:

> *At that time, I was the French representative to the United Nations International Atomic Energy*

Commission, which comprised both diplomats and scientists. It was there that I met Robert Oppenheimer, with whom I struck up a friendship. Like many American scientists, he had been very much influenced by European science, having worked in Niels Bohr's group, in particular. During one of our conversations, he said, more or less, the following: 'We have learned all we know in Europe. But in the future, fundamental physics research is going to require substantial resources that will be beyond the means of individual European countries. You will need to pool your efforts to build these big machines that are going to be needed. It would be unhealthy if the Europeans were obliged to go to the United States or the Soviet Union to conduct their fundamental research. The idea fascinated me, and I arranged for him to meet the French scientific advisers from my Commission, Pierre Auger, Francis Perrin, Lew Kowarski, and Bertrand Goldschmidt" (Rose, 2008).

In 1949, François de Rose returned to Paris and went on a tour of European capitals with Francis Perrin to see what sort of reception Oppenheimer's idea would be given. He recalls:

We were confronted with a lack of interest: the scientists were afraid that a big research centre would swallow all the available funds and soak up the resources of their own laboratories. They were wrong, however, because as soon as CERN started to request resources, there was an increase in the funding allocated to research. What's more, the governments had no idea of what it was all about: when they heard the words 'atomic research', they immediately thought of the atomic bomb and were afraid that it would not go down well with the Americans. Last but not least, the fact that Frédéric Joliot Curie, an eminent member of the Communist Party, was incharge of the French Atomic Energy Commission caused the other European scientists to have cold feet. We, therefore, failed in our mission. However, the idea was now on the table and Isidor Rabi's speech at the Florence General Conference secured the breakthrough we needed. CERN was created so Europeans were not forced to go to the United States. Today, Americans are coming to Europe to work on CERN's machines, something which I don't think Oppenheimer had anticipated. I find that an extraordinary turnaround. (Rose, 2008)

François de Rose served as the President of the CERN Council from 1958 to 1960, during which time he helped to prepare the laboratory's extension into French territory. Following the construction of CERN's oldest accelerator, the Synchrocyclotron, the lab built bigger and bigger accelerators: the Proton Synchrotron, the Intersecting Storage Rings, the Super Proton Synchrotron, the Large Electron–Positron collider, and the Large Hadron Collider. Many important achievements were made, some of them being rewarded with the Nobel Prize. The Multiwire Proportional Chamber (MWPC) and the drift chamber revolutionised particle detection, the cooling of particle beams, the discovery of the carriers of the weak interaction, and the Higgs boson, which proved the existence of the Brout-Englert-Higgs. What started once as a vision for European science grew into a unique model for global scientific and technological collaboration. CERN demonstrated how science can unite nations and contribute to a better world.

The Higgs Boson

Satyendra Nath Bose was one of the founding fathers of quantum mechanics, the most successful framework for describing the physical world. His pioneering work on quantum statistics (the mathematical rules governing how particles interact) laid the foundation for many modern advancements in physics. His contributions have led to the formulation of Bose-Einstein statistics, laying the foundation for phenomena such as Bose-Einstein condensation, quantum superconductivity, and modern quantum information science. His groundbreaking derivation of Planck's law, in a novel way, deeply impressed Einstein, leading to a collaboration that revolutionised our understanding of quantum particles.

In June 1924, Albert Einstein received an unexpected letter from an Indian professor who introduced himself as a "complete stranger." Enclosed with the letter was a short, five-page paper that the author hoped Einstein would review. The paper claimed to address a crucial flaw in quantum theory—one that Einstein himself had grappled with for years without success. At the time, Einstein was based at the University of Berlin, and upon reading the paper, he immediately recognised that its author, Satyendra Nath Bose, had solved the very problem that had eluded him. The issue concerned the proper derivation of Planck's law, which describes the spectrum of radiation emitted by a black body. While Max Planck had first formulated the law in 1900, classical physics had predicted that radiation intensity would rise infinitely at shorter wavelengths—a contradiction known as the ultraviolet catastrophe. Bose's method provided a fully satisfactory statistical explanation, offering a groundbreaking insight into quantum theory. Their brief but highly significant collaboration led to the prediction of a new quantum phenomenon, known as Bose-Einstein condensation.

The Bose-Einstein exchange remains one of the most remarkable correspondences in the history of physics. Interestingly, Einstein saw an even deeper implication in Bose's work than Bose himself had envisioned. Bose's treatment of photons as statistically dependent suggested a key feature of wave interference. Einstein, however, realised that this statistical behaviour wasn't limited to photons alone—it could also apply to other types of particles. This idea laid the foundation for what we now understand as bosons—particles with integer spin values that can occupy the same quantum state. Two decades later, Paul Dirac formalised this distinction, coining the term "boson" in honour of Bose (Crease & Elia , 2024).

Bosons and fermions are the two fundamental types of particles in the universe. While bosons are shaping the forces of nature, fermions build the matter around us. Bosons are particles that carry forces and can share the same quantum state, meaning they do not mind 'clumping together.' This property allows for phenomena like Bose-Einstein condensation, where many bosons act as a single quantum entity. Examples include photons (particles of light), gluons (which hold atomic nuclei together), and the Higgs boson (which gives particles mass). Fermions, on the other hand, make up matter and obey the Pauli exclusion principle, meaning no two identical fermions can occupy the same quantum state. This rule is why atoms have complex structures and why matter has solidity. Electrons, protons, and neutrons are all fermions.

After seven decades since the theoretical prediction in 1924, Bose-Einstein condensation was experimentally confirmed in 1995, a discovery that earned Eric Cornell, Wolfgang Ketterle, and Carl Wieman the Nobel Prize in Physics six years later (Nobel Prize Outreach 2025, 2025).

Another such legacy in Nobel Prizes that followed was the experimental discovery of the Higgs boson. Peter Higgs built on the quantum foundations laid by Bose and others to propose a mechanism explaining how particles acquire mass. The Higgs boson was proposed in 1964 by Peter Higgs, François Englert, and Robert Brout. It was discovered at the Large Hadron Collider at CERN in 2012, which completed the missing puzzle of the Standard Model of particle physics. The Higgs boson, associated with the Higgs field, gives mass to elementary particles such as quarks and electrons, making up atoms, molecules, and ultimately, the universe as we know it. Peter Higgs' theoretical discovery earned him and François Englertthe 2013 Nobel Prize in Physics, recognising its fundamental role in shaping our understanding of matter.

The Higgs boson—a fundamental piece of modern physics—holds the key to understanding the deepest mysteries of the visible universe. While the Higgs boson explains why particles have mass, bosons dictate how forces act in nature. Bose and Higgs have not only deepened our fundamental understanding of nature but have also paved the way for groundbreaking applications in particle physics and quantum technologies. Marking a century of these groundbreaking contributions, the BoseStat@100: Centenary of Bose Statistics, was celebrated by the Department of Science and Technology, Government of India, in 2024, honouring Bose's legacy and its profound impact on modern physics (Satyendra Nath Bose National Centre for Basic Sciences, 2024).

A century after Bose's pioneering work; his ideas continue to drive breakthroughs in physics. Earlier in 2024, CERN's AEgIS experiment achieved a remarkable milestone by demonstrating laser cooling of positronium, a short-lived atom made of an electron and its antimatter counterpart, the positron. This breakthrough opens up new possibilities for antimatter research, including precise studies of its gravitational behaviour and the potential to uncover new physics beyond our current understanding. It enables the creation of a positronium Bose-Einstein condensate, where all particles occupy the same quantum state, much like Bose's original idea. Such a condensate could pave the way for the production of coherent gamma-ray light, akin to a laser but at much higher energy levels. This gamma-ray laser could allow scientists to probe the atomic nucleus with unprecedented precision, leading to revolutionary applications in both fundamental research and practical technologies. AEgIS spokesperson Ruggero Caravita from AEgIS says: "A Bose-Einstein condensate of antimatter would be an incredible tool for both fundamental and applied research" (CERN, 2024).

Bose's work, once a purely theoretical breakthrough, is now shaping the frontiers of modern physics, from quantum technologies to the mysteries of antimatter, proving that the Higgs and the boson are more than just theoretical ideas—they are key to unlocking the deepest secrets of the universe. Satyendra Nath Bose's legacy resonates beyond physics, as his name is shared with another towering figure of Indian history—Subhas Chandra Bose, the visionary leader of India's independence movement. While one Bose fought to free India from colonial rule, the other revolutionised our understanding of the quantum world. Both, in their respective fields, embodied the spirit of scientific and political emancipation, leaving behind legacies that continue to inspire generations.

CERN and India

India is known for its vibrant culture across the world. This presence also resonates at CERN, boldly depicted by the striking Nataraja statue at its headquarters in Meyrin, Switzerland– a gift from India's Department of Atomic Energy in 2004. It is a fitting, evocative, and exquisite gift for a laboratory studying the subatomic universe, symbolised by Ananda Tandava. Carl Sagan, in his book Cosmos, drew the metaphor between the 'cosmic dance' of the Nataraja and the modern study of the dance of subatomic particles.

CERN's long association with India started in the 1960s with individual and institutional participation. In 1992, the Department of Atomic Energy (DAE) formalised this partnership,and the Department of Science and Technology (DST) later joined, strengthening India's academic participation. Recognising India's growing contributions, CERN granted the country Observer Status in 2002, paving the way for deeper engagement. A major milestone was reached in 2017 when India became an Associate Member of CERN. This status not only signifies India's commitment to fundamental physics but also brings tangible benefits. The membership allows greater participation for Indian scientists and staff members in leadership roles, research positions, student training programmes, and industrial business. With an annual contribution of ₹1.71 crore (1.38 per cent of CERN's total budget of ₹124.27 crore) (CERN, 2022), India has firmly positioned itself as a key player in the world's most ambitious particle physics experiments.

Indian scientists played a pivotal role in designing and building several key components of the LHC, as well as in the physics data analysis that contributed to the Nobel-prize winning discovery of the Higgs boson by the ATLAS and CMS experiments. More than 400 Indian scientists are engaged in projects like the LHC and its experiments, namely, CMS and ALICE collaborations. Other experiments with participation from Indian institutes include physics facilities liken_ TOF and ISOLDE andWA93 experiment at the CERN accelerator, Super Proton Synchrotron. India's participation extends far across the lab, including scientists of Indian origin and students affiliated with abroad universities.

Experiments at CERN produce colossal amounts of data (roughly 30 petabytes a year), which are processed using Grid computing, enabling the sharing of resources belonging to computer centres located around the world. Indian scientists have contributed substantially to the building and operation of the Worldwide LHC Grid (WLCG) (CERN, 2025). WLCG has a hierarchical structure of data dissemination, of which India hosts two

Tier 2 centres at Variable Energy Cyclotron Centre (VECC) and Tata Institute of Fundamental Research (TIFR), in addition to several Tier 3 centres. The two Tier-2 Grid computing centres at VECC and TIFR are performing a large part of LHC computing.

CERN acts as an interface between fundamental research and technological applications in society: the invention of the WWW, the first capacitive touch screen and positron-emission tomography (PET) technology are some of the greatest, well-known examples to the common man. Projects like Smart Technologies to Extend Lives with Linear Accelerators (STELLA) (CERN, 2024) aim to democratise access to cutting-edge cancer treatment using linear accelerators, ensuring that technology born from particle physicsserves beyond the laboratory.

Beyond research, India's partnership with the Laboratory is leading to emerging business with Indian industries. Recent contracts signed with HCLTech and Sailotech focus on delivering agile application development services and supporting CERN's digital transformation.

Finally, sharing the wonders of the lab with students and teachers in India has been a huge outreach effort done by the Indian personnel at CERN. The author facilitates several school visits to CERN, both on-site and virtually, helping students position their studies in the real-world context at a lab like CERN, where they get to watch science and scientists inaction and pick the brains of renowned physicists like John Ellis and Michal Doser.

Asia-Europe-Pacific School of High-Energy Physics (AEPSHEP) is a series of schools being held in the Asia-Pacific region every two years, in even-numbered years, similar to the CERN Latin-American School of High-Energy Physics. The first school in the AEPSHEP series was held in Fukuoka, Japan, in 2012, the second one was held in Puri, India, in 2014, the third one was held near Beijing, China, in 2016, and the fourth one was held in Quy Nhon, Vietnam, in 2018. The next school will be held in 2026. The purpose of the School is to provide young physicists with an opportunity to learn about recent advances in elementary-particle physics from world-leading researchers. It also aims to encourage communication among Asian, European and Pacific-region young researchers. The School provides High-Energy Physics courses from an experimental and phenomenological perspective, with a focus on accelerator-based programmes in Asia and Europe, and other related fields such as astro-particle physics and cosmological aspects of particle physics.

Programmes like the South Asia Science Education Programme (SASEP) and South Asian High Energy Physics Instrumentation (SAHEPI) workshop (Krishna, 2022)have also been organised. In 2024, CERN had a significant presence at the India Science Festival held in Pune, Maharashtra, with keynote talks and media lab installations with popular games like Proton Football marking the Organization's 70th-anniversary celebration in the Indian subcontinent. These efforts, however, are mostly done on an individual basis. A well-established consortium actively working for the interests of Indian institutions and universities can help reap benefits for the country's growing population of students and researchers. Though one thing is for sure, there lies a rewarding path forward for India and CERN's strategic and win-win collaboration.

Science Diplomacy during a World in Churn

From probing particles to partnerships, CERN has stood the test of time as a beacon of international collaboration. Today, the Organization has 24 Member States, 10 Associate Member States including India, and international organisations like the European Union and UNESCO with Observer status. On 30 August 2024, CERN welcomed its first Baltic country, Estonia, as a full Member State, and Brazil joined CERN as an Associate Member State earlier in 2024.

However, looking back into CERN's history, the enlargement of CERN was a hotly debated subject. Over 50 years, the CERN Council interpreted the 1953 CERN Convention as limiting membership to European states. But the LHC era changed that.

In response to great participation from non-Member States contributing to the LHC experiments, and in anticipation of the post-LHC era, the Council in 2010 approved the most significant shift in CERN's membership policy—officially opening the door to non-European countries (CERN/2918/Rev.). The underlying message was that CERN is fundamentally a European organisation, but there is no rule which prohibits non-European countries from becoming member states. The Laboratory recognised that future particle physics endeavours must be globally designed, funded, and governed.

Between 1955 and 1975, the collaboration between CERN and Soviet scientific institutions stood as a powerful symbol of how science could transcend political divides. In the midst of the Cold War, when ideological and military tensions were high, physicists from CERN and the Soviet Union worked side by side—building equipment, designing experiments, and, perhaps most importantly, building trust. A cornerstone of this collaboration was the formal 1967 agreement with the USSR State Committee for Atomic Energy, which laid the groundwork for joint scientific and technical efforts at the newly constructed proton accelerator known as Serpukhov in the Soviet Union which was the most powerful proton machine in the world at the time with an energy of 70 giga electron volts (GeV). Engineers and their families relocated across borders, seminars brought together scientists from rival superpowers, and collaborative research laid the foundation for CERN's own 400 GeV Super Proton Synchrotron. These weren't just experiments in physics; they were experiments in diplomacy, curiosity, and hope. For decades, even as global politics shifted, CERN remained one of the rare spaces where collaboration continued between East and West. But history has turned again.

Switzerland has the oldest policy of military neutrality in the world. In February 2022, Switzerland adopted sanctions imposed by the European Union against Russia and froze a significant amount of assets held by Russian civilians and companies as a response to the invasion of Ukraine. Some described this as "a sharp deviation from the country's traditional neutrality." Many media outlets labelled this as a break with 500 years of Swiss neutrality (Seitz-Wald, 2022). Russia perceived the sanctions similarly, as it rejected Switzerland's offer to mediate the conflict (Aljazeera, 2022). As CERN's host states, Switzerland and France provide its land and much of its general infrastructure, making their policies and decisions particularly significant in shaping the Organization's operations, governance, and international engagements. Sometimes, such international relations shape the contours of scientific collaboration.

In response to Russia's invasion of Ukraine, the CERN Council also took decisive action. It voted to end cooperation with Russia and Belarus upon the expiration of their International Cooperation Agreements (ICAs) in 2024, reinforcing CERN's stance that aggression and war stand in direct opposition to its mission. At the same time, CERN has taken significant steps to support Ukrainian scientists, including waiving Ukraine's financial contributions for 2022 and launching initiatives to sustain Ukrainian scientific activity in high-energy physics. Russian colleagues affiliated with non-Russian institutes continue to collaborate with CERN.

CERN was born in the aftermath of World War II as a promise that science could be a force for unity rather than division. It brought nations together to pursue knowledge in peace, creating a space where dialogue flourished even when diplomacy failed elsewhere.

To many in the global scientific community, the end of this era is heartbreaking—not because it's unjustified, but because it signals how fragile scientific bridges can be in the face of war. The human connections, friendships, and shared dreams built over decades are overshadowed by violence and aggression that run counter to everything CERN stands for. Yet even in this moment, CERN reaffirms its commitment to scientific collaboration as a driver for peace. Individual scientists of Russian and Belarusian nationality who are affiliated with CERN remain part of its community, and the Organization continues to uphold the ideals that built it: openness, cooperation, and the belief that knowledge belongs to all of humanity. Beyond institutional action, CERN's global scientific community has shown remarkable solidarity, raising 7.87 crores for the Red Cross's humanitarian efforts in Ukraine. Practical support initiatives were also launched, ranging from material assistance and psychological aid for Ukrainian personnel working at CERN, as well as remote training opportunities for students in Ukraine.

The story of CERN's collaboration with the Soviet Union is a reminder that even in divided times, science can reach across walls. And as those walls rise again, the challenge for the scientific world is to continue holding space for dialogue, to keep the doors open for when peace makes collaboration possible once more.

Over the years, the CERN model has served as a blueprint and sometimes even a launchpad to many well-known intergovernmental organisations in the world as we know them today. One of the best-known examples is the European Southern Observatory (ESO) in Munich, which was strongly inspired by CERN's model of collaboration and governance. In the 1970s, the ESO lab was also based at CERN using its infrastructure and computing facilities, before it moved to Munich as its official headquarters. European Molecular Biology Laboratory (EMBL), headquartered in Heidelberg, Germany, and founded in 1974, was also built upon inspiration from the CERN model. The SESAME laboratory, based in the Middle East, is an intergovernmental organisation established on the CERN model under the auspices of UNESCO.

SESAME has eight full Members (Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine, and Türkiye) and 17 Observers, including CERN. The international light source SESAME (Synchrotron-light for Experimental Science and Applications) in Allan, Jordan, provides an intense source of light from infrared to X-ray wavelengths, allowing researchers from the region to investigate the properties of advanced materials, biological processes and cultural artefacts. The Israeli and the Palestinian scientific communities were among the founding members of SESAME.

CERN is currently developing a pilot to advance Europe's next-generation gravitational-wave observatory, known as the Einstein Telescope, using its expertise in vacuum technologies and civil engineering, originally developed for the LHC. Scientific institutes from Italy, the Netherlands, and Germany are currently leading efforts to offer land and house the Einstein Telescope. The final location is expected to be decided by the end of next year, with the telescope aimed to be operational from 2035 and collecting physics data by 2040. While CERN offers it technical expertise in vacuum systems, civil engineering, power distribution, ventilation and underground safety, it is also acting as a neutral party to offer space for collaboration meetings for the next-generation gravitational-wave observatory in Europe as scientists from various countries in Europe find CERN as the most central and ideal location to discuss this emerging, next-generation project.

CERN hosts roughly 300 students every year in its summer student programme, open to students of all nationalities. In the last few years, a special effort has been made to take up two Palestinian students per year to participate in the CERN Summer Student Programme. CERN and Society Foundation sponsor programmes to support bringing students from countries that are not full members of the lab but have particle physics interests and competence. In 2024, CERN welcomed students for a short visit for the first time from Bhutan. Since 2003, more than 6000 students have participated in the programme, attracting students from various disciplines like physics, mechanical engineering, electrical engineering, and computer science (CERN & Society Foundation, 2025).

Looking 70 years Ahead

Particle physics is the exploration of nature at its most fundamental level. It has come to a pivotal moment today. The landmark discovery of the Higgs boson at the LHC in 2012 confirmed the final predicted piece of the Standard Model of particle physics. Yet, the Standard Model accounts for only 5 per cent of the Universe, leaving us with major mysteries of our universe unresolved.

The Standard Model cannot explain the unseen dark matter, an elusive substance that neither emits nor absorbs light, yet exerts a gravitational pull strong enough to shape galaxies and influence their rotation. Without dark matter, galaxies would not hold together as observed, yet their true nature remains unknown. Similarly, the accelerating expansion of the Universe defies explanation within the Standard Model. The discovery that the cosmos is not just expanding but doing so at an increasing rate suggests the presence of an unknown force or energy—often referred to as dark energy—that counteracts gravity on cosmic scales.However, its origin and properties remain one of the greatest mysteries in physics.

Additionally, the Standard Model does not hint at why the Universe exists in its current form, dominated by matter. According to known physics, the Big Bang should have created equal amounts of matter and antimatter, which would have annihilated each other, leaving behind only radiation. Yet, for reasons still unknown, a tiny imbalance in the early Universe allowed matter to dominate, forming stars, galaxies, and ultimately, life. Understanding this baryon asymmetry is a fundamental goal in modern physics led by experiments such as the Large Hadron Collider beauty (LHCb) experiment and other antimatter experiments at CERN's Antimatter Factory that produces, stores and studies anti-hydrogen to understand the fundamental properties of antimatter and how it behaves differently (or similar) as compared to matter.

To address these questions fundamental to human curiosity, scientists must push the frontiers of particle physics delving deeper into the Higgs boson's properties, studying elementary particles with unprecedented precision, and reaching higher energies with next-generation colliders. Although not guaranteed, which is against the true nature of a scientist, the successors of the world's most powerful accelerator, the LHC, will provide a genuine chance of new major discoveries. It will be a big step forward in human capability.

The High-Luminosity LHC (HL-LHC) will be a significant revamp of the LHC, with two-thirds of its largest particle detectors, ATLAS and CMS, replaced with new detector technology. More than one kilometre of the LHC machine will be replaced with about 100 magnets of new types. The HL-LHC will produce at least 15 million Higgs bosons per year, compared to around three million from the LHC in 2017. More collision data will bring opportunities to unleash physics beyond our current understanding. In the process of building HL-LHC, the technological feat attempted by accelerator physicists, engineers, and technicians is particularly exciting. In particular, new quadruple magnets, for the final focusing of the beams before collisions, will be installed in the insertion regions on either side of the ATLAS and CMS detectors. These magnets exploit a key innovative technology providing magnetic fields of up to 12 Tesla. They are built from a novel superconducting material called niobium-tin (Nb3Sn), using a unique design that allows the peak magnetic field strength to be increased by around 50 per cent compared with the current LHC magnets. High-temperature superconductors made of magnesium diboride are also being employed in the HL-LHC, that can operate at 25 K (-248 °C) instead of the conventional superconductor operating temperature of 1.9 K (271.3 °C). These higher temperatures will help save the energy required to freeze these magnets at temperatures lower than outer space. The new electric line powering the triplet magnets of HL-LHC will be made of innovative superconducting links, colloquially known as "python" due to its flexible nature. This new type of superconducting transmission line also has potential outside accelerator technology. These lines can transfer vast amounts of current within a small diameter and could, therefore, be used to deliver electricity in big cities or to connect renewable energy sources to populated areas. CERN's High-Temperature Superconducting (HTS) rare-earth barium copper oxide (also referred to as REBCO) power transmission cable is also being used to study the feasibility of superconductivity for aircrafts by Airbus UpNext. Once adopted by industries, it can lead the future of low-emission airplanes. But the R&D of the technology and planning begins years ahead at CERN.

CERN is looking towards the future with ambitious plans for its next-generation collider, aiming to push the boundaries of particle physics beyond what the LHC and HL-LHC can achieve. The leading candidate for this future machine is the Future Circular Collider (FCC), a proposed 90-kilometre ring that would significantly surpass the HL-LHC in energy and precision while using it as a pre-accelerator for higher energies. If approved, construction of the FCC tunnel would begin in the 2030s, with FCC-ee being the first phase of the project. This initial electron-positron collider would run for about 15–20 years, serving as a high-precision Higgs factory to study the Higgs boson, W and Z bosons, and the top quark with unprecedented accuracy. It is later planned to be transitioned to the FCC-pp (proton-proton collider) in the second half of the century. It would be housed in the same tunnel reaching energies up to 100 TeV, nearly seven times that of the LHC.

CERN is also studying an entirely different approach: the Muon Collider. Unlike traditional electron or proton colliders, a muon collider would use muons—heavier cousins of electrons—that can reach high energies in a much smaller ring, potentially offering a more cost-effective and energy-efficient path to new physics. While technically challenging due to the short lifetime of muons, recent advancements have reignited interest in this concept. The Particle Physics Project Prioritisation Panel (P5) report of the US presents themuon collider as an attractive option both for technological innovation and for bringing energy frontier colliders back to the US. The footprint of a 10 tera electronvolt (TeV)momentum in the centre-of-mass frame (pCM) muon collider is almost exactly the size of the Fermilab campus in Illinois, near Chicago (Particle Physics Project Prioritization Panel, 2023).

The quest for a future collider is not just about pushing the limits of energy and precision—it is about exploring the deepest mysteries of the universe. Regardless of the final choice, CERN's next machine could redefine our understanding of the fundamental forces that shape reality. But this choice is at a crossroads, balancing scientific ambition, financial constraints, and the responsibility of the scientists to come. The European Strategy for Particle Physics has commenced a process to develop a common vision for the future of particle physics in Europe. The process is expected to be concluded at the end of 2025, after which the European Strategy Group will submit its recommendations to the CERN Council.

The debate over a future collider is not just a question of physics; it is also about the future of the scientists who will drive the field forward. The academic landscape is already challenging, with a highly competitive job market, uncertain career paths, and a growing reliance on short-term postdoctoral positions. A future collider must not come at the cost of a sustainable career pipeline, where talented researchers can find stable positions, contribute meaningfully to the field, and have opportunities beyond just one mega-project. At the same time, without a bold new collider, particle physics risks stagnation, losing its role as a frontier science driving technological progress. The challenge ahead is not just about building the next machine—it is about building a future for the field that is sustainable, inclusive, and capable of precision science and discovery.

A future collider should be a catalyst for growth in particle physics. The challenge is to strike a balance—advancing scientific exploration while ensuring that physics remains an attractive and viable career path for young researchers. With funding pressures mounting and a global shift toward diversified research agendas, the next European Strategy for Particle Physics must navigate a complex landscape—balancing legacy projects with the need for adaptability, equity in scientific investment, and fresh perspectives from the next generation of physicists.

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PERSPECTIVE

International Cooperation for Green Hydrogen

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Introduction

Green Hydrogen has become a key contender in the drive toward decarbonisation and is set to play a vital role in India's ambition to achieve energy independence by 2047. It has garnered significant attention as an efficient and adaptable energy source with the potential to decarbonise key sectors such as transportation, power generation, and heavy industries, making it a crucial component of hybrid renewable energy systems. Currently, most global hydrogen production relies on fossil fuels, accounting for 2.5 per cent of total emissions and generating 900 Mt of CO_2. Blue Hydrogen holds a 0.7 per cent share, while Green Hydrogen remains in an early developmental stage, with production under 0.1 Mt in 2022 (IEA, 2023).

Green Hydrogen stands apart due to its distinct properties as an energy carrier. With a molecular weight of 2.016 g/mol, it is the lightest element and exists as a colourless, odourless, and tasteless gas. At standard temperature and pressure (STP), it has an exceptionally low density of 0.08988 kg/m^3, making it approximately 14 times lighter than air (Shen, 2023). Green Hydrogen has the potential to be a cornerstone of low-carbon and self-sufficient economic models (Maka, 2025). It facilitates the use of abundant domestic renewable resources across different regions, seasons, and industries, serving multiple applications as either fuel or industrial feedstock. It can effectively replace fossil-derived inputs in petroleum refining, fertiliser production, and steel manufacturing. A well-developed Green Hydrogen value chain can

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generate new employment opportunities, decrease reliance on fossil fuel imports, improve trade balance, eradicate energy poverty, promote energy inclusion, reduce greenhouse gas emissions, and strengthen energy governance (Harichandanet al., 2023).

India and Green Hydrogen

India introduced the National Green Hydrogen Mission,which seeks to create a detailed strategy for developing a Green Hydrogen ecosystem while driving a coordinated effort to address both the opportunities and challenges of this emerging industry. The Mission aims to position India as a global leader in the production, utilisation, and export of Green Hydrogen and its derivatives. This initiative supports India's vision of Aatmanirbhar Bharat (self-reliance) through clean energy while catalysing the global clean energy transition, and will also help achieve the Panchamrit targets of India. Five Panchamrit targets includes (i) India will reach its non-fossil energy capacity to 500 GW by 2030, (ii) India will meet 50 per cent of its energy requirements from renewable energy by 2030, (iii) India will reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030, (iv) by 2030, India will reduce the carbon intensity of its economy by less than 45 per cent, and (v) by the year 2070, India will achieve the target of Net Zero.

By driving significant decarbonisation, reducing fossil fuel dependence, and fostering technological and market leadership, the Mission seeks to establish India at the forefront of the Green Hydrogen industry. To accomplish this, the Mission targets an annual Green Hydrogen production capacity of at least 5 Million Metric Tonnes (MMT) by 2030, with the potential to scale up to 10 MMT as export markets expand. It will enable the shift from fossil fuel-based feedstocks to renewable alternatives derived from Green Hydrogen. This includes replacing fossil-derived Hydrogen in ammonia production and petroleum refining, integrating Green Hydrogen into City Gas Distribution systems, and utilising it in steel manufacturing. Additionally, Green Hydrogen-derived synthetic fuels, such as Green Ammonia and Green Methanol, will be deployed across transportation sectors, including mobility, shipping, and aviation, to replace conventional fossil fuels. The Mission also strives to establish India as a technological and manufacturing leader in electrolysers and other critical Green Hydrogen technologies.

Green Hydrogen and International Cooperation

- To support this transition, a diverse range of financial and non-financial strategies need to be devised. To drive the production of cost-effective Green Hydrogen, essential equipment and technologies will require national and international cooperation. The following section will analyse phase 1 of the Green Hydrogen Mission in light of international cooperation.
- India and the European Union (EU) have finalised a detailed roadmap for advancing the Green Hydrogen sector, focusing on infrastructure development, technological collaboration, and strengthening supply chains. This partnership was formalised at the 10th India-EU Energy Panel in Brussels, where both regions established a comprehensive framework to drive progress in Green Hydrogen, encompassing regulatory alignment, innovation, and sectoral integration.

- Japan International Cooperation Agency (JICA) has entered into a strategic collaboration between Mitsubishi Power and Hygenco Green Energies through a Memorandum of Understanding (MoU). This partnership, facilitated by JICA's India Office, aims to explore the deployment of green hydrogen/ ammonia-fired gas turbine combined cycle (GTCC) power plants in India and globally. Under this initiative, Hygenco will provide green fuel for Mitsubishi Power's GTCC technology to prospective customers. The company aims to establish large-scale, commercially viable green hydrogen and green ammonia production facilities through a build-own-operate approach or a gas-as-a-service model, ensuring sustainable and scalable deployment. Meanwhile, Mitsubishi Power is advancing hydrogen and ammonia combustion technologies to decarbonise existing GTCC plants by transitioning their fuel source from natural gas to hydrogen or ammonia.
- India and Australia reaffirmed their mutual commitment to advancing Green Hydrogen in May 2023 by formally exchanging the agreed Terms of Reference for the India-Australia Green Hydrogen Taskforce. This initiative underscores their collaborative efforts in scaling up Green Hydrogen technologies and infrastructure to support sustainable energy goals. The Taskforce will consist of experts from both Australia and India, specialising in Green Hydrogen. It will provide insights into the India-Australia Ministerial Energy Dialogue, focusing on trade, commercial prospects, and research collaborations related to the production and deployment of Green Hydrogen between the two nations. The focus areas of the taskforce are Hydrogen Electrolysers, Production of green Hydrogen and fuel cell manufacture, supporting infrastructure, and Standards and regulations.
- The Solar Energy Corporation of India Ltd (SECI), under the Ministry of New and Renewable Energy, has signed a Memorandum of Understanding (MoU) with H2Global Stiftung to establish a collaborative framework for advancing Green Hydrogen initiatives. This partnership aims to facilitate knowledge exchange on market-based mechanisms and strengthen cooperation between India and hydrogen-importing nations, contributing to the global Green Hydrogen economy.Through this collaboration, India gains the opportunity to explore joint tender design concepts, and also provides valuable insights into global hydrogen market dynamics, encompassing trade logistics and stakeholder engagement, which will play a crucial role in shaping India's Green Hydrogen strategies.
- 7th India-Germany Inter-Governmental Consultation 2024 (IGC) Under the motto "Growing Together with Innovation, Mobility and Sustainability", emphasised on climate action, green and sustainable development, technology and innovation, labour and talent, migration and mobility, along with economic, defence and strategic cooperation. During the 6th IGC, both governments announced the Green and Sustainable Development Partnership (GSDP), which serves as an umbrella for bilateral formats and joint initiatives in this field. India and Germany have jointly launched the India-Germany Innovation and Technology Partnership Roadmap and introduced the Indo-German Green Hydrogen Roadmap, designed to accelerate the market expansion of Green Hydrogen. This collaboration reflects their shared commitment to

advancing clean energy solutions while fostering peace, security, and stability through sustainable innovation.

- The Strategic Clean Energy Partnership (SCEP) between India and US drives innovation and reinforces the clean energy supply chains between the two nations. It resulted in the introduction of India's new National Centre for Hydrogen Safety. Both countries have expanded their collaboration on green hydrogen research, including cost reduction and the establishment of hydrogen hubs.
- India and France have established the "Indo-French Roadmap on the Development of Green Hydrogen," aiming to align their hydrogen ecosystems for a sustainable value chain. This collaboration focuses on carbon-content certification, scientific research, and industrial partnerships to advance green hydrogen innovation. It aims at establishing a regulatory framework for developing a decarbonised hydrogen value chain, covering production, storage, transportation, and consumption.
- The Bureau of Indian Standards (BIS), and British Standard Institution (BSI) and the UK Government's Foreign, Commonwealth & Development Office (FCDO) hosted a two-day India-UK Standards Partnership Workshop on Green Hydrogen. It was part of the UK Government's Standards Partnership programme, which aims to increase the use of international standards in India to accelerate growth, attract investment and enhance trade. This initiative facilitated the identification of standardisation gaps, exploration of new opportunities, and engagement with industry experts. Leveraging insights from global best practices will strengthen India's certification, testing, and regulatory frameworks, fostering a more sustainable and competitive Green Hydrogen economy.
- Hosted by the International Solar Alliance (ISA) and backed by the Asian Development Bank (ADB), the Green Hydrogen Innovation Centre (GHIC) has been formed to provide information regarding the latest advancements, findings and resources related to Green Hydrogen. The Centre aims to decentralise knowledge, empower decision-making, facilitate global collaboration, promote training and awareness, track global developments and inspire innovation.

Way Forward

As India is near the end of Phase 1 of the National Hydrogen Mission, a self-reliant ecosystem is in the process. R&D is going to play a crucial role in shaping the green hydrogen ecosystem in India. It is assumed that sectors like refineries, fertilisers and city gas will serve as a first step to ensure sustained demand for green hydrogen. This will also boost the green financing from the public and Private Sectors, which can further pave the way to cost reduction of green hydrogen as fuel and make it a more competitive fuel. Global collaborations are essential for accelerating research and development across the hydrogen value chain. Promote technology transfer and collaborative research initiatives to accelerate India's progress in hydrogen innovation. Prioritising knowledge exchange and joint research efforts with international experts can drive innovation in key areas, enhancing hydrogen production, storage, and transportation efficiency. Establishing a strong network of global partnerships will also support the development of standardised certification frameworks and industrial applications, ensuring Green

Hydrogen's long-term viability (Ogino, 2025).India has significant potential to become a key player in the global hydrogen energy landscape and establish itself as a hub for the production of green hydrogen. Realising this ambition will require strong policy frameworks, industry cooperation, and efforts to drive market adoption of green hydrogen.

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PERSPECTIVE

Forging a Tech Partnership: Strategic Convergence of S&T Diplomacy in India-Taiwan Relations

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Introduction

India and Taiwan have been developing a robust technological partnership in recent years despite the absence of formal diplomatic relations. The collaboration between the two countries is expanding through science, technology and diplomacy (S&TD) convergence, particularly in ensuring a strong R&D ecosystem, semiconductors, artificial intelligence, cyber-security and "several high-technology areas" (Balakrishnan, 2021; Reghunadhan, 2022; 2025). Historically, India and Taiwan have been involved in scientific exchanges and personnel training, though not the other way around. During the 1940s, in the backdrop of a visit by Chiang Kai-shek to India, the Second World War, student exchanges with scholarships in engineering and technology were pursued, though it didn't fructify due to various geopolitical reasons (Reghunadhan, 2025). Since 1995, India and Taiwan have established representative offices, known as the India-Taipei Association (ITA) in Taipei and the Taipei Economic and Cultural Centre (TECC) in New Delhi. This led to the establishment of a cooperative framework, which gained momentum with the New Southbound Policy (NSP), designating India as a key priority country (Hashmi &Mankikar, 2025).

The advancements in Taiwan's technology sector enable the navigation of complex international dynamics to enhance its global technological and security partnership. Both nations have recognised their complementary strengths in the

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technology sector, with Taiwan offering cutting-edge technological expertise and India providing a large market and skilled workforce. The Department of Science & Technology (DST) of India and the Ministry of Science & Technology (MOST) of Taiwan have formalised their collaboration through joint programs that provide financial support to scientists and researchers. This includes initiatives that facilitate research, scientific experimentation, and institutionalisation of the knowledge (digital) economy (Oleksiyenko et al., 2021; Ho, 2021; Gurukkal, 2019; Reghunadhan, 2022; 2025).

Interestingly, in the context of the impending institutionalisation of the Trump Administration's trade-cum-tariff war with various countries across the globe and the increasingly aggressive posturing by the Xi Administration (Bown, 2022), the potential for elevating India-Taiwan relations with S&TD as a tool is unprecedented. The integration and institutionalisation of S&TD into India-Taiwan relations not only reinforce the corresponding national interest and security aspirations but also position them strategically to leverage scientific capabilities and technological strengths and, in turn, address existing and future regional challenges as well as exigencies and enhance mutual economic benefits (Reghunadhan, 2025).

The Strategic Convergence: S&T Diplomacy between India and Taiwan

The burgeoning strategic convergence between India and Taiwan is anchored in critical technology sectors, showcasing a deepening partnership aimed at mutual growth and security. This collaboration is prominently marked by significant strides in semiconductor manufacturing, exemplified by joint ventures (JVs), which could propel India's Make in India and Digital India initiatives (Reghunadhan, 2022). Beyond chip fabrication, both nations could actively foster cooperation in domains like Artificial Intelligence (AI) and digital technologies, recognising the synergistic potential in areas like the Internet of Things (IoT), Big Data, and cyber-security. Furthermore, with the shared threat landscape, India and Taiwan can initiate structured dialogues to enhance cyber-security cooperation, thereby potentially highlighting a multifaceted approach to evolving strategic alliances between the two countries.

In this context, the need for institutionalising strategic partnership between India and Taiwan raises the pathway for technological self-reliance and diversification of global supply chains. The economic interdependence of both India and Taiwan with the Chinese economy has created an urgent need for mitigating vulnerabilities, especially in trade and technology. India-Taiwan relations primarily entail improving foreign investment (FDI), technology transfer, and exchange/skilling of personnel. From an Indian standpoint, developing and institutionalising an ecosystem suitable for nurturing domestic human capital (talent) and creating a conducive environment for the indigenisation of technology (including emergent and futuristic tech) is very critical. A collaborative effort with Taiwan will lay the groundwork for developing sustainable technological growth while contributing towards development and strategic autonomy.

As a technological powerhouse, Taiwan's strengths extend far beyond just the development of chips and semiconductors. It is a global power in developing AI, 5Gtechnology, and other critical high-end technologies. An aspiring tech power, the Indian Government has prioritised upgrading and revamping technology and its integration into Indian critical national infrastructure (CNI) (Reghunadhan, 2022; 2025). Thus, a comprehensive collaboration between the two countries is a priority, wherein an integrative ecosystem can be created. Moreover, Taiwan's decades of experience in navigating complex geopolitical pressures, particularly those stemming from its unique relationship with the Communist Party of China (CPC), adds more depth to countering the Chinese posturing, aggression and threat in the Indo-Pacific region.

Collaboration with India provides Taiwan access to a massive (largely untapped) market, offering crucial avenues for Taiwan to expand its economic footprint, reducing its reliance and (inter) dependence on the Chinese market. According to the International Monetary Fund (IMF), theIndian market was the fastest growing among the top ten largest national economies[1] in 2024, at 6.5 per cent (Lu, 2025).Despite many advantages, like being the fifth largest economy (with an estimated GDP of 3.56 trillion USD) and having the largest working-age population, which could enable India to complement Taiwan and overcome its major weakness, India has been punching below its potential (Worldometer, 2025). In 2023-24, India is ranked 12th (31.32 per cent growth rate) in terms of exports from Taiwan, 24th (0.69 per cent growth rate) in terms of imports from Taiwan and 16th (1.22 per cent growth rate) in terms of total trade with Taiwan. India has been a major factor in Taiwan's NSP, being part of the NS18 countries.[2] However, India is not even in the top five amongst the NS18 countries, behind Singapore (6th in trade ranking with Taiwan), Malaysia (7th), Vietnam (9th), Australia (11th), and Thailand (12th) (ITA, 2025).

India-Taiwan collaboration can lead to extensive and expansive opportunities (minilaterals) and pluralistic regional cooperation beyond the dominance of China and thus create avenues for partnership, resilient alliance building (to these shocks), and a more balanced and stable security architecture in the region. The key areas of strategic convergence include semiconductor manufacturing, artificial intelligence and digital technologies, and cyber-security cooperation. The semiconductor industry represents the cornerstone of the India-Taiwan tech partnership, which includes the establishment of a wafer fab and an AI-enabled chip fabrication facility (Lin, 2025; Saxena, 2024).

Manharsinh L. Yadav, the Indian Representative to Taiwan, has expressed hope that 'the two countries can leverage their strengths through bilateral partnership to drive growth in AI and chip-making industries' (Lin, 2025). Both countries have increasingly focused on collaboration in AI, IoT, Big Data and cyber-security as priority areas for joint R&D projects. The collaboration extends to areas like "outsourced semiconductor assembly and test (OSAT)", "assembly, test and packing (ATP) plants", embedded systems, sensors, and other digital technologies that form the backbone of modern (digital public) technological infrastructure (Bhandari, 2024; Rajan & Lamba, 2024). Cyber-technological threats and vulnerabilities in security have become a priority. India and Taiwan have begun deliberating joint efforts to secure cyberspace, the digital economy and associated critical information infrastructure (CII). The first meeting occurred in New Delhi in December 2023 as part of the US-led Global Cooperation and Training Framework (GCTF), including Japan (Saxena, 2024).

In the Indian context, (the human capital) accumulation of skilled young population, especially engineers and scientists, synergises Taiwan's high-end technical-cum-technological capacities and capabilities. A MoU was signed in February 2025 to facilitate and integrate skilled personnel from India into the manufacturing, construction, and agriculture sectors of Taiwan. The agreement is critical in addressing the labour shortage in Taiwan while providing opportunities for India's workforce (Saxena, 2024; Reghunadhan, 2025). The prospects for establishing science parks, industrial zones (coupled with Special Economic Zones or SEZs)and townships for Taiwanese investment in India can attract more foreign companies and investments from the US, Japan, Australia, and the European Union (EU) (Hashmi & Mankikar, 2025). This would strengthen the technological partnership and enhance economic ties with regional and global powers. The success of India-Taiwan technological cooperation hinges on navigating complex geopolitical influences while identifying mutually beneficial opportunities. (Reghunadhan, 2025).The combination of advanced manufacturing (and tech) capabilities of Taiwan, combined with India's humungous (potentially untapped) market and human (capital accumulation), can build a more robust and resilient technological partnership, which is relatively and marginally less susceptible to disruptions from geopolitical calamities and/or geo-economic shocks. This cooperation is more critical in the Indo-Pacific region, which is exalted as the next theatre or platform of global geo-economic competition and geopolitical rivalry.

Navigating the Nuances for Strategic Convergence

Meanwhile, though strategic convergence between India and Taiwan holds immense promise, it's crucial to demarcate the inherent convergence zone. The geopolitical sensitivities necessitate cautious yet prudent diplomacy and strategic (channels of) communication. It should be initiated through and by building trust and fostering deeper (institutionalised) understanding (track diplomacy) between the two countries. Further, this also means provoking backlash from neighbouring countries, which considers Taiwan as an undisputable part of its territorial integrity and a fundamental part of their country, accepted by India since the Panchsheel Accords in the 1950s. However, alliance between India and Taiwan can spur economic growth and technological advancement, as well as contribute towards the skilling and employability of the Indian working population and provide dividends for sustainable and technological development in India.The role of the State governments and the private sector in India is very critical. Joseph Wu, the Minister of Foreign Affairs of Taiwan, has identified India's complex administrative structure as a significant obstacle for Taiwanese investments. The Government of India, under Prime Minister Narendra Modi, has recognised this issue and established the India Semiconductor Mission to expedite clearances, but regulatory complexities remain a significant deterrent (Reghunadhan, 2023).

The cumbersome laws and regulations in India create bureaucratic barriers that discourage semiconductor companies from establishing operations. This is often exacerbated by the lack of Chinese language experts in the government or private contingent that are part of the negotiation for trade and commerce. Recently, Taiwan-based tech giant Foxconn has increased investments in southern states of India, namely Karnataka, Andhra Pradesh, Telangana and Tamil Nadu, all of which have been reshaping the regulatory checkpoints and have (re)prioritised investments and skilling opportunities for the workforce.

A significant challenge for trade between India and Taiwan is the high tariffs on electronics component imports, which is nearly half of the share of the exports by Taiwan to India (comprising 48.38 per cent) and saw a growth rate of 50.31 per cent for the period 2023-24.[3] According to the Deputy Minister of the National Development Council (Taiwan),a Free Trade Agreement (FTA) would be crucial in attracting Taiwanese suppliers to set up operations in India. Minister Wu states that an FTA should be negotiated and signed between India and Taiwan. This will deliver several significant benefits to the tech industry in both countries (Barik, 2024). Interestingly,(foreign) private investment and its reforms have been the priority of the Modi Government since 2014, which brought out the 10-point vision. The possibilities for enhancing the role of Taiwan-based companies will hinge on creating "a prudent regulatory landscape" that supports the revitalisation of private investments. According to a Morgan Stanley study, the implementation of private projects in India has been improving, which is "linked to [the] revival of private investment and capacity" building (Reghunadhan, 2023). Additionally, India's robust intellectual property protection mechanisms are vital to safeguard innovation and foster trust in these companies.

Finally, academic exchanges and joint research initiatives are vital in fostering innovation, targeted skilling and talent development. Thus, creating a strong startup ecosystem through incubators, venture capital, and supportive regulatory frameworks will drive innovation and create a vibrant technology sector. It should be coupled with increasing the number of Chinese language centres atleast four-fold, in collaboration with TECC across various universities and institutes in India. This should be prioritised towards engineering and science institutes in India, which can do wonders for scaling up Indian students and professionals in Taiwan companies. This multifaceted approach, encompassing diplomacy, technology, and economic collaboration, will ensure the India-Taiwan partnership flourishes, contributing to a stable and prosperous Indo-Pacific region.

Conclusion

The strategic convergence of India and Taiwan in the realm of S&T diplomacy represents a pivotal development in the Indo-Pacific, far exceeding the sum of its bilateral parts. This partnership, forged in the crucible of evolving geopolitical realities, is about exchanging technological expertise and building a robust and resilient ecosystem that strengthens both nations' strategic autonomy and contributes to a more balanced and secure regional order. Combining India's vast market and burgeoning talent pool with Taiwan's technological prowess, particularly in semiconductors, AI, and 5G/6G, lays the groundwork for a future where technological self-reliance and diversified supply chains are paramount. Together, India and Taiwan could navigate the complex geopolitical pressures, provide each other with crucial strategic autonomy and access to market and technology, and reshape the strategic landscape of the Indo-Pacific region.

As the Indo-Pacific grapples with evolving geopolitical realities, particularly with China's rise, India and Taiwan are moving towards forging deeper technological ties to secure their respective strategic autonomies. India, aspiring to be a technological powerhouse and a leading player in the Indo-Pacific, will perceive this collaboration as a crucial leverage for enhancing its capabilities in critical sectors like semiconductors, AI, and cybersecurity. In turn, for Taiwan, a global leader in high-end tech and manufacturing, this partnership is a means to diversify its strategic dependencies and expand its economic footprint in a rapidly growing global value chain. As India and Taiwan seek cooperation and collaboration to forge a stronger strategic partnership in the digital age, it is expected to thrive and serve as a model for other nations seeking to build resilient and prosperous futures in the dynamic Indo-Pacific region.

Endnotes

1. The top ten national economies are: the US, China, Germany, Japan, India, the UK, France, Italy, Brazil and Canada (Worldometer, 2025).
2. The NS18 countries are Thailand, Indonesia, Philippines, Malaysia, Singapore, Brunei Darussalam, Vietnam, Myanmar, Cambodia, Laos, India, Pakistan, Bangladesh, Nepal, Sri Lanka, Bhutan, Australia and New Zealand (ITA, 2025).
3. This is categorised under Chapter 85, which contains of "electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles" (ITA, 2025).

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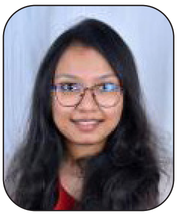
EVENT REPORT

Global Ministerial Dialogue on Science Diplomacy: A Review

Sneha Sinha*



Sneha Sinha

Introduction

Science has increasingly gotten entangled in geopolitics with growing tensions over access to technology, technological and data sovereignty, vaccine nationalism, and critical minerals, etc. Additionally, fragmented multilateralism highlights the growing need for science diplomacy not just as a tool for peace but also for collective and effective problem solving based on science. With a mandate in science, education and culture, UNESCO has focused on promoting science, science capacity, open science and setting ethical frameworks in emerging technologies like AI, facilitating international science cooperation, and improving international relations through it, as well as science for sustainable development, informing policy with scientific data and advice. Science Diplomacy is increasingly recognised as a strategic tool to tackle global challenges.

Over the past fifteen years, the theoretical understanding of science diplomacy has evolved and has been recognised as a significant pillar of the foreign policies of many countries. Science diplomacy has shown potential to advance peace, build trust and foster cooperation between nations to address global challenges. Considering challenges that the world faces today, scientific advancements, and competition over shared resources, it can reinforce power asymmetries and widen global divides and inequalities. COVID-19 has slowed the progress towards the SDGs and recognising the international decade of sciences for sustainable development, there is a need to accelerate the achievement of SDGs in a multifaceted global context. The Sustainable Development Goals Report 2024 also indicates that "current progress falls short of what is required to meet the SDGs. Only 17 per cent of the 169 SDG targets are on track, 48 per cent show insufficient progress and 18 per cent have regressed since

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2015." It underlined the hindrances caused by "lingering impacts of the COVID-19 pandemic, escalating conflicts, geopolitical tensions and growing climate chaos."

In this context, UNESCO organised the timely and important Global Ministerial Dialogue on Science Diplomacy. It was held at the UNESCO Headquarters in Paris during 25-26 March 2025. The Ministerial Dialogue aimed to create a global framework for science diplomacy based on today's needs through international dialogue to promote openness, foster equitable collaboration and peaceful management of shared and common goods in the current global context.

The Ministerial Dialogue was convened with aims which included (a) fostering high-level commitment to science diplomacy as an instrument for promoting dialogue and peace; (b) exploring innovative science diplomacy initiatives through meaningful exchanges among ministers, scientists, diplomats, and experts that contribute to peace-building and the protection of human rights (c) an agreement on a common framework for advancing shared global goals through science diplomacy; and (d) highlighting ongoing initiatives and emerging opportunities for collaboration across borders, disciplines, and sectors. These objectives anchored the discussions across the two-day forum and were reflected substantively in the Co-Chairs' Statement. In the context of the International Decade of Sciences for Sustainable Development, the Statement laid the groundwork for working towards a more inclusive, collaborative, and capacity-building-oriented approach to science diplomacy.

The Ministerial Dialogue brought together approximately 1000 participants, including 60 high-level representatives. The event featured diverse representatives, including ministers, government ministries, diplomats, academia, science diplomacy networks, and international organisations from countries across the world, including those from the Global South, especially Latin America, Africa, and parts of Asia. While the voices from the LDCs (except DR Congo) and Small Island Developing States remained quite limited.

Apart from these, ministerial dialogue saw representation from the UN and international organisations, together with representatives from France, the European Union, Canada, the USA, Japan, etc. Representatives from International Science Council, *Centre National de la Recherche Scientifique* (CNRS) (French National Centre for Scientific Research), International Centre for Theoretical Physics (ICTP), Chinese Academy of Sciences were also present, along with science diplomacy and networks like International Network for Government Science Advice (INGSA), American Association for the Advancement of Science (AAAS), Geneva Science and Diplomacy Anticipator (GESDA) and civil society and advocacy organisations like Women in Tech Global and Tech Diplomacy Forum. However, the private sector, youth and early career researchers, as well as indigenous and local community networks, were not well represented. The Global Ministerial Dialogue certainly brought together a diverse and high-level panel, reflecting stakeholders necessary for contemporary priorities in science diplomacy.

The two-day event was structured as a hybrid gathering. The first day of the Global Ministerial Dialogue featured *the*

Multistakeholder High-Level Conference on Science Diplomacy. The *Global Ministerial Segment* was held on the second day. The *Multistakeholder High-Level Conference on Science Diplomacy* began by emphasising the need for renewed efforts in science, diplomacy and identification of priorities for action for leveraging science diplomacy for peace.

The opening remarks presented Colombia's commitment to protect the ecosystem, foster international cooperation, and advance sustainable, science-based solutions through research, clean technology and global partnerships. Thus, underlining science diplomacy as a vital tool for tackling global challenges like climate change. Several EU initiatives were discussed, which indicated the power of science diplomacy. Recognizing challenges like the transformation of science from a soft power to hard power, together with security and geopolitics, the need for unlocking the true power of science as a tool for diplomacy and a source of renewed spirit was underlined. The Keynote address emphasised that there is a need to build trust in science, prove its positive impact, ensure fairness and use it as a bridge for global cooperation and shared understanding.

The Conference consisted of plenary and roundtable sessions which focused on a wide array of themes including science diplomacy for tackling twenty-first-century challenges, open science, development and responsible use of new and emerging technologies, and management of shared resources and common goods. Some of the initiatives discussed included the Human Cell Atlas Collaboration and the Guaraní Aquifer System Project. The Human Cell Atlas Collaboration aims to map all human cells to revolutionise disease diagnosis and treatment. The Guaraní Aquifer System Project is viewed as an example of science diplomacy to facilitate joint management and equitable use of shared water resources across Argentina, Brazil, Paraguay and Uruguay.

The *Global Ministerial Segment* held on day two consisted of several ministerial roundtables on leveraging science diplomacy for shared natural and scientific resources, tackling crises, disruptive technologies, and secure and open science. They focused on the nature of science diplomacy and policy tools leveraged by countries to tackle transboundary resources and global commons, integrations of scientists, diplomatic strategies to protect scientific collaboration, the role of UNESCO in bridging divide and support science diplomacy, lessons from emerging tech governance, frameworks for technology transfer and open science, etc.

The Co-Chairs' Statement enumerated and brought together issues underlined by the Ministers during the high-level dialogue. The statement underlined the pressing need to enhance the dialogue between science and diplomacy to tackle the complex challenges faced today effectively. They emphasised that with growing geopolitical tensions, S&T advancements and pressures on shared natural resources, science diplomacy can play a significant role in promoting dialogue, fostering trust in science and strengthening international cooperation.

In line with UNESCO's focus on Open Science, the statement emphasises the need for upholding open science that would ensure inclusive accessibility of scientific knowledge. It also stressed on inclusive and diverse stakeholder participation in science diplomacy to effectively address global challenges. Additionally, the need to integrate scientific knowledge and evidence into diplomatic decision-making was emphasised to enable informed policies to address the challenges that we face today. The statement also called for strengthening scientific institutions and institutional and human capacities in science diplomacy for enhancing its effectiveness through training, knowledge-sharing and mutual learning, which would also require the collaborative effort of several stakeholders. The high-level dialogue also reaffirmed their support in leveraging diplomacy for peace, cooperation and sustainable progress and collective commitment to share a future where science serves as a bridge for dialogue and collective global action towards the global common good.

The Global Ministerial Dialogue on Science Diplomacy reaffirmed science diplomacy as an essential tool for fostering peace, trust, and international cooperation in an increasingly fractured world. Amid escalating geopolitical tensions, technological inequalities, and environmental crises, the dialogue underscored the urgent need to integrate scientific knowledge into global policy and diplomacy. It emphasized inclusive participation, open science, equitable access to technology, and UNESCO's central role in enabling collaborative, ethical, and science-informed governance, laying a collective foundation for a more sustainable, just, and united future. However, greater representation across the world and engagement of diverse stakeholders would be critical. Additionally, tackling tension between open science and national security, and clear implementation mechanisms are necessary, calling for more actionable frameworks and inclusive engagement. The Co-Chair's Statement is a step ahead in this direction.

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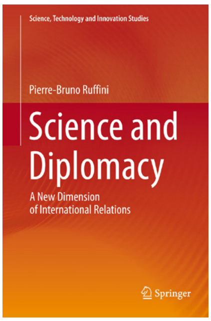
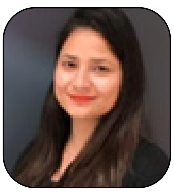
BOOK REVIEW

Science and Diplomacy: A New Dimension of International Relations



Author: **Pierre-Bruno Ruffini**
Publisher: **Springer**
Year: **2017**
ISBN: **978-3-319-55103-6**

Famida Khan* and Brajesh Pandey**



Famida Khan

Brajesh Pandey

In an age when global challenges demand collaborative solutions, the intersection of science and international relations has become more relevant. *Science and Diplomacy: A New Dimension of International Relations* by Pierre-Bruno Ruffini explores this critical interface. The book does not simply advocate for more scientific involvement in diplomacy; it explains why this involvement is both necessary and unavoidable in today's interconnected world.

Professor Ruffini, a professor of international affairs, provides a detailed but understandable exploration of how science is used as a tool in diplomatic efforts and vice versa. His book isn't limited to scholars or diplomats; it is written in a way that even someone without prior knowledge in science policy or foreign affairs can easily grasp its ideas. His efforts are particularly effective because of the blend of historical context, conceptual clarity, and concrete case studies from around the world.

The book begins with an introduction that sets the stage by referring to major global events where science and diplomacy intersected meaningfully, such as the

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collaborative work on nuclear fusion under the ITER project and President Obama's 2009 Cairo speech that laid the foundation for new scientific collaborations between the U.S. and Muslim-majority nations. These examples are more than merely symbolic; these are examples of how science can help bridge political divides and build new relationships.

Professor Ruffini then moves on to define what exactly science diplomacy is. Drawing on the framework introduced by the Royal Society and the American Association for the Advancement of Science, he describes it through three overlapping categories: science in diplomacy (where scientific knowledge supports foreign policy decisions), diplomacy for science (where diplomatic efforts promote international scientific collaboration), and science for diplomacy (where scientific partnerships help improve international relations). These definitions are useful because they give readers a structured way to understand the many roles science can play in foreign affairs.

One of the most compelling aspects of this book is its historical narrative. Professor Ruffini traces the history of diplomacy Interconnection with science to the times of colonialism and exploration, demonstrating how political or military strategies tended to accompany scientific expeditions. He also explored the role of science in the Cold War, especially in relation to the struggle for dominance in space and in the arms control discussions. These sections are not just informative; rather, they help the reader to see that science diplomacy is not a new phenomenon but an evolving one.

The book also covers the different countries' approaches to the contemporary practice of science diplomacy. Professor Ruffini analyses national strategies across Europe, North America, and Asia, showing that while some nations like the U.S. and the UK have integrated science into their diplomatic services, others are still working towards such capabilities. Other emerging powers are also discussed in depth, such as India, China, and Russia, who use scientific cooperation to showcase soft power.

The book includes Professor Ruffini's ideas on how science has advanced the multilateral approaches to global issues. He cites how International organisations like the United Nations and UNESCO use scientific data and expertise to shape global policies on topics like climate change, biodiversity, and health.

He highlights the work of the Intergovernmental Panel on Climate Change (IPCC) to show how scientific reports can influence international treaties and negotiations. This section is especially relevant in light of the ongoing climate crisis and debates over global governance.

Professor Ruffini is open about the challenges concerning the boundaries of science and diplomacy. He flags the problem of national interests and the openness of science. He thoughtfully pointed out that at times, political considerations may influence the course of scientific collaboration.

He reflects on the balance of power between the goals of diplomacy and the independence of scientific work. These important points support the narrative, offering a rounded and thoughtful exploration of science diplomacy. It gives rationale without being overly critical, while considering both opportunities and pitfalls.

Professor Ruffini places special attention on the individuals, the scientists and diplomats operating in this domain. He elaborates on their particular role and how their skills can complement each other. He noted that Scientists contribute credibility, objectivity, and technical knowledge, while on the other hand, diplomats contribute negotiating ability, cultural awareness, and strategic thought. He argues, when these two worlds work well together, they can achieve remarkable outcomes.

Though the book emphasises state-level actors, it also acknowledges the growing role of non-governmental organisations, like universities, and international research groups. These organisations often work more transnationally than governments do, and can serve as important bridges in fostering global cooperation. The book writing is clear, concise, and free of unnecessary complexity.

Even in the context of a complex discussion, Professor Ruffini uses straightforward language and examples. Professor Ruffini doesn't burden the readers with jargon or hard-to-grasp concepts. The structure of the book is simple, moving from conceptual groundwork to historical background, followed by national case studies, then multilateral engagements. This structure makes the content easy to follow. Each chapter ends with references, making it a useful resource for further reading.

While the book offers a well-rounded and thought-provoking exploration of science diplomacy, it does not include a timely and growing angle, which is the role of digital technologies in the evolving landscape of both science and diplomacy. For instance, topics around artificial intelligence, data privacy, and cyber security have been increasingly visible in terms of their impact on international scientific collaboration and policy development, and do not feature in the book. Since these digital technologies will continue to shape the ways we connect internationally, it would be useful for future editions to outline how the rise of digital transformation overlaps with the field of science diplomacy.

Science and Diplomacy: A New Dimension of International Relations is an interesting and timely reading book that makes arguments regarding the need for science in contemporary global politics. Global challenges such as environmental crises, public health emergencies, and rapid technological advances demand collaborative action. Not even a single nation can deal with these issues alone, and that's where science diplomacy plays a crucial role; it encourages cooperation through shared knowledge and mutual understanding. While countries may differ in how they practice science diplomacy, the goal remains the same: to foster cooperation, trust, and peaceful engagement. Supporting research partnerships and promoting scientific excellence are pivotal in building stronger global relationships. The book leaves readers with a clear message that the bond between science and diplomacy is becoming more essential. Hence, scientists and diplomats' combined efforts are crucial as scientists contribute evidence and innovation, while diplomats bring dialogue and strategic thinking to the table.

Guidelines for Authors

1. Submissions should contain institutional affiliation and contact details of author(s), including email address, contact number, etc. Manuscripts should be prepared in MS-Word version, using double spacing. The text of manuscripts, particularly full length papers and essays may range between 4,000- 4,500 words. Whereas, book reviews/event report shall range between 1,000-15,00 words.

2. In-text referencing should be embedded in the anthropological style, for example '(Hirschman, 1961)' or '(Lakshman 1989:125)' (Note: Page numbers in the text are necessary only if the cited portion is a direct quote). Footnotes are required, as per the discussions in the paper/paper.

3. Use's' in '-ise' '-isation' words; e.g., 'civilise', 'organisation'. Use British spellings rather than American spellings. Thus, 'labour' not 'labor'. Use figures (rather than word) for quantities and exact measurements including per centages (2 per cent, 3 km, 36 years old, etc.). In general descriptions, numbers below 10 should be spelt out in words. Use fuller forms for numbers and dates— for example 1980-88, pp. 200-202 and pp. 178-84. Specific dates should be cited in the form June 2, 2004. Decades and centuries may be spelt out, for example 'the eighties', 'the twentieth century', etc.

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About FISD

As part of its ongoing research studies on Science &Technology and Innovation (STI), RIS together with the National Institute of Advanced Studies (NIAS), Bengaluru is implementing a major project on Science Diplomacy, supported by the Department of Science and Technology. The programme was launched on 7 May 2018 at New Delhi. The Forum for Indian Science Diplomacy (FISD), under the RIS–NIAS Science Diplomacy Programme, envisages harnessing science diplomacy in areas of critical importance for national development and S&T cooperation.

The key objective of the FISD is to realise the potential of Science Diplomacy by various means, including Capacity building in science diplomacy, developing networks and Science diplomacy for strategic thinking. It aims to leverage the strengths and expertise of Indian Diaspora working in the field of S&T to help the nation meet its agenda in some select S&T sectors.

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