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DYNAMICS OF THE EVOLUTION OF SCIENCE DIPLOMACY RESEARCH (1999–2024)

EVOLUCIÓN DE LA INVESTIGACIÓN SOBRE DIPLOMACIA CIENTÍFICA (1999-224)

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ABSTRACT

Objective: This article examines the evolution, institutionalization, and diversification of science diplomacy research from 1999 to 2024 through co-word analysis. **Methodology:** A systematic search was conducted in two leading academic databases, Web of Science (WOS) and Scopus. The term "science diplomacy" was used for the search. This approach captures relevant works, encompassing relevant terms such as health diplomacy and nuclear diplomacy. The strategy resulted in 362 articles and review articles, the main channels of knowledge. **Results and Discussion**: The study identifies three stages: (1) 1999–2017, the foundational phase, shaped by the dynamics of the post-Cold War and globalization, in which topics such as science policy, diplomacy, and technology emerged alongside initiatives such as SESAME and the Human Genome Project; (2) 2018–2021, the institutionalization phase, driven by global crises such as climate change, COVID-19, and geopolitical tensions, with a growing role for health diplomacy and Arctic governance; (3) 2022–2024, the maturity phase, highlighting digital diplomacy, space diplomacy, and the governance of emerging technologies amid disruptions. **Conclusions:** The results underscore the interdisciplinary nature of science diplomacy, its adaptability to global crises, and its role in addressing transnational challenges and geopolitical instability. **Contribution:** This study provides insights into its dynamic evolution and future paths in an interconnected world.
KEY WORDS: diplomacy; foreign affairs; international collaboration; international relations; scientific collaboration; science diplomacy

RESUMEN

Objetivo: Este artículo examina la evolución, institucionalización y diversificación de la investigación sobre diplomacia científica de 1999 a 2024, mediante el análisis de co-palabras. **Metodología:** Se realizó una búsqueda sistemática en dos bases académicas líderes Web of Science (WOS) y Scopus, para la búsqueda se

empleo el término diplomacia científica, este enfoque capta trabajos relevantes, que abarcan términos relevantes, como: diplomacia sanitaria y diplomacia nuclear. La estrategia derivo en 362 artículos y artículos de revisión, principales canales del conocimiento. **Resultados y Discusión**: El estudio identifica tres etapas: (1)1999-2017, la fase fundacional, moldeada por la dinámica de la posguerra fría y la globalización, en la que surgieron temas como la política científica, la diplomacia y la tecnología junto con iniciativas como SESAME y el proyecto Genoma Humano; (2) 2018-2021, la fase de institucionalización, impulsada por crisis mundiales como el cambio climático, el COVID-19 y las tensiones geopolíticas, con un creciente protagonismo de la diplomacia sanitaria y la gobernanza del Ártico; (3) 2022-2024, la fase de madurez, en la que se destacan la diplomacia digital, la diplomacia espacial y las gobernanzas de las tecnologías emergentes en medio de las disrupciones. **Conclusiones:** Los resultados subrayan la interdisciplinariedad de la diplomacia científica, su adaptabilidad a las crisis mundiales y su papel a la hora de afrontar los retos transnacionales y la inestabilidad geopolítica. **Aporte:** Este estudio aporta ideas sobre su evolución dinámica y sus vías de futuro en un mundo interconectado.
PALABRAS CLAVE: diplomacia; asuntos exteriores; colaboración internacional; relaciones internacionales; colaboración científica; diplomacia científica

INTRODUCTION

Science diplomacy has emerged as a critical field at the intersection of science, technology, and international relations, offering unique frameworks to address complex challenges at both national and global scales (Flink & Kaldewey, 2018). It facilitates international cooperation, promotes dialogue, and advances shared solutions to pressing issues such as climate change, global health crises, and emerging technological disruptions (Adamson & Lalli, 2021; Asadi-Lari et al., 2021; Fedoroff, 2009; Flink, 2020; P.-B. Ruffini, 2020). Despite its growing prominence in practice and policymaking, the historical evolution, research trends, and thematic transformations of science diplomacy remain underexplored. This gap in understanding calls for a systematic, comprehensive analysis to identify the dominant themes, key drivers, and global contexts that have shaped science diplomacy as a distinct research domain over time.

The Royal Society report "New Frontiers in Science Diplomacy: Navigating the Changing Balance of Power" (Society, 2010) highlights that: "Science diplomacy is not new, but is has never been more important. Many of the defining challenges of the 21st century – from climate change and food security, to poverty reduction and nuclear disarmament – have scientific dimensions". Science diplomacy has evolved into a multifaceted and strategic tool for promoting global development, fostering international collaboration, and advancing diplomatic relations (Adamson & Lalli, 2021; Mercer et al., 2022; Rüffin & Rüland, 2022). Its growing importance is evident in its contributions to environmental sustainability, public health (e.g., global health diplomacy during COVID-19), and technological innovation, serving as a bridge between scientists, policymakers, and diplomats to navigate shared global concerns (Kontar et al., 2021; Miranda, 2021).

While existing studies have explored critical dimensions of science diplomacy —including its globalization since the 1970s (Robinson et al., 2023), the diplomacy-knowledge nexus (Adamson & Lalli, 2021), and its dual logic of collaboration and competition (P. B. Ruffini, 2020) — there remains a lack of comprehensive bibliometric analyses tracing its long-term historical and thematic evolution. Bibliometric methods offer a valuable tool for systematically analyzing scientific literature, revealing the dominant themes, influential works, and research clusters that define the field. Such an approach provides a structured perspective on how science diplomacy has responded to major global events, geopolitical shifts, and technological advancements.

The significance of examining the historical evolution of science diplomacy lies in its ability to:

1. Offer insights into the interplay between science and international relations, particularly in influencing global policymaking (Fedoroff, 2009; Flink & Schreiterer, 2010);
2. Identify patterns and trends that can inform future diplomatic strategies and international collaborations (Stone, 2019; Turekian, 2018); and
3. Highlight the growing need for interdisciplinary approaches that bridge scientific knowledge with policymaking to address global challenges effectively (Fähnrich, 2017; Stone, 2019).

To address this gap, the aim of this paper is to conduct a comprehensive bibliometric analysis of science diplomacy research spanning the past 25 years (1999–2024). Specifically, this study seeks to:

1. Examine the thematic evolution and growth of science diplomacy as a research domain;
2. Identify the key trends, drivers, and patterns shaping the field; and
3. Contextualize these findings within significant global events, offering insights into science diplomacy's dynamic responses and evolving role.

Science diplomacy can be understood as a multifaceted practice at the intersection of science, policy, and international relations, where scientific expertise and collaboration are strategically leveraged to achieve diplomatic and scientific goals. It operates on two interconnected dimensions: fostering international cooperation to address shared global challenges while simultaneously advancing national interests in an increasingly competitive global landscape P. B. Ruffini (2020).

At its core, science diplomacy promotes peace, stability, and mutual understanding by building bridges between nations through scientific exchange and collaborative initiatives. This positive dimension positions science diplomacy as a means to address pressing transboundary issues such as climate change, global health crises, and sustainable development. By creating platforms for dialogue and joint action, it contributes to peacebuilding, trust-building, and the development of shared solutions to collective problems.

However, science diplomacy is not devoid of strategic interests. P. B. Ruffini (2020) highlights a critical duality in its logic: while collaboration remains essential, states also employ science diplomacy as a competitive tool to enhance national prestige, technological leadership, and geopolitical influence. From securing leadership in space exploration to gaining dominance in emerging technologies, countries use scientific partnerships and investments to strengthen their position in global power dynamics.

Science diplomacy can therefore be defined as the strategic use of scientific collaboration, knowledge exchange, and expertise to foster international cooperation and address global challenges while simultaneously serving national interests. Rooted in a twofold logic of collaboration (promoting peace, stability, and mutual understanding) and competition (advancing national power and influence), science diplomacy bridges scientists, policymakers, and diplomats to navigate shared challenges and strategic opportunities in an interconnected world (P. B. Ruffini, 2020).

This study contributes to advancing the academic understanding of science diplomacy's trajectory and highlighting its increasing relevance in addressing contemporary global crises. It also provides valuable insights for policymakers, scientists, and diplomats on the strategic applications of science diplomacy for fostering international cooperation and mitigating geopolitical tensions.

This paper is organized as follows: Section 2 reviews existing literature, outlining key debates and thematic dimensions in science diplomacy research. Section 3 presents the bibliometric methodology, detailing the data collection, analytical approach, and visualization techniques. Section 4 discusses the findings, highlighting thematic clusters across distinct time periods. Section 5 provides a critical discussion, linking the results to broader theoretical and global contexts, and Section 6 concludes with key insights, contributions, and recommendations for future research.

Background

The concept of science diplomacy, though formalized in academic and policy discussions post-2010, has roots that can be traced back to earlier historical periods. During the Cold War, scientific collaborations—such as the Apollo-Soyuz Test Project in space exploration (Micale et al., 1978) and the Pugwash Conferences on Science and World Affairs (Kraft & Sachse, 2016)—exemplified how science served as a bridge to ease geopolitical tensions and foster dialogue between rival nations. These retrospective examples illustrate the implicit use of science as a diplomatic tool long before it was formally conceptualized.

Post-2010, however, science diplomacy emerged as a distinct and formalized framework for analyzing the strategic intersection of science and international relations. It gained prominence as a critical area of scholarship and policy, particularly with organizations like the AAAS (American Association for the Advancement of Science) and the Royal Society playing key roles in defining and popularizing its principles

(Society, 2010). This period marked a significant shift, as SD began to be recognized both as a mechanism for international cooperation and as a competitive strategy within global power dynamics.

The field of *science diplomacy* has undergone a significant transformation, evolving into a distinct area of academic research. While its formal conceptualization emerged post-2010, the historical evolution of science diplomacy can be traced to earlier periods, particularly the Cold War, when scientific collaboration served as a tool for easing geopolitical tensions. This retrospective application highlights how the intertwining of science and diplomacy predates its formal academic recognition.

Globalization of Science Diplomacy

The globalization of science diplomacy, especially since the 1970s, marks a critical phase in its historical trajectory. Robinson et al. (2023) provide a detailed historical exploration of this period, underscoring the increasing interconnectedness of scientific and diplomatic efforts across national borders. Science diplomacy has become an essential mechanism for addressing challenges that transcend national boundaries—climate change, global pandemics, and technological advancements Ingvarsdóttir and Hauksdóttir (2024); Mastrángelo et al. (2024). This phase reflects how science diplomacy fosters international cooperation while embedding itself within global governance frameworks.

The Diplomacy–Knowledge Nexus

At the heart of science diplomacy lies the intricate relationship between scientific knowledge production and diplomatic practices Hekim et al. (2014); Knight (2022); Kontar et al. (2021). Adamson and Lalli (2021) reveal how historical and contemporary studies of science emphasize this interdependence, portraying scientific progress as inseparable from diplomatic agendas. Kaltofen and Acuto (2018) further explore the "boundary problem," highlighting how the distinctions between science and diplomacy are often blurred. This perspective necessitates a nuanced understanding of their interaction, particularly as scientific knowledge increasingly informs global decision-making processes (Gricius, 2024).

Collaboration and Competition

Science diplomacy operates within a *dual logic of collaboration and competition* (P. B. Ruffini, 2020). On one hand, scientific collaboration fosters peace and mutual understanding through cooperative initiatives addressing shared challenges. On the other, science diplomacy is strategically leveraged by states as a competitive tool to achieve geopolitical advantage and technological leadership (Gamito-Marques, 2020; Rüffin & Rüland, 2022; P. B. Ruffini, 2020). Ruffini P. B. Ruffini (2020) articulates this duality, demonstrating how nation-states navigate scientific collaboration while pursuing their national interests. Importantly, Ruffini and Krasnyak (2023) contextualize science diplomacy within the Global South, illustrating how emerging nations use science diplomacy to address unique challenges and assert their roles in the global arena.

Practical Frameworks and Curricula Development

The practical application of science diplomacy has led to the development of theoretical frameworks and specialized curricula. Chubaryan et al. (2021) provide foundational insights into the theory and practice of science diplomacy, while Mauduit and Gual Soler (2020) emphasize the importance of educational programs designed to equip future diplomats and scientists with relevant skills. These developments ensure that science diplomacy practitioners are prepared to bridge scientific expertise and international policymaking effectively.

Science Diplomacy as a Tool for Foreign Policy

The strategic use of science diplomacy within foreign policy underscores its dual purpose as both a cooperative and competitive instrument. Gutenev (2021) highlights how countries employ scientific collaboration to enhance international standing, influence global governance, and advance national interests. In this regard, science diplomacy emerges as a critical tool in a state's foreign policy toolkit, integrating scientific advancements into broader diplomatic and geopolitical strategies.

Perspectives from Scholars

Scholarly perspectives on the intersection of science and politics offer valuable insights into science diplomacy’s theoretical underpinnings. Fähnrich (2017) explores the interplay between scientific research and

political decision-making, revealing how science diplomacy functions as a platform for negotiation, cooperation, and knowledge exchange. Such analyses deepen our understanding of how science and diplomacy co-evolve, shaping international relations and governance.

Nation Branding and Science Diplomacy

Nation branding has become an essential dimension of science diplomacy, as countries increasingly use scientific achievements to enhance their international image and reputation (Raev & Minkman, 2020; Schlegel et al., 2011; Velikaya, 2022). These efforts align scientific success with soft power strategies, strengthening diplomatic ties and fostering national prestige on the global stage (Raev & Minkman, 2020; Velikaya, 2022).

The historical evolution of science diplomacy reflects its growing significance as both a collaborative and strategic endeavor. From its informal origins in earlier periods to its formal recognition as a research field post-2010, science diplomacy has emerged as a key mechanism for addressing global challenges while navigating the dual logic of cooperation and competition (P. B. Ruffini, 2020). As it continues to evolve, science diplomacy will play an increasingly vital role in integrating scientific knowledge and diplomatic efforts to foster global cooperation, address shared concerns, and advance national interests.

MATERIALS AND METHODS

Data Curation

To ensure a comprehensive and robust dataset for this study, a systematic search was conducted in two leading academic databases, Web of Science (WoS) and Scopus. These databases were selected due to their extensive coverage of high-quality, peer-reviewed literature across multiple disciplines. The search query employed the term “science diplomacy” in the title, abstract, or keywords of the articles (TS = "science diplomacy"). This approach captures relevant works explicitly focused on science diplomacy while also encompassing related terms and subfields, such as “health diplomacy”, “nuclear diplomacy”, and other domain-specific variants that inherently intersect with science diplomacy.

The chosen search strategy ensures inclusivity by identifying articles where science diplomacy is either the primary focus or a critical component of the study, reflecting its thematic and contextual diversity. By leveraging two authoritative databases, the study minimizes the risk of overlooking key contributions to the field while enhancing the reliability and breadth of the retrieved dataset. This rigorous methodological approach provides a solid foundation for the subsequent bibliometric analysis, enabling a thorough examination of the evolution, trends, and global responses shaping the science diplomacy research landscape.

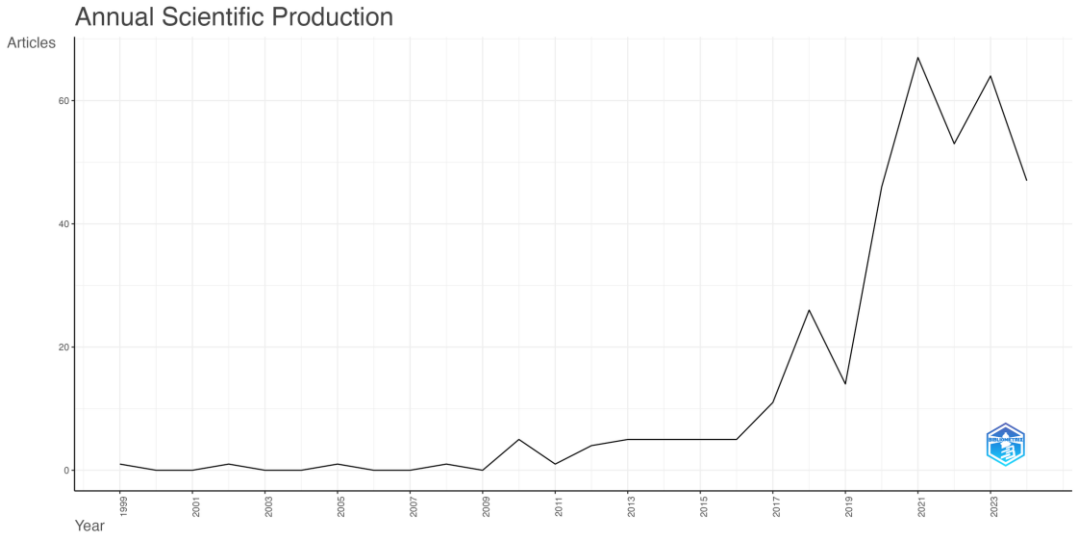
The search encompassed the Science Citation Index Expanded, Social Science Citation Index, and the Arts and Humanities Citation Index editions of WoS. The search yielded 189 results in WoS and 340 in Scopus, with 167 records overlapping between the two databases. The final dataset comprised 362 documents, categorized as “Article” and “Review Article”. These categories were selected as they represent the primary channels for disseminating new scientific knowledge (Adams, 2013).

Time Framing for Science Diplomacy Research Evolution

Based on the scientific production of science diplomacy research shown in Figure 1 we segmented into three time periods reflecting different stages of the field’s evolution. The rationale of the segmentation reflects shifts in scientific production and corresponds to broader historical, geopolitical, and scientific developments. The sharp increase in production after 2018 likely stems from global challenges that underscored the importance of science diplomacy, such as the pandemic and climate action.

Figure 1. Trends in Scientific Production of Science Diplomacy Research (1999–2023). The figure illustrates the annual scientific production in the field of science diplomacy research from 1999 to 2023. The data reveals distinct phases of development, including early foundations (pre-2000), gradual growth (2000–2010), rapid expansion (2018–2022), and recent stabilization (2023). Peaks in production align with heightened global interest in addressing crises such as climate change, the COVID-19 pandemic, and technological advancements.

Figure 1. Trends in Scientific Production of Science Diplomacy Research (1999–2023)



Rationale for the Time Frame: 1999–2017, 2018–2021, 2022–2024

This segmentation is based on distinct phases of development in science diplomacy research, reflecting shifts in global challenges, scientific priorities, and academic output trends:

Stage 1. Foundational and Growth Phase (1999–2017)

This period reflects the establishment and growth of science diplomacy as a research field, transitioning from a niche concept to a recognized interdisciplinary area. Scientific production gradually increased as global challenges like climate change, sustainability, and international scientific collaboration gained attention.

Events like the 2015 Paris Agreement and the rise of discussions around sustainability catalyzed interest in science diplomacy. Conceptual frameworks and case studies were developed, focusing on historical contexts (e.g., Cold War) and emerging global issues. Theoretical foundations, operationalization of science diplomacy, and case studies that link science, policy, and international relations.

Stage 2. Acceleration and Crisis Response Phase (2018–2021)

This phase saw a sharp rise in research output, driven by the urgency of global crises like the COVID-19 pandemic and heightened geopolitical tensions. The pandemic underscored the critical role of international scientific collaboration in addressing global health challenges, leading to a surge in publications.

COVID-19 became a defining moment, with science diplomacy recognized as a key tool for managing global health, vaccine distribution, and crisis communication. Topics like climate diplomacy, nuclear diplomacy, and Arctic cooperation gained momentum, reflecting geopolitical and environmental concerns. Application of science diplomacy in addressing immediate crises and fostering international cooperation.

Stage 3. Diversification and Stabilization Phase (2022–2024)

Research output stabilized, signaling the maturation of the field, while focus diversified into niche and emerging areas. Themes like digital diplomacy, space diplomacy (e.g., Artemis Accords), and regional focuses (e.g., Arctic science diplomacy) gained prominence.

The rise of new technological and geopolitical challenges shifted research priorities to address emerging frontiers in diplomacy and science. Thematic diversification reflects the field's expansion into specialized and applied contexts.

Exploring new applications of science diplomacy in diverse contexts and solidifying its role in addressing both traditional and contemporary challenges.

Rationale Summary

This segmentation highlights a logical progression:

1999–2017: Establishment and steady growth as the field gained recognition.

2019–2021: A surge driven by global crises, particularly the pandemic, highlighting the field's relevance.

2022–2024: Stabilization accompanied by diversification into new thematic and regional areas, reflecting the field's maturity and adaptability.

These framing balances historical trends with global developments that shaped the evolution of science diplomacy research.

The strategic diagram

The strategic diagram in Figure 2 was introduced by Callon et al. (1991). It is a visualization tool designed to analyze and interpret the dynamics of research networks. This diagram is part of their co-word analysis methodology, which evaluates the relationships and interactions between keywords in scientific and technical literature. Below is the explanation of the methodology.

Key Features of the Strategic Diagram

Axes Definition

Centrality (x-axis): Measures the strength and intensity of a cluster's links with other clusters. High centrality indicates that a cluster plays a key role in structuring the overall network, acting as a pivotal area of research or an "obligatory passage point."

Density (y-axis): Reflects the internal cohesion or strength of connections within a cluster. High density suggests a well-integrated and internally consistent research theme that can sustain itself over time.

Quadrants

The diagram is divided into four quadrants (see Figure 2), categorizing clusters based on their centrality and density.

Quadrant 1 (Top Right): Central and developed clusters. These are highly connected to the broader network and internally cohesive, often representing core, strategic research areas.

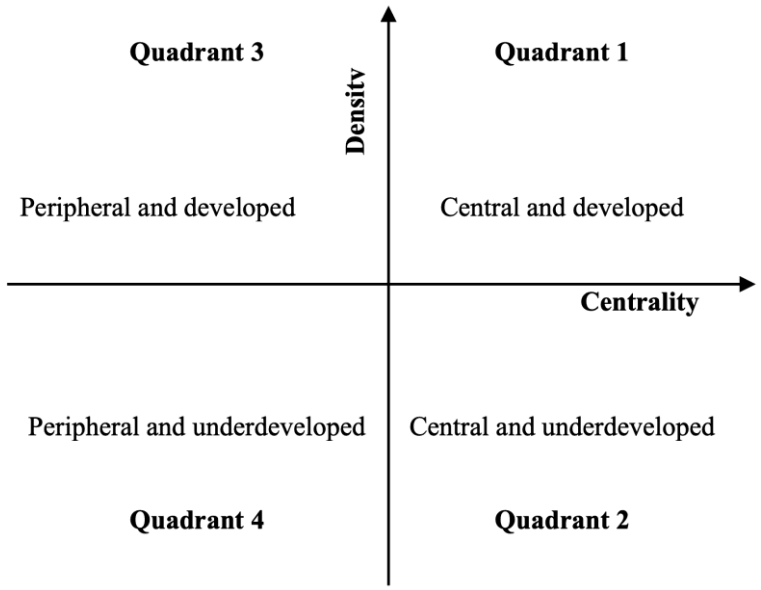
Quadrant 2 (Bottom Right): Central but undeveloped clusters. These are emerging areas that are central to the network but not yet internally cohesive, indicating potential for growth and investment.

Quadrant 3 (Top Left): Peripheral but developed clusters. These are well-developed themes with strong internal links but weak connections to the rest of the network, often representing specialized or niche areas.

Quadrant 4 (Bottom Left): Peripheral and undeveloped clusters. These represent marginal areas of the network with low connectivity and limited development, often indicating nascent or declining themes.

Figure 2. General Representation of the Strategic Diagram. The strategic diagram illustrates the classification of clusters based on their centrality (x-axis) and density (y-axis). The four quadrants represent different types of clusters: central and developed (upper-right), central but undeveloped (lower-right), peripheral and developed (upper-left), and peripheral and undeveloped (lower-left). This framework provides a synthetic visualization of research networks, highlighting core, emergent, specialized, and marginal themes within the field under study.

Figure 2. General Representation of the Strategic Diagram



Dynamic Analysis

The strategic diagram is not static; it can represent the evolution of research themes over time. By tracking clusters' movements across quadrants, researchers can study the life cycle of research areas, such as their emergence, growth, and decline.

Application

The diagram simplifies the complex structure of research networks, helping to identify strategic areas for funding, collaboration, or further study. It highlights "crossroads clusters," which are pivotal in connecting multiple research areas, driving innovation and integration across disciplines. This framework is especially useful for understanding the interplay between academic research and technological innovation, as demonstrated by Callon et al. (1991) study on polymer science.

The methodology outlined by Callon and colleagues, particularly the use of the strategic diagram, is well-suited to trace the dynamics of the evolution of science diplomacy research for several reasons:

1. Mapping the Interdisciplinary Nature of Science Diplomacy

- Science diplomacy is inherently interdisciplinary, involving interactions between fields such as political science, international relations, and specific scientific domains.
- The co-word analysis can identify clusters of research themes, revealing how these disciplines interact, merge, or diverge over time.
- By visualizing the centrality and density of clusters, this methodology can highlight which areas of science diplomacy are core (central and developed) versus peripheral or emergent.

2. Tracing Historical and Emerging Trends

- The strategic diagram allows the tracking of clusters over time, helping to chart the evolution of science diplomacy research.
- For instance, it can reveal shifts from traditional diplomacy to issues like global health diplomacy, climate diplomacy, or technology-driven international collaborations.
- Emerging clusters in quadrant 2 (central but undeveloped) could signify new areas of strategic importance, such as artificial intelligence in diplomacy or science as a tool for conflict resolution.

3. Identifying Core and Peripheral Areas

- By analyzing centrality, the methodology can identify research areas that are strategically positioned within the broader field of science diplomacy.
- Peripheral but developed clusters (quadrant 3) might indicate niche areas, such as specific regional studies (e.g., EU science diplomacy) or policy mechanisms, which could influence broader trends.

4. Understanding the Role of Actors and Networks

- Science diplomacy research often involves institutional, governmental, and non-governmental actors. Co-word analysis can help identify "crossroads clusters" that connect diverse research or policy domains, reflecting integrative efforts or collaborations.
- It can also uncover key players or dominant narratives by examining frequently co-occurring terms and their linkages.

5. Informing Policy and Strategic Investments

- As science diplomacy often has direct policy implications, understanding which areas are central and mature versus emergent can guide strategic funding and collaboration.
- For example, governments or international organizations could prioritize investments in clusters with high centrality but low density, fostering their development.

6. Dynamic Representation of Global Research Agendas

- The methodology captures the evolution of global challenges that influence science diplomacy, such as climate change, pandemics, or technology governance.
- This dynamic capability is essential for a field that evolves in response to real-world events and shifting political landscapes.

7. Comparative Analysis Across Regions or Periods

- Co-word analysis can compare science diplomacy research trends across countries or time periods, revealing how geopolitical priorities shape the discourse.
- For example, it could show how research in developing nations differs from that in developed nations, or how themes like "North-South collaboration" emerge and evolve.

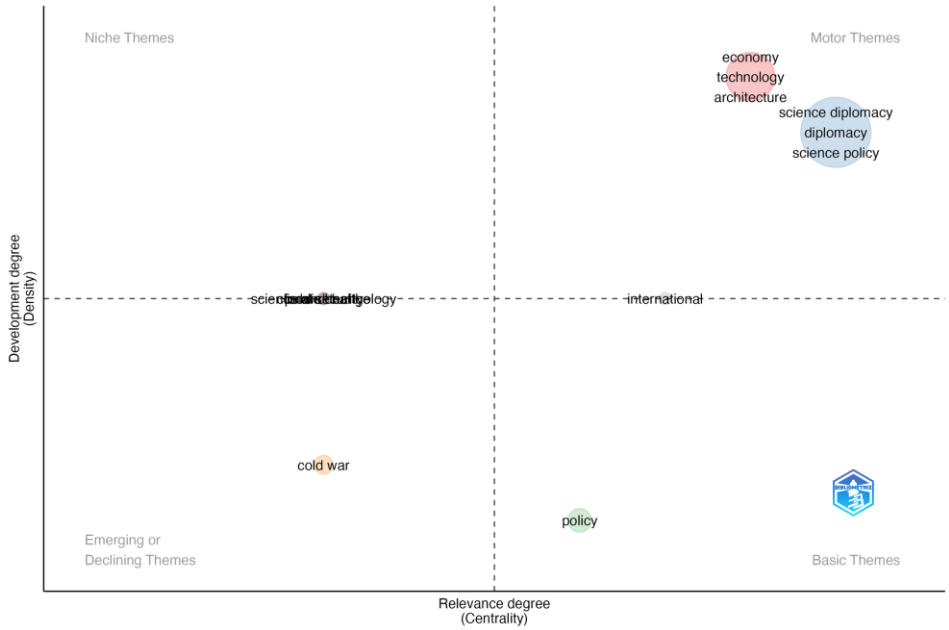
RESULTS

The historical evolution of publications on science diplomacy was analyzed in three distinct stages: 1999–2017, 2018–2021, and 2022–2024. Each stage reflects thematic priorities and emerging trends shaped by broader scientific, economic, and political developments. This section provides a detailed synthesis of the thematic quadrants—motor themes, basic themes, niche themes, and emerging/declining themes—and links them with relevant contextual events to highlight their trajectory within science diplomacy research.

Stage I (1999–2017): Foundation of science diplomacy, dominated by themes of science policy, diplomacy, and technology in a post-Cold War globalized scientific landscape.

The 1999–2017 period was a transformative era marked by globalization, technological innovation, geopolitical realignments, and rising transnational challenges like climate change and health crises. Figure 3 shows the strategic diagram of the research on science diplomacy during this stage. During this period, science diplomacy emerged as a conceptual and operational framework, heavily influenced by post-Cold War geopolitical dynamics and global scientific collaborations.

Figure 3. Thematic Evolution of Science Diplomacy Research (1999–2018)



Caption: This figure highlights the distribution of themes related to science diplomacy during 1999–2018. Key motor themes include "science diplomacy," "diplomacy," and "science policy," reflecting their role in driving research development. Emerging or declining themes, such as "cold war" and "policy," represent less-central yet notable topics during this period.

Motor Themes: Science diplomacy, diplomacy, and science policy were the most developed and central themes. Foundational studies, such as Ritch Iii (1999) on "Atoms for Peace" and Flink and Schreiterer (2010) on science diplomacy typologies, established theoretical and practical intersections between science and foreign policy.

Basic Themes: Policy was identified as central yet underdeveloped. Suttmeier (2010) highlighted Sino-American scientific collaborations, while Hotez (2015) introduced the concept of "vaccine diplomacy," emphasizing the role of health policy in global collaboration.

Niche Themes: Themes such as economy, technology, and architecture, though specialized, revealed interdisciplinary potential. Notable works included Goodsite et al. (2016) on Arctic research stations as geopolitical tools and Schlegel et al. (2011) on technology-driven diplomacy in the Swissnex China initiative.

Emerging or Declining Themes: Cold War-related topics, such as espionage and scientific tensions, reflected historical narratives transitioning to more cooperative frameworks (e.g., Smith (Smith, 2014).

Below an analysis connecting the findings to key events and contexts:

Post-Cold War Geopolitical Dynamics and Science Diplomacy

The results show that science diplomacy emerged as a dominant conceptual and operational framework in a post-Cold War landscape. The Cold War's end (1991) significantly influenced science policy and diplomacy, leading to a shift from competition and espionage to cooperation and multilateral initiatives. This explains why Cold War topics appeared as "emerging or declining themes," signaling a transition from a historical focus on scientific tensions to more collaborative frameworks. Examples like SESAME (Synchrotron-Light for Experimental Science and Applications in the Middle East) reflect efforts to use science to build trust and collaboration in politically fraught regions, similar to how initiatives like CERN previously united European nations. The Human Genome Project (1990–2003), referenced indirectly, epitomized international scientific collaboration, transcending political borders to achieve shared scientific progress. Thus, the reduced hostilities post-1990 allowed science diplomacy to thrive as a "soft power" tool, particularly in resolving conflicts, rebuilding trust, and creating platforms for international scientific cooperation.

The Globalization of Science and Technology

The timeframe (1999–2017) coincided with an unprecedented acceleration of globalization, largely driven by technological advancements. The rise of digital technologies, the Internet, and increased connectivity enabled global scientific collaboration at a scale not previously feasible. Initiatives like Swissnex China (technology-driven diplomacy) illustrate how nations leveraged technology to expand their diplomatic reach and foster bilateral scientific relationships, particularly between developed and emerging economies.

Arctic research, discussed in the findings, highlights how technology, geopolitics, and climate change converged. The Arctic became a hotspot for scientific collaboration as nations sought to stake claims and study the environmental impacts of a warming climate. This reflects growing awareness of environmental diplomacy as a strategic priority.

Climate Change and Environmental Diplomacy

The findings highlight the emergence of "climate diplomacy" themes, particularly linked to interdisciplinary research on environmental crises. The Kyoto Protocol (1997) set the stage for climate diplomacy, urging nations to cooperate scientifically to address greenhouse gas emissions and global warming. This underscores why the environment and policy emerged as key yet underdeveloped themes, pointing to the nascent nature of climate-related science diplomacy during this period. Climate-focused initiatives, such as Arctic research, not only tackled ecological questions but also demonstrated how scientific endeavors served geopolitical and economic agendas in contested regions. The broader social implication of these developments was the growing recognition of science diplomacy as essential for addressing shared transnational challenges like climate change.

Global Health Diplomacy and Vaccine Diplomacy

The mention of vaccine diplomacy Hotez (2015) ties into a critical global development: the increasing use of science in addressing public health crises.

During this period, health issues like HIV/AIDS, SARS (2003), and later Ebola (2014) spurred international collaboration to contain outbreaks and develop vaccines. Such crises emphasized the diplomatic and geopolitical role of science, particularly in fostering cooperation between countries to tackle global health threats. Vaccine diplomacy also aligns with broader economic and political interests, as nations like the U.S. and China began to integrate health science into their foreign policy agendas.

Sino-American Scientific Collaboration and Technology-Driven Diplomacy

The findings indicate that Sino-American collaborations played a central role in this period (e.g., Suttmeier (2010).

This reflects China's rising influence as a scientific powerhouse post-2000, driven by economic reforms and state investment in science and technology. Initiatives like Swissnex China symbolize Western efforts to engage with China through science and education, even as political and economic tensions increased.

The broader geopolitical implications include China’s use of scientific collaboration to assert its soft power and the West’s parallel efforts to maintain influence through partnerships and technology-driven diplomacy.

Science Diplomacy as Soft Power in a Globalized World

The period studied (1999–2017) witnessed the proliferation of soft power strategies wherein nations used science to build partnerships, influence international agendas, and compete for global leadership.

Themes like "architecture" and "technology" reveal the interdisciplinary dimensions of science diplomacy, as infrastructure projects (e.g., research stations) became tools for geopolitical engagement. Arctic research, for instance, not only advanced science but also solidified territorial claims and alliances.

This aligns with Nye (2017)’s concept of soft power, where science becomes a means to achieve geopolitical objectives through cooperation and influence rather than military confrontation.

Key Implications and Contributions

The results section highlights that science diplomacy during 1999–2017 was not only about science for science’s sake but also served broader social, political, and economic purposes:

Trust-building: Post-Cold War initiatives like SESAME illustrate how science helped bridge divides.

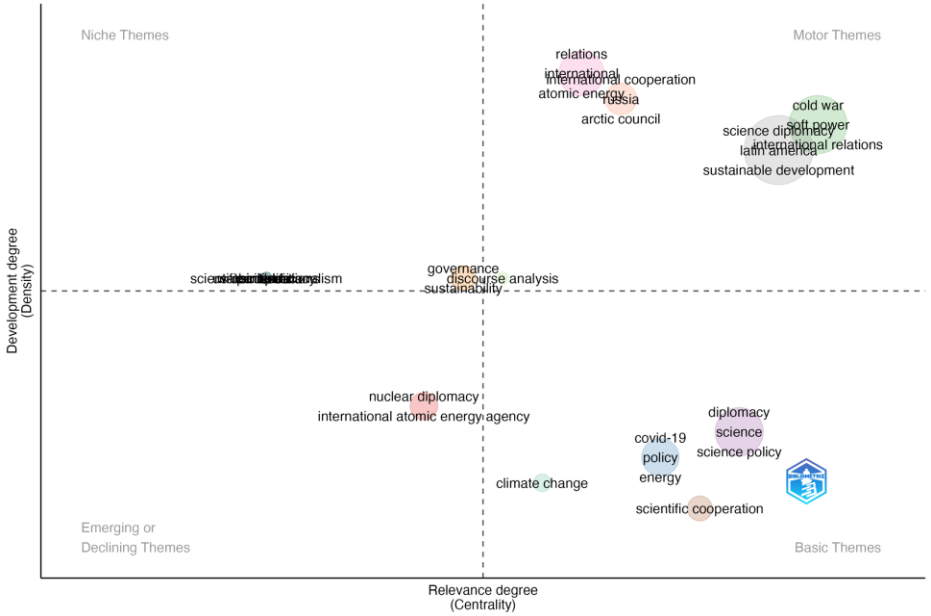
Global challenges: Climate diplomacy and vaccine diplomacy show the role of science in addressing shared crises.

Power dynamics: Technological diplomacy and Sino-American collaborations reveal science's intersection with geopolitical competition.

This period laid the groundwork for modern science diplomacy frameworks, where global challenges—such as climate change, health crises, and technological advancements—demand collective scientific solutions in increasingly multipolar geopolitical landscapes.

Stage II (2018–2021): Institutionalization of science diplomacy, driven by challenges such as climate change, COVID-19, and geopolitical tensions.

Figure 4. Emerging and Motor Themes in Science Diplomacy Research (2019–2021)



Caption: The figure illustrates the thematic landscape for science diplomacy research between 2019–2021. "Cold war," "soft power," and "sustainable development" emerge as motor themes, while "climate change," "policy," and "energy" appear as basic themes. This period also shows the rise of nuclear diplomacy and COVID-19-related research.

The second stage (Figure 4) witnessed a surge in the institutionalization of science diplomacy, driven by global challenges such as climate change, geopolitical tensions, and the COVID-19 pandemic.

Motor Themes: International cooperation, Arctic diplomacy, and multilateral relations became central. Studies such as Berkman (2020) emphasized governance in the Arctic, while Harden-Davies (2018) discussed marine biodiversity governance.

Basic Themes: COVID-19 and energy diplomacy became prominent, reflecting science diplomacy's relevance in addressing global health crises and climate challenges. AlKhaldi et al. (2021) proposed new frameworks for health diplomacy during the pandemic.

Niche Themes: Governance and sustainability emerged as specialized themes, with Ruffini (2020) introducing innovation diplomacy and Arapostathis and Laborie (2020) exploring technoscientific governance.

Emerging or Declining Themes: Nuclear diplomacy, though less central, remained relevant through studies such as Adamson (2021) on isotope hydrology's diplomatic impact.

The Stage II (2018–2021), the institutionalization of science diplomacy during this period reflects an era marked by unprecedented global crises, geopolitical realignments, and accelerated international interdependence. Science diplomacy was no longer conceptual but evolved into a robust, institutionalized tool for addressing immediate and structural challenges. Below the analysis of the identified themes to the broader global political, social, and economic context:

COVID-19 and the Rise of Health Diplomacy

The COVID-19 pandemic was a defining global event during this period, revealing vulnerabilities in global health systems and prompting the institutionalization of health diplomacy. **COVAX**, a multilateral initiative, epitomized vaccine diplomacy as a means to ensure equitable access to vaccines for developing nations. This reflects the practical application of science diplomacy to achieve global public goods amidst a health emergency.

The pandemic spurred studies like AlKhaldi et al. (2021), which proposed new frameworks for health diplomacy, highlighting the need for cooperation across nations to contain pandemics and strengthen global governance.

Science diplomacy also became a tool of soft power: vaccine development and distribution became geopolitical tools, particularly for nations like China (Sinovac) and the U.S. (Pfizer and Moderna), competing for influence in regions like Africa and Latin America.

Climate Change and Arctic Diplomacy

Climate change continued to dominate the science diplomacy agenda, particularly in regions like the Arctic, which emerged as a contested yet collaborative space.

Arctic diplomacy, identified as a motor theme, reflects the confluence of science, governance, and geopolitics in addressing resource politics and environmental changes. Berkman et al. (2017) emphasized the importance of multilateral governance, recognizing the Arctic's strategic and ecological significance.

Climate diplomacy became increasingly institutionalized, with global agreements like the Paris Agreement (2015) shaping energy and sustainability frameworks. The inclusion of energy diplomacy as a basic theme reflects growing concerns around energy transitions and geopolitical tensions tied to resources like oil, gas, and renewable energy.

The thematic rise of sustainability aligns with the UN Sustainable Development Goals (SDGs), particularly Goals 7 (Affordable and Clean Energy) and 13 (Climate Action), institutionalizing science as a critical driver of sustainable development.

Geopolitical Tensions and Scientific Neutrality

The second stage saw an intensification of US-China geopolitical tensions, which began earlier but escalated significantly during the Trump administration's trade policies (2018–2020).

Science diplomacy, historically viewed as apolitical, faced challenges in maintaining neutrality amidst increasing competition for technological and scientific dominance.

This era witnessed rising concerns about dual-use technologies (e.g., AI, biotechnology), where scientific advancements intersected with national security considerations. These tensions strained international collaborations, as evidenced by restrictions on academic partnerships and research funding.

The emergence of nuclear diplomacy during this period Adamson (2021) further reflects renewed focus on non-proliferation and energy governance, particularly in regions of tension like Iran and North Korea.

Institutionalization of Governance and Innovation Diplomacy

Science diplomacy in this stage saw its institutional foundations strengthened, particularly in areas of governance and innovation. P.-B. Ruffini (2020) concept of innovation diplomacy highlights the role of science and technology in advancing diplomatic goals. Countries began formalizing frameworks to integrate scientific innovation into foreign policy, particularly in addressing issues like climate change, health crises, and economic development. Governance frameworks, explored in studies such as Harden-Davies (2018) on marine biodiversity governance, reflect an institutional response to global environmental and resource

challenges. Technoscientific governance, as explored by Arapostathis and Laborie (2020), underscores how emerging technologies and scientific expertise became critical components of policymaking in an increasingly complex geopolitical environment.

Soft Power and the Resurgence of Nuclear Diplomacy

The resurgence of nuclear diplomacy as an emerging theme points to the renewed focus on non-proliferation treaties and the peaceful use of nuclear technologies:

Nuclear energy emerged as a strategic topic within the context of climate change and energy diplomacy, highlighting its role in reducing carbon emissions while addressing global energy demands. Additionally, the peaceful use of nuclear technologies, such as isotope hydrology Adamson (2021), reflects the diplomatic impact of science in fostering cooperation on resource management and sustainable development.

Soft power strategies, identified through themes like "sustainable development" and "policy," further underscore how science diplomacy enabled countries to enhance their global influence. The institutionalization of these themes reflects efforts to formalize scientific collaborations as diplomatic tools.

Key Contextual Highlights

The institutionalization of science diplomacy during 2018–2021 was driven by:

1. **COVID-19**: Health diplomacy became critical for pandemic responses, with vaccine access and multilateral frameworks exemplifying science diplomacy's practical application.
2. **Climate Change**: Arctic diplomacy and energy diplomacy highlight the intersection of science, governance, and geopolitics in addressing climate crises and resource politics.
3. **Geopolitical Tensions**: US-China competition underscored challenges to scientific neutrality, as nations increasingly leveraged science and technology for geopolitical gains.
4. **Governance and Innovation**: Institutional frameworks for science diplomacy became more structured, addressing sustainability, resource governance, and innovation.
5. **Soft Power**: Science diplomacy continued to be a tool for influence, promoting global cooperation while advancing national interests.

Significance and Implications

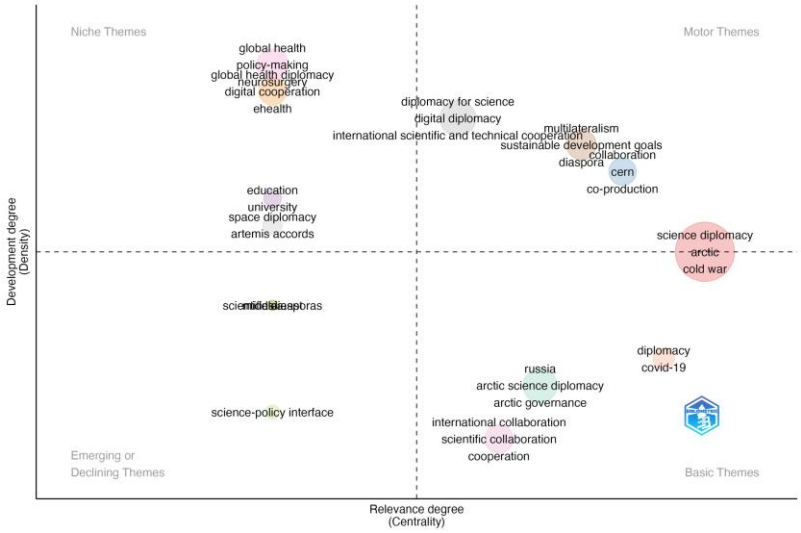
This period marks a shift from conceptual to institutionalized science diplomacy, where science became an integral part of global governance and international relations. The COVID-19 pandemic, climate change, and geopolitical tensions served as accelerators, demonstrating that science diplomacy is not merely a tool of cooperation but a critical mechanism for addressing global challenges and reshaping power dynamics in a multipolar world.

The study's findings highlight how science diplomacy matured into a strategic, institutionalized framework, capable of fostering collaboration while navigating the complexities of geopolitics and transnational crises.

Stage III (2022–2024): Maturity and diversification, with focus on digital diplomacy, SDGs, and disruptions caused by conflicts like Russia-Ukraine, Israel-Hamas and others.

The most recent period highlights the maturity of science diplomacy (Figure 5), with a focus on digital technologies, climate change, and geopolitical shifts.

Figure 5. Current Trends and Thematic Dynamics in Science Diplomacy Research (2022–2024)



Caption: The thematic analysis for 2022–2024 identifies "science diplomacy," "arctic," and "cold war" as prominent motor themes driving research. Topics such as "global health," "digital diplomacy," and "space diplomacy" are explored in niche themes, reflecting the increasing intersection of diplomacy with modern scientific challenges.

Motor Themes: Digital diplomacy, multilateralism, and the Sustainable Development Goals (SDGs) defined the core themes. Fuentes, Cárdenas, Olivares, et al. (2023) explored how digital tools facilitated global coordination on climate and sustainability.

Basic Themes: Arctic science diplomacy and COVID-19 diplomacy continued to evolve, as illustrated by Everett and Halasková (2022) on Arctic climate strategies and Adamson (2023) on crisis-driven scientific collaboration.

Niche Themes: Specialized themes such as global health and neuroscience gained traction, with Arsentyeva (2022) highlighting transformations in vaccine diplomacy and Das et al. (2022) integrating neuroethics into global health diplomacy.

Emerging or Declining Themes: Scientific diasporas and the science-policy interface emerged as areas with growth potential, with studies like Avendano-Uribe et al. (2022) examining transnational collaboration in Latin America.

The Stage III (2022–2024) reflects the maturity and diversification of science diplomacy amidst major technological advancements, climate imperatives, and disruptions caused by geopolitical conflicts like the Russia-Ukraine war. Science diplomacy, during this phase, has become a multi-faceted, resilient, and adaptive tool addressing both emerging global challenges and enduring transnational priorities.

Digital Diplomacy and Technological Disruptions

The rise of digital diplomacy as a motor theme aligns with advances in artificial intelligence (AI), quantum computing, and digital communication tools, which have reshaped global scientific collaboration and governance.

The accelerated adoption of digital platforms post-COVID-19 facilitated virtual international cooperation, overcoming physical barriers to collaboration. Digital diplomacy tools have been instrumental in achieving the UN Sustainable Development Goals (SDGs), particularly in climate action (SDG 13), quality education (SDG 4), and global partnerships (SDG 17).

AI and quantum computing present significant governance challenges as nations race to lead in these transformative technologies. These challenges underscore the need for new diplomatic frameworks to regulate AI ethics, cybersecurity, and equitable access to emerging technologies.

The work of Fuentes, Cárdenas, Olivares, et al. (2023); Fuentes, Cárdenas, Urbina, Vidal, Olivares, Lawler, Azocar, et al. (2023); Fuentes, Cárdenas, Urbina, Vidal, Olivares, Lawler, Bustos Azocar, et al. (2023) exemplifies how digital tools can promote scientific collaboration, climate coordination, and innovation diplomacy, illustrating science diplomacy's evolution to address 21st-century challenges.

Climate Change and Arctic Diplomacy

The Arctic continues to emerge as a critical basic theme of science diplomacy, reflecting the intersection of climate change, resource politics, and geopolitical competition. The Arctic region is both a barometer of climate change and a contested geopolitical space. As nations compete for resources and influence, science diplomacy has been a vital tool for promoting governance and multilateralism. Everett and Halasková (2022) highlight Arctic climate strategies that balance scientific cooperation with geopolitical considerations. This demonstrates the dual role of science diplomacy in addressing environmental crises while managing geopolitical tensions. The Arctic's increasing strategic relevance reflects broader global concerns about climate change, resource management, and environmental security, reinforcing science diplomacy's importance in promoting stability.

Impact of the Russia-Ukraine Conflict on Science Diplomacy

The Russia-Ukraine war (2022–present) has disrupted traditional East-West collaborations, particularly in science and technology. The conflict forced scientists and institutions to adapt, fostering resilience in global science diplomacy through alternative networks and diasporas. For example, transnational collaborations, such as the growing importance of Latin American scientific diasporas Avendano-Uribe et al. (2022), highlight how displaced talent and alternative partnerships can maintain scientific cooperation amidst geopolitical instability. Russia's exclusion from collaborative programs (e.g., the Arctic Council) highlights the geopolitical tensions influencing science diplomacy. However, the crisis has also accelerated dialogue on the role of science as a neutral platfo**rm** for maintaining fragile connections in divided geopolitical environments. This development underscores the adaptability of science diplomacy, which balances geopolitics with the necessity for scientific continuity in addressing shared global challenges.

Global Health and Vaccine Diplomacy

Global health diplomacy remains a niche yet growing theme, reflecting the long-term implications of COVID-19 and the focus on health resilience. Vaccine diplomacy, as explored by Arsentyeva (2022), continues to evolve, addressing challenges of global equity, preparedness, and innovation in vaccine development. Nations like China, the U.S., and Russia have strategically used vaccines to expand their geopolitical influence, solidifying health diplomacy as a tool for soft power.

Neuroscience and neuro ethics have emerged as specialized domains within health diplomacy, as discussed by Das et al. (2022). This reflects increasing attention to the ethical implications of cutting-edge research, particularly in neuroscience and biotechnology.

Global health diplomacy remains essential in managing pandemic preparedness and emerging health threats, reinforcing the critical role of science in fostering international cooperation and equity.

Science-Policy Interface and Scientific Diasporas

The emergence of themes like the science-policy interface and scientific diasporas reflects new dimensions of science diplomacy:

The science-policy interface highlights the need for evidence-based policymaking to address global challenges. This interface is critical for achieving the SDGs and managing geopolitical and technological disruptions. Scientific diasporas play a growing role in fostering transnational collaborations, as demonstrated in Latin America. Diasporas serve as bridges between countries, enabling knowledge exchange and resilience in science diplomacy amidst political or economic instability.

Space Diplomacy and Emerging Technologies

The inclusion of space diplomacy as a niche theme reflects the growing strategic and scientific importance of outer space:

Advances in space exploration, led by programs from the U.S., China, and private entities like SpaceX, have created new opportunities for collaboration and competition. Space diplomacy is increasingly seen as critical for governing issues like space debris, resource extraction, and satellite usage.

This aligns with the broader trend of emerging technologies—including AI, quantum computing, and advanced materials—shaping science diplomacy frameworks. Governance mechanisms for these technologies are essential to ensure ethical use and equitable access globally.

Key Contextual Highlights and Implications

The maturity and diversification of science diplomacy during 2022–2024 highlights its adaptive nature amidst technological disruptions, climate crises, and geopolitical tensions. The following developments are central to understanding the findings:

Digital Diplomacy: Advances in AI, quantum computing, and digital tools transformed science diplomacy, driving global coordination on SDGs and climate action.

Climate and Arctic Diplomacy: The Arctic remains a geopolitical and scientific priority, illustrating the dual role of science diplomacy in fostering cooperation and managing resource competition.

Russia-Ukraine Conflict: The war disrupted traditional networks, highlighting the resilience of science diplomacy through alternative collaborations, diasporas, and transnational partnerships.

Health Diplomacy: The evolution of vaccine diplomacy and global health initiatives underscores science's role in addressing pandemics and advancing equitable health outcomes.

Emerging Technologies and Space Diplomacy: Governance frameworks for emerging technologies and space exploration reflect new frontiers of science diplomacy.

Scientific Diasporas: Transnational collaborations led by diasporas highlight adaptive pathways for maintaining scientific progress amidst instability.

The period of 2022–2024 marks a mature and diversified phase of science diplomacy, where traditional themes (e.g., climate and health) intersect with new frontiers like digital diplomacy, space governance, and emerging technologies. Geopolitical disruptions, such as the Russia-Ukraine conflict, underscore science diplomacy's adaptability and its role in fostering resilience, cooperation, and innovation in an increasingly fragmented yet interdependent world.

DISCUSSION

This study reveals the evolution, institutionalization, and diversification of science diplomacy across three distinct stages, reflecting its growing significance as a tool for addressing global challenges and navigating geopolitical complexities. The findings highlight key themes, their transformations over time, and the broader contextual drivers influencing science diplomacy's trajectory.

Evolution of Science Diplomacy: From Conceptual Foundations to Institutional Maturity

Stage I (1999–2017) marked the foundational phase of science diplomacy, driven by post-Cold War geopolitical dynamics and globalization. Research during this stage focused on building conceptual and operational frameworks, with themes such as science policy, diplomacy, and technology dominating. Initiatives like SESAME and the Human Genome Project illustrated how science facilitated trust-building and international cooperation.

Stage II (2018–2021) witnessed the institutionalization of science diplomacy, accelerated by global crises such as climate change, the COVID-19 pandemic, and US-China geopolitical tensions. During this phase, health diplomacy, energy governance, and Arctic cooperation emerged as critical tools for addressing transnational challenges. COVID-19 particularly catalyzed frameworks for global health diplomacy, exemplified by COVAX and vaccine diplomacy, showcasing science as both a cooperative and competitive tool.

Stage III (2022–2024) reflects the maturity and diversification of science diplomacy, with a focus on emerging themes like digital diplomacy, space diplomacy, and scientific diasporas. Advances in digital tools, AI, and quantum computing transformed international scientific cooperation, while geopolitical disruptions,

such as the Russia-Ukraine conflict, forced adaptation through alternative networks and diasporic collaborations.

This trajectory underscores how science diplomacy has evolved from a conceptual ideal into a dynamic, institutionalized, and adaptable practice, capable of addressing evolving global and geopolitical challenges.

Key Drivers of Change in Science Diplomacy

The results suggest that science diplomacy's evolution has been shaped by four interconnected drivers:

1. *Global Crises and Transnational Challenges*

Climate change emerged as a central and consistent theme across all three stages, highlighting the role of science diplomacy in fostering governance mechanisms, such as Arctic cooperation, and advancing Sustainable Development Goals (SDGs).

The COVID-19 pandemic emphasized the urgency of global health diplomacy, showcasing how scientific collaboration can drive equitable health responses and strengthen pandemic preparedness.

2. *Technological Advancements*

Advances in digital technologies, artificial intelligence, and quantum computing in Stage III have reshaped global science diplomacy frameworks, facilitated international coordination and introduced governance challenges. Emerging technologies are also driving new arenas of cooperation and competition, such as space diplomacy and innovation diplomacy.

3. *Geopolitical Shifts and Disruptions*

The post-Cold War détente (Stage I) enabled renewed collaboration, while rising geopolitical tensions in Stages II and III (e.g., US-China competition and Russia-Ukraine conflict) disrupted traditional networks. The resilience of science diplomacy, particularly through scientific diasporas and alternative partnerships, highlights its adaptability in times of geopolitical instability.

4. *Soft Power and Global Governance*

Science diplomacy has increasingly become a tool for soft power, where nations use science to build influence, strengthen alliances, and promote global public goods. Frameworks for multilateral governance (e.g., climate strategies, Arctic diplomacy) have been central to addressing shared challenges while managing resource politics and geopolitical interests.

Science Diplomacy as a Resilient and Adaptive Framework

Across these stages, science diplomacy has demonstrated remarkable resilience and adaptability:

In times of cooperation (Stage I), it fostered trust and multilateral collaboration. During crises (Stage II), it provided institutional solutions to health and environmental challenges. Amidst fragmentation (Stage III), it adapted through digital diplomacy, scientific diasporas, and alternative networks to ensure the continuity of global science.

This adaptability underscores the critical role of science diplomacy as a bridge between science, policy, and international relations, enabling nations to collaborate, compete, and address shared challenges effectively.

CONCLUSIONS

The results of the study provide a comprehensive understanding of the thematic evolution, key trends, and contextual responses shaping science diplomacy over the past 25 years (1999–2024). First, the findings illustrate the maturation and diversification of science diplomacy as a research domain, confirming its thematic evolution into a critical tool for addressing transnational challenges such as climate change, health crises, and resource governance. This reflects the field’s significant growth and adaptability, fulfilling the objective of examining its scholarly development over time.

Second, the study identifies key drivers and trends that have shaped science diplomacy, including the institutionalization driven by global crises (e.g., the COVID-19 pandemic) and technological advancements. The expansion into emerging domains such as digital diplomacy, space diplomacy, and technological

governance highlights the dynamic patterns influencing the field. Furthermore, the resilience of science diplomacy during geopolitical disruptions, such as the Russia-Ukraine conflict, underscores the evolving role of alternative networks, including scientific diasporas, as vital contributors to international collaboration.

Finally, by contextualizing the findings within significant global events, the study demonstrates how science diplomacy has dynamically responded to challenges like climate change governance, the pandemic, and geopolitical shifts. It emphasizes science diplomacy's role in fostering multilateral cooperation and mitigating tensions during periods of instability, aligning with the objective of understanding its responses to global crises.

In sum, this study achieves its aims by mapping the thematic and structural evolution of science diplomacy, identifying its major trends and drivers, and contextualizing its development within critical global events. The insights generated provide a foundation for future research and practical applications, positioning science diplomacy as an indispensable tool for promoting global equity, innovation, and sustainable development in an increasingly interconnected and complex world.

Possible New Lines of Research

Future research in science diplomacy can explore several critical areas to advance the field. The *impact of digital diplomacy* is an emerging topic, focusing on how digital tools and platforms are transforming international collaborations and influencing science diplomacy policymaking. The *post-COVID-19 world* presents another significant avenue for investigation, particularly in understanding how the pandemic reshaped global health diplomacy and introduced lasting changes to international scientific partnerships. Additionally, the role of *science diplomacy in climate action* warrants further examination, with emphasis on its effectiveness in supporting international agreements like the Paris Agreement and advancing coordinated global responses to climate change. Research on *polar science diplomacy* is also crucial, given the geopolitical and environmental significance of the Arctic and Antarctic regions; scientific collaborations in these areas provide a unique lens for analyzing their influence on global governance and policies. Finally, exploring *interdisciplinary approaches* will shed light on the benefits and challenges of integrating diverse scientific disciplines to address complex, multifaceted global issues, reinforcing the need for holistic strategies in science diplomacy.

Practical Implications for Academics and Practitioners

For academics, the findings in science diplomacy offer several key opportunities. First, curriculum development should integrate science diplomacy into international relations and public policy programs, emphasizing its evolving role in addressing global challenges. Second, encouraging interdisciplinary research will enable scholars to combine insights from science, technology, and diplomacy, fostering innovative solutions to complex global issues. Additionally, the creation of case studies based on real-world applications of science diplomacy can provide valuable teaching tools, illustrating its practical impact and relevance.

For practitioners, the implications are equally significant. Insights from science diplomacy research can guide policy formulation, ensuring that science-based strategies effectively address pressing issues such as climate change, global health security, and technological governance. In parallel, training and development programs for diplomats and international relations professionals can equip them with the skills to integrate scientific knowledge and digital tools into their work. Furthermore, fostering international collaborations will require leveraging historical context and contemporary trends, particularly in critical areas such as climate action and global health diplomacy. Finally, strategic planning can benefit from these findings, particularly in engaging with geopolitically significant regions like the Arctic and enhancing the role of science as a tool for diplomatic engagement.

By understanding the historical evolution, current dynamics, and practical applications of science diplomacy, both academics and practitioners can contribute to more effective, innovative, and science-informed approaches to international relations and global cooperation.

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Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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