The Policy Effectiveness of Complexity Science: Measuring Divergent Impact Across Sustainable Development Goals

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Abstract

Contemporary policy challenges, from climate adaptation to poverty and economic inequality, demand approaches that account for interconnected systems, feedback loops, and emergent dynamics. This study maps the intersection between complexity science research and public policy impact through comprehensive bibliometric analysis. Using a corpus of complexity science publications, we integrate co-citation network analysis with policy mention data and Sustainable Development Goal (SDG) classifications to identify where academic research translates into policy practice.

Our analysis reveals that policy-influential papers often differ substantially from those with the highest academic citations. We introduce a Policy Effectiveness Index (PEI) that quantifies the relative influence of papers across policy, academic, and media domains. Results show that papers addressing SDGs related to socioeconomic prosperity and governance—Decent Work and Economic Growth, Climate Action, and Peace, Justice and Strong Institutions—demonstrate the highest policy effectiveness ratios. Our findings suggest that successful policy applications of complexity science require accessible frameworks that balance rigor with clear communication of practical implications. This research provides actionable insights for scholars seeking to maximize policy impact and for policymakers navigating complexity science approaches under conditions of bounded rationality and systemic uncertainty.

Keywords: Complexity science, Public Policy, Policy Effectiveness Index, Sustainable Development Goals, Systems thinking, Network analysis, Participatory modeling

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1 Introduction

Today's public policy confronts unprecedented complexity. Climate adaptation requires coordination across multiple scales and sectors; Health crises reveal vulnerabilities in interconnected systems; Economic inequality emerges from feedback loops between markets and institutions and Digital transformation reshapes governance itself.

Traditional policy approaches often fail when applied to complex adaptive systems. Treating symptoms instead of systemic structures, optimizing individual components rather than whole-system dynamics, or imposing rigid top-down control on self-organizing processes—these conventional strategies frequently backfire. The results include policy resistance, unintended consequences, and worsening of the very problems policymakers intended to solve.

Over the past two decades, complexity science has evolved from a primarily theoretical field into a practical framework for understanding and managing real-world systems. Complexity science offers both conceptual lenses and technical methods to study public policy problems and to inform policy cycles. For instance, behavioral insights teams apply complexity concepts about bounded rationality and emergent social norms to "nudge" behavior change[Dosi et al., 2021]; Organizations employ adaptive co-management frameworks in pursuit of sustainable resource use and social-ecological resilience [Plummer and Armitage, 2007]; Environmental governance increasingly embraces adaptive and polycentric approaches informed by complex systems thinking [Staub and Tirmizi, 2025], and more. The field has achieved cultural diffusion through worldwide communities composed of members from multiple disciplines. It has been driven by intellectual curiosity and an openness to engage with new problems, fostering a shared recognition of the importance of interdisciplinarity and even embracing "the vagueness" of the term [Hébert-Dufresne et al., 2024].

Although public policy problems increasingly display hallmarks of complex systems—such as heterogeneous agents, dense interdependencies, and strong feedback loops, there remain gaps in the literature on how complexity science has influenced public policy at large. Most policies adopt complexity methods pragmatically without explicit reference to underlying theoretical foundations. This gap between practice and theory is consequential. Without understanding why complexity methods work, practitioners cannot distinguish effective applications from superficial ones, cannot adapt tools appropriately to context, and cannot articulate their value to skeptical policymakers.

We draw from Simon [1976]'s initial concept of bounded rationality in policymaking to argue that methodological approaches and tools of complexity science can and should be systematically integrated into the policy process. This project addresses the following central question: *How are complexity science methods being employed and applied in public policy, and how are complexity concepts being understood in this field?* Complementary sub-questions include:

- What specific complexity methods (system dynamics, agent-based modeling, network analysis, participatory systems mapping) are being integrated into policy?
- In what forms is complexity being interpreted in policy? Is it implemented pragmatically through policy strategies or left only as proposals and drafts?

We therefore hypothesize that complexity science tools can be systematically integrated into policy processes, bridging the gap between theoretical foundations and practical applications. However, at the same time, we expect that some of the most influential scholarly works in complexity science do not reach policymakers, while the methods that are most useful or practical for policy tend to diffuse independently of deeper theoretical foundations.

This research builds directly on the Global Complexity School's emphasis on moving from metaphorical uses of "complexity" toward analytically rigorous applications in public policy. The CGS curriculum provided the methodological foundation for this empirical investigation, particularly through modules on network science, systems mapping, and adaptive governance.

The remainder of this paper proceeds as follows. Section 2 presents the literature review and the theory behind applying Complexity Science to policy. Section 3 describes the methodological approach of this research. Section 4 presents preliminary findings. Section 5 discusses the results, the current challenges and what Complexity Science could contribute to policy in practice in the future. Section 6 outlines potential future steps. Section 7 concludes with implications for practice and research.

2 Theoretical Framework and Literature Review

2.1 Policy as Design: Adaptive Problem-Solving under Bounded Rationality

In this section, we introduce Herbert´s Simon concept of bounded rationality in the context of policy-decision making, and the role of complexity science at the operational layer of policy design.

Policy design faces an enduring challenge: decision-makers must act under cognitive and informational limits. Herbert Simon's concept of bounded rationality overturned the assumption that policymakers can achieve full rationality as posited in classical economics. Instead, Simon demonstrated that attention, memory, and computational capacity constrain what agents can know and process [Simon, 1947, 1955, 1996a]. Because of these limits, actors satisfice rather than optimize, they search for solutions that are "good enough" to meet aspiration levels rather than maximizing utility [Simon, 1957].

This idea reoriented the study of decision-making toward the actual processes through which choices are made. As Jones [2002, p. 269] observed, "bounded rationality insists that processes matter, that successful science must properly link the process of making individual decisions to organizational processes responsible for collective choices." Policy outcomes, therefore, depend less on idealized rational calculation and more on the procedural architectures —heuristics, routines, and institutional rules—that shape how decisions unfold [March and Simon, 1958, Newell and Simon, 1972]. In his later work, Simon extended bounded rationality into a broader philosophy of design. In *The Sciences of the Artificial* [Simon, 1996b], he argued that designed systems, including policies, should be understood not through universal laws but through their fitness to purpose within specific environments. Policymaking thus becomes an iterative process of constructing artifacts that perform well in their context rather than deriving optimal solutions from abstract principles.

Simon described design as "devising courses of action aimed at changing existing situations into preferred ones" [Simon, 1996b, p. 111]. This "design stance" reframes policy-making as crafting under constraint: given limited information and uncertainty, policymakers must proceed through experimentation, feedback, and progressive refinement. Decision-making under bounded rationality thus becomes a process of adaptive problem-solving, learning by doing in complex and evolving environments.

Building on Simon's insights, Barzelay [2019] developed a design-oriented vision for public management. In *Public Management as a Design-Oriented Professional Discipline*, he argues that public management should unite multiple conceptions of professional practice around an expansive notion of design. Drawing on Simon's ideas, Barzelay defines the field as requiring "thoughtful and skillful use of purposive theories of public organizations, along with reverse-engineered design-precedents, in problem-solving for public programs and organizations" [Barzelay, 2019, p. 23].

Rather than prescribing fixed solutions, Barzelay's framework is generative: it equips practitioners with conceptual tools to create context-appropriate interventions. Its knowledge base integrates three key elements: design precedents (reverse-engineered cases that illustrate successful problem-solving in specific contexts), purposive theories (frameworks that link mechanisms to intended outcomes), and professional judgment (the practical wisdom to know which precedents and theories apply to which problems). This approach resonates with Simon's emphasis on procedural rationality—knowing how to approach problems rather than seeking universal optima [Simon, 1976].

Geyer and Rihani [2010] extend this design-oriented perspective by exploring the connection between complexity science and policy entrepreneurship. They present adaptive capacity as a framework for enhancing policy design through a complex adaptive systems (CAS) lens. Their analysis highlights several properties particularly relevant to policy studies: the presence of negative and positive feedback loops; strange attractors, which present recurring patterns of behavior that can be disrupted by brief periods of change; sensitivity to initial conditions and path dependence; and the emergence of system-level patterns from interactions among local elements [Geyer and Rihani, 2010]. These complexity-informed insights provide operational tools for the adaptive problem-solving that Simon's bounded rationality framework requires.

2.2 Complexity Science at the Operational Layer

Complexity science provides the computational and participatory tools that operationalize Simonian design principles in real-world policy contexts. Its methods translate the abstract logic of design into practical, data-driven modeling techniques.

First, complexity methods make visible the feedback loops, nonlinearities, and emergent properties that Simon recognized but could not formally model. System dynamics represents the "accumulation processes and feedback structures" that generate counterintuitive policy outcomes [Forrester, 1961, Sterman, 2000]. Classic works such as Meadows et al. [1972] show how feedback delays can lead to overshoot and collapse—dynamics missed in equilibrium frameworks. Likewise, agent-based modeling reveals how macro-level patterns emerge from micro-level interactions, explaining why aggregate interventions often fail [Epstein, 1999]. For instance, in their study [Goldstick and Jay, 2022] showed that ABMs leverage major advantages in community violence research in their capacity to study the natural evolution of a process governed by the actions of autonomous agents and how it changes based on counterfactual conditions, such as policy changes (e.g alcohol licensing policies). Other use cases can be seen in public health and epidemic control [Morshed et al., 2019].

Second, complexity tools enable iterative design cycles. Rather than requiring full information before action, they allow policymakers to test ideas through simulation, observe system reactions, and refine their assumptions [Miller and Page, 2007]. For example, before introducing the congestion tax in Stockholm, policymakers used system dynamics and traffic simulations to test different fee structures and assess public response and traffic flow impacts. This model was refined iteratively with real-world traffic data and during trial before the implementation [Eliasson, 2008]. Other applications include system dynamics learning to resource allocation in different decision scenarios, as the case of Weeks et al. [2022] who used systems thinking to understand HIV continuum in the Ryan White CARE Act, which provides federal resources supporting low-income people living with HIV/AIDS to help the Regional Ryan White Planning Councils responsible for prioritizing these resources.

Third, participatory complexity methods bring bounded rationality into the collective domain. Techniques such as participatory system dynamics and group model building help articulate and integrate diverse stakeholder perspectives [Vennix, 1996, Sterman, 2000].

This addresses Simon's insight that decision-making in organizations depends on the coordination of distributed, partial knowledge [March and Simon, 1958]. By making mental models explicit and shared, these participatory processes strengthen implementation and foster mutual understanding. Barbrook-Johnson and Penn [2021] present a method called participatory systems mapping (PSM), which involves stakeholders collaboratively creating a causal map of a system to capture variables, feedback loops, and interconnections in complex policy environments. They present two real-case world studies in the UK on energy policy, combining network analysis with subjective information from stakeholders and showing that PSM is particularly appropriate when there is stakeholder diversity, when complexity and feedback are significant, when new questions or evaluation scopes need to emerge, and when existing models (logic models, theories of change) are too linear or narrow.

The trajectory from bounded rationality to design-based governance and finally to complexity-informed design represents a coherent intellectual lineage. Simon's recognition of cognitive limits prompted a shift from optimization to procedural intelligence; Barzelay institutionalized this shift as a design discipline in public management; and complexity science now provides the computational and participatory infrastructure to enact it in practice.

Together, they advance a vision of policy-making as adaptive design under constraint: an iterative, feedback-driven, and context-sensitive process of sense-making and intervention in complex systems. Rather than abandoning rationality, this evolution redefines what it means to act rationally under uncertainty—transforming policy design into a science of learning within complexity.

3 Methodology

This section presents our methodology for tracking the impact of complexity science and its methods on public policy. First, we describe the data construction process and present descriptive insights. Second, we analyze these metrics and outline our analytical approach for subsequent sections.

3.1 Core Corpus Construction

To construct a representative corpus of complexity science literature, we employed a multi-stage filtering approach informed by network analysis. We began with a seed corpus comprising all publications authored by researchers affiliated with three prominent complexity science institutions: the Santa Fe Institute, the Vermont Complex Systems Center, and the Complexity Science Hub Vienna. These publications and their metadata were retrieved from the OpenAlex database.

From this seed corpus, we extracted all cited references, yielding an initial candidate set of approximately 10,000 publications. We applied an initial citation threshold, retaining only works cited at least three times by the seed corpus to ensure a baseline level of relevance to complexity science research.

To systematically reduce this set while preserving the field's intellectual structure, we constructed a bibliographic coupling network in which nodes represent publications and edge weights reflect co-citation frequency—specifically, how often two papers were cited together by works in the seed corpus. We then applied two network-based filtering criteria. First, we retained only the M strongest connections for each node (where M represents the maximum number of edges per node), which reduces network density while preserving the most important relationships and removing isolated nodes. Second, we applied k-core decomposition, a standard graph-theoretic technique that recursively removes nodes with fewer than k connections until all remaining nodes have at least k neighbors, thereby extracting the densely interconnected core of the network (see section A.1 for more details.).[2]

3.2 Descriptive Statistics of the Co-Citation Network

The resulting co-citation network comprises 5,252 publications connected by 80,045 edges, with an overall network density of 0.0058 (Figure A.2). The network exhibits full connectivity, primarily as a result of the process followed to obtain the "gold standard" core of complexity science, though it still shows a low density, characteristic of citation networks where authors cite selectively.

The degree distribution reveals substantial heterogeneity, with an average degree of 30.34 but a maximum of 626, suggesting the presence of highly influential hub publications that serve as common references across multiple research streams (Figure A.4).[3] The minimum degree of 3 reflects our k-core filtering criterion. Edge weights, representing co-citation frequency normalized by the bibliographic coupling measure, average 0.36 with a maximum of 1.0, indicating that while most publication pairs share only a modest proportion of common citations, some exhibit nearly identical citation patterns, signaling tightly coupled research subdomains or methodological clusters.

[2] The parameters M and k were not predetermined but rather selected iteratively through community detection analysis. Specifically, we tested various parameter combinations and evaluated their ability to preserve both the field's major thematic communities (identified through modularity-based clustering) and a set of highly influential "gold standard" papers (identified through network centrality measures). This procedure yielded a refined core corpus of approximately 5,000 publications that capture the essential literature of complexity science while maintaining computational tractability for bibliometric analysis.

[3] The node with the highest degree is *Emergence of Scaling in Random Networks*[Barabási and Albert, 1999] followed by *Collective Dynamics of 'Small-World' Networks*[Watts and Strogatz, 1998] and *Statistical Mechanics of Complex Networks*[Albert and Barabási, 2002], all highly influential papers in the field of complexity science.

3.3 Policy Impact Measurement

To analyze the policy and public engagement impact of the complexity science core corpus, we integrated bibliometric data from two complementary sources. OpenAlex provided comprehensive academic metadata including citation counts, author affiliations, institutional networks, journal information, referenced works, and SDG (Sustainable Development Goals) classifications. Altmetric supplemented this with alternative impact indicators, including policy document mentions, mainstream media coverage (news outlets, blogs, videos, podcasts), social media engagement (Twitter, Facebook, Reddit), and additional scholarly metrics (Mendeley readership, peer reviews, Wikipedia mentions). Altmetric data were retrieved via API using DOIs from the 5,252 deduplicated OpenAlex records as query parameters. This yielded 3,652 matched records (69.53% coverage), with the match rate determined by DOI availability in the Altmetric database.[4]

The merged dataset enables comparative analysis of academic versus policy impact, identification of papers with disproportionate policy influence relative to academic citations, and examination of how complexity science research propagates through different dissemination channels.

4 Results

The merged OpenAlex-Altmetric dataset (N=3,652) reveals substantial heterogeneity in both academic and alternative impact indicators for complexity science publications. The "Golden Standard" literature in complexity science shows strong coverage with median academic citations of 372 in OpenAlex and 315 in Altmetric and mean citations of 1,620 and 1,292, which reflects the well-studied power law in academic citations documented in the literature [Redner, 1998], with high variability (SD>4,500) (See Figure A.3 for the Zipf plot for the citations and co-citations in the network). Among alternative metrics, Mendeley readership shows the highest penetration (98.7% of papers, mean=728), followed by mentions in Twitter/X (64.3%, mean=63.4), Wikipedia (45.6%, mean=3.6), mainstream media (30.7%, mean=7.9), patents (23.3%, mean=8.7), Facebook (17.4%, mean=0.8), Bluesky (8.0%, mean=0.3), and Reddit (5.0%, mean=0.2). **Policy impact remains concentrated, with only 32.8% of papers mentioned in policy documents (mean=4.6)** (See Table A.1).

All indicators exhibit substantial right-skewness, with means consistently exceeding medians. This pattern suggests that impact—whether academic or societal—concentrates

[4] Both datasets underwent internal deduplication using normalized DOIs (removing URL prefixes, standardizing format). For the small subset of papers where API retrieval succeeded but records lacked DOIs or contained duplicates in the Altmetric data, title-year matching with aggressive text normalization (lowercasing, punctuation removal, whitespace standardization) was applied as a fallback. Post-merge validation confirmed no duplicate entries in the final dataset.

heavily in a small subset of highly influential papers, consistent with the well-documented Matthew effect in scholarly communication [Teixeira da Silva, 2021].

4.1 Divergent Pathways of Scholarly and Policy Impact

There exists a divergence between academic influence and policy/media engagement. Papers achieving the highest academic citations are predominantly focused on methodological and research tools, with 7 out of 10 top papers focused on bioinformatics and molecular biology, while three of the top ten papers focused on theoretical approaches to behavior, communication, and management. In contrast, the top policy-cited papers center on economics and behavioral decision-making, particularly Prospect Theory, agency theory, and financial economics. Only one paper, Jensen and Meckling [1976]'s foundational work on the theory of ownership structure of the firm, appears in both the academic and policy top-10 lists. This paper's dual prominence reflects its integration of rigorous economic modeling—synthesizing the theory of agency, the theory of property rights, and the theory of finance—with directly actionable implications for corporate governance and regulatory design through mathematical formalization of principal-agent relationships. (See Figure A.5)

Interestingly, mainstream media coverage demonstrates near-complete temporal clustering, with all top-10 media papers published in 2020 addressing COVID-19 transmission dynamics and epidemiological modeling, papers that have far fewer academic citations despite their immediate societal relevance. This underscores that academic impact, policy influence, and public attention tend to operate as uncorrelated dimensions of scholarly impact.

Top papers cited in policy articulate clear, portable mechanisms that simplify complex phenomena into intelligible causal structures. Examples include loss aversion in Prospect Theory [Kahneman and Tversky, 1979], liquidity-driven equilibria in bank run dynamics [Diamond and Dybvig, 1983], or weak ties as bridges for information diffusion [Granovetter, 1973]. Such mechanisms balance simplicity with explanatory power, enabling policymakers and practitioners to reason about systems without requiring full formal expertise.

These influential works share key characteristics. First, they provide general-purpose analytical tools rather than domain-specific prescriptions. The Fama–French risk factors [Fama and French, 1993], the Reflection Problem in econometrics [Manski, 1993], and the Product Space framework for economic development [Hidalgo et al., 2007] operate as reusable analytical architectures applicable across governments, industries, and social systems. This portability mirrors the adaptability of core complexity science tools—agent-based models, network analysis, systems mapping—which gain value by creating "trading zones" between different scientific communities [Grauwin et al., 2012], facilitating interdisciplinary knowledge transfer. Second, they illuminate nonlinearities, interdependencies, and emergent dynamics that conventional linear models overlook. Credit Cycles [Kiyotaki and Moore, 1997] reveals amplification mechanisms in financial systems through collateral constraints, while Weak Ties [Granovetter, 1973] demonstrates how local relational structures shape macro-level information diffusion patterns.

The top 10 papers cited in policy documents (see Figure A.5) cluster into four distinct methodological approaches: (1) Behavioral Decision-Making Under Uncertainty; (2) Endogenous Instability in Financial and Organizational Systems; (3) Networks, Social Interactions, and Structure-Induced Outcomes; and (4) Planetary Systems and Global Thresholds. These clusters reflect different modes of translating complexity science insights into policy-relevant frameworks.

4.2 Key Topics of Policy-Relevant Complexity Science

Figure A.6 presents the network of primary fields for papers in the analyzed corpus, where node size represents the number of papers within each field and edge width indicates the relative co-occurrence of two fields in the same paper. Green nodes denote fields where the share of academic citations exceeds the share of policy citations. The network reveals that Biochemistry, Genetics, and Physics & Astronomy are the most represented fields in the corpus with greater academic importance, followed by Economics, Social Sciences, and Environmental Sciences that have a higher citation share in the policy domain. The high connectivity of the network underscores the multidisciplinary nature of the Complexity Science "Golden Standard."

Figure A.8 and Figure A.7 display keyword co-occurrence networks for the whole corpus and policy-cited papers respectively, with node size indicating frequency, edge width representing co-occurrence strength, and colors identifying communities detected through modularity maximization using the Louvain algorithm[5]. In the policy network, several distinct communities emerge: biology-related papers frequently co-occur with ecology, ecosystems, and genetics; computer science papers occupy a central position and co-occur with statistical physics and network analysis; economics and business papers cluster with sociology and mathematics; while psychology and anthropology form a less common community. In contrast, the academic network reveals three main communities: a central biology cluster related to ecology, evolution, genetics, and virology; a computer science community associated with methods such as statistical physics and mathematics; and a socioeconomic network encompassing economics, business, psychology, and cognitive sciences.

Figure A.10 presents a ranking comparison of the top 20 topics by citations in the whole Complexity Science corpus versus policy-related citations. This graph shows that

[5]Which partitions the network to maximize the density of edges within communities compared to edges between communities

Economic Theories and Models, Financial Markets and Investments, Experimental Behavioral Economics, and Opinion Dynamics and Social Influence are relevant topics in both the academic and policy fields, all ranking among the top 10 topics in both dimensions. Other topics with policy relevance that are more impactful in the academic field include Complex Network Analysis Techniques and Evolutionary Game Theory and Cooperation.

4.3 Policy Effectiveness Index and the Sustainable Development Goals

The 2030 Agenda for Sustainable Development recognizes that the most urgent global challenges requiring solutions for a sustainable and prosperous future are inherently complex, multidimensional, and highly interconnected. Achieving these goals necessitates integrated strategies: ending poverty and other deprivations must proceed in tandem with improvements in health and education, reductions in inequality, and sustained economic growth, all while addressing climate change and preserving oceans and forests in the middle of a pressing environmental crisis.

Studying and offering solutions for these interconnected challenges represents an application domain for complexity science. In this section, we analyze how complexity science has engaged with the Sustainable Development Goals (SDGs) and assess its impact on policy and public discourse.

Figure 1 presents the citation network for complexity science papers with SDG classifications, where node size indicates policy impact on a logarithmic scale. Edges are directed from citing papers to cited papers. Figure 2 displays two complementary visualizations: the left panel shows a bar chart of the Policy Effectiveness Index (PEI) by SDG, defined as:

$$PEI = \frac{\text{Policy citations share}}{\text{Academic citations share}} \tag{1}$$

The right panel of Figure 2 presents a scatter plot of each SDG's relative share within the Complexity Science corpus against its share of total policy citations. This visualization reveals that most SDGs with PEI values below 1 represent relatively small shares of the Complexity Science corpus (under 4 percent each), with only Good Health and Well-Being and Life on Land accounting for shares between 8 and 12 percent.

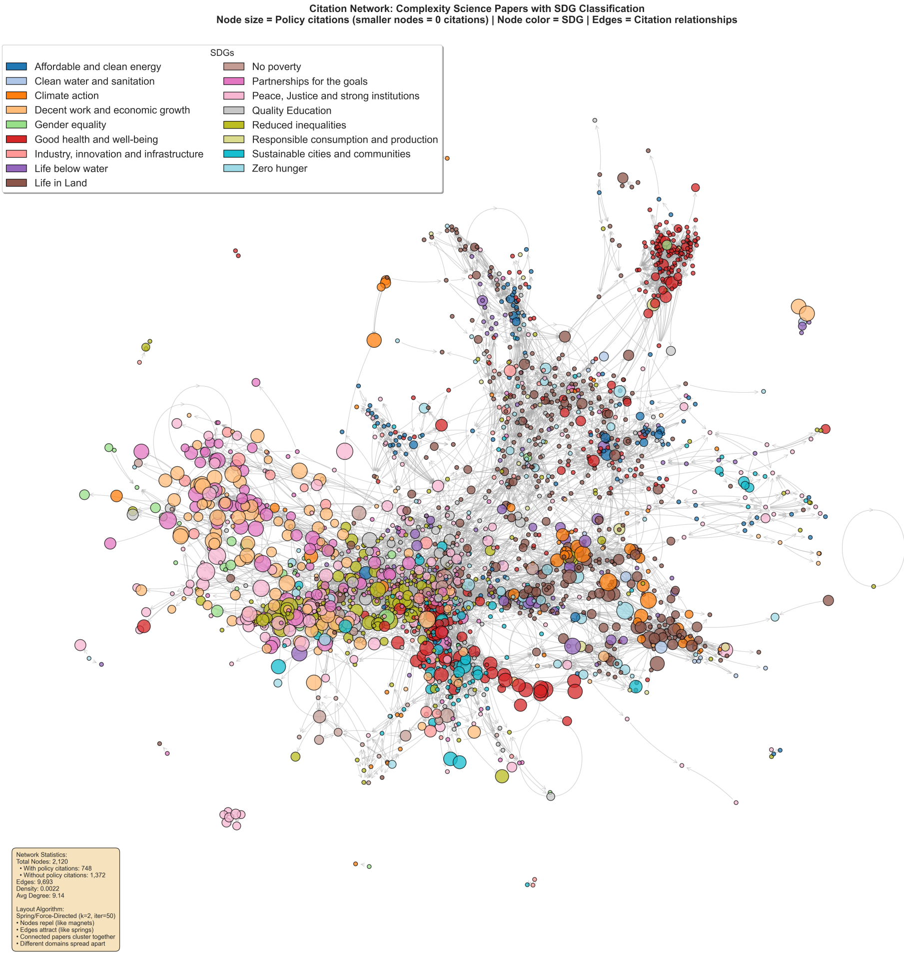

Figure 1: Citation Network in Complexity Science for Papers with SDG Classification
Source: Own construction using OpenAlex and Altmetric bibliometric data. Formula for node size: $100 + log(1 + policy_cites)150$

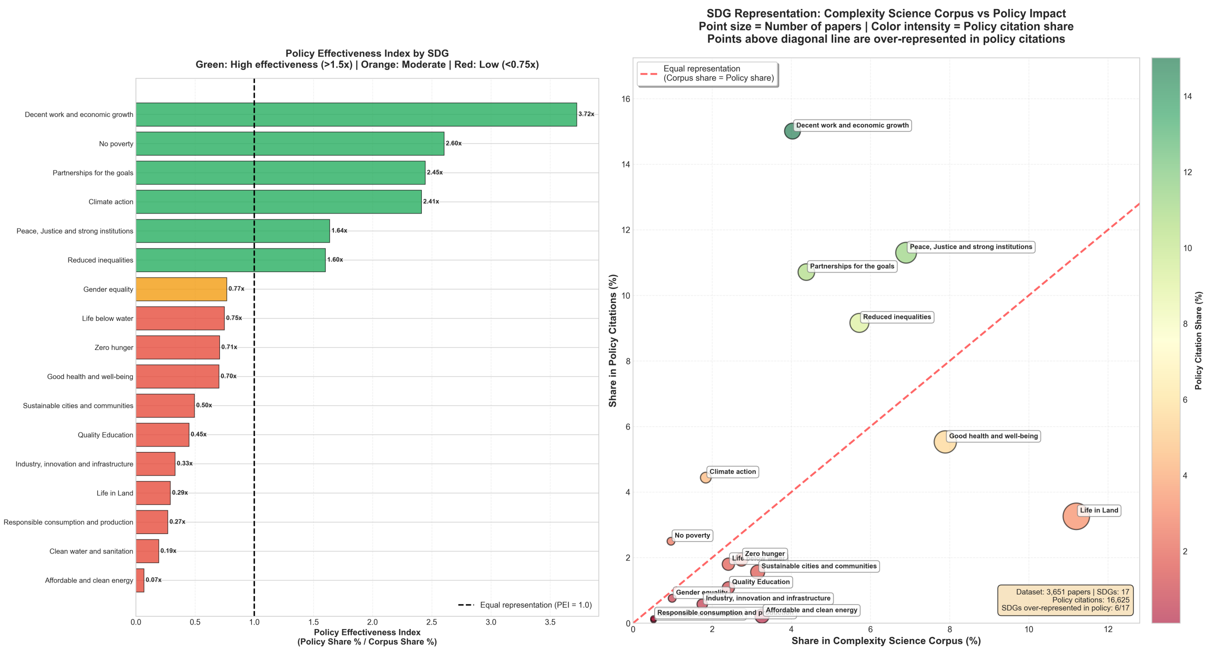

Figure 2: Policy Effectiveness Index
Source: Own construction using OpenAlex and Altmetric bibliometric data.

As discussed in subsection 4.1, the impact of academic papers can be quite heterogeneous in the policy, academic, and media domains. Figure 3 presents the normalized impact profile of the papers within each SDG by their impact in each of these domains.[6] This heatmap shows that while the most impactful SDGs in policy citations are those related to socioeconomic prosperity (Decent Work and Economic Growth and No Poverty), Quality Education and Reduced Inequalities are the most impactful in the academic field. In contrast, the most impactful SDGs in the media domain are Good Health and Well-Being and Gender Equality. Nevertheless, as shown in Figure A.11, academic production within Complexity Science seems to be highly correlated with the potential general impact, as the SDGs with more written papers are those with higher general impact when accounting for total mentions in academic papers, policy-related literature, and other media.

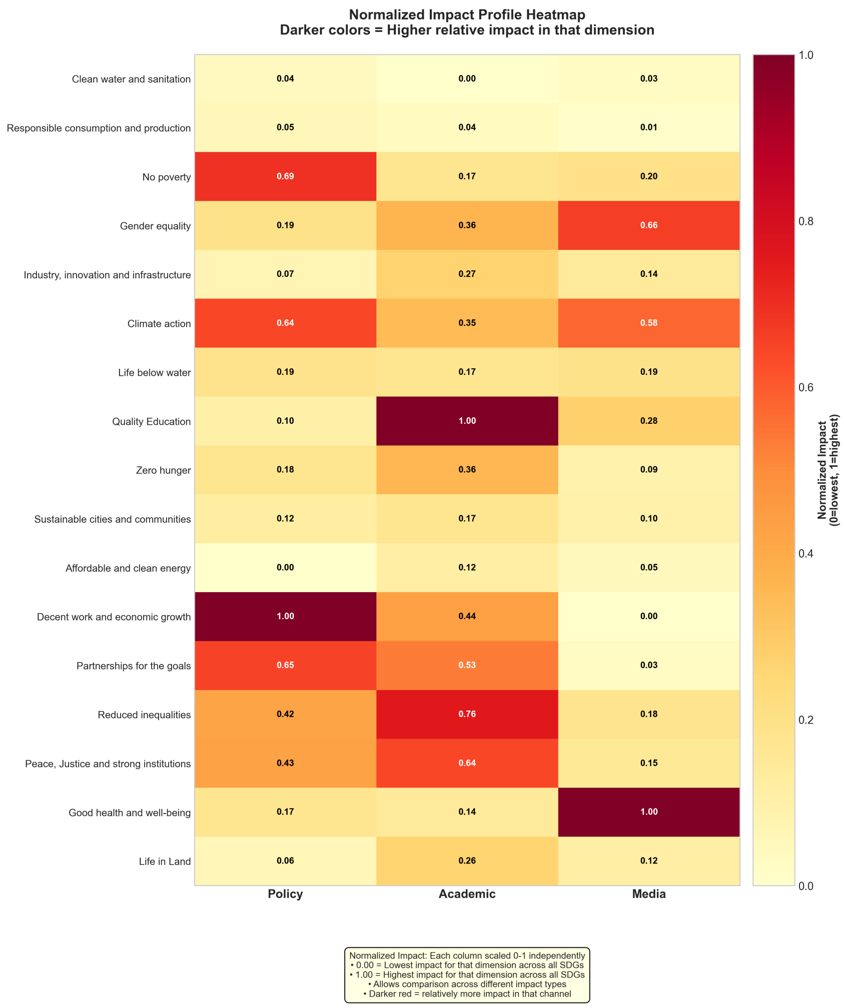

Figure 3: Heatmap of normalized impact
Source: Own construction using OpenAlex and Altmetric bibliometric data. Formula for node size

[6]The normalization sets the lowest impact for the given impact dimension across SDGs to 0.00 and the highest impact for that dimension across SDGs to 1.00.

4.4 Complexity Science Is Also Concentrated Institutionally and Geographically

Figure 4 presents an institutional collaboration network for papers cited in policy documents. Nodes represent institutions to which paper authors were affiliated, and edge width indicates the number of collaborations between institutions. Node size corresponds to the total number of papers associated with each institution, while node color represents betweenness centrality—a measure of how frequently an institution serves as a bridge connecting other institutions in the network.

The network reveals that leading institutions producing policy-cited complexity science research are heavily concentrated among top US universities and research centers, particularly the Santa Fe Institute (which exhibits the highest betweenness centrality), Harvard University, and Stanford University. The visualization further demonstrates that most visible nodes in the network are based in the Global North, highlighting significant geographical concentration in the field's policy-relevant research output.

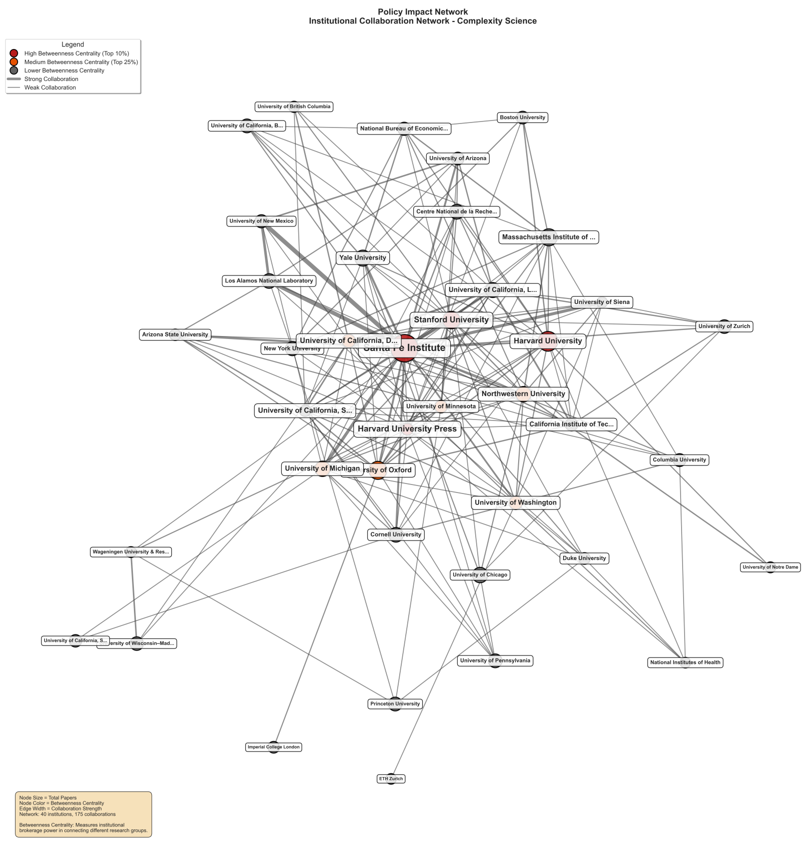

Figure 4: Institutional Collaboration Network for Policy Cited Papers
Source: Own construction using OpenAlex and Altmetric bibliometric data.

Figure 5 presents a country-level collaboration network for papers cited in policy documents. Nodes represent the countries of author affiliation, and edge width indicates the number of collaborative papers between countries. Node size corresponds to the total number of policy-cited papers associated with each country, while node color represents betweenness centrality—measuring how frequently a country serves as a bridge connecting other nations in the collaboration network.

The network reveals that policy-cited complexity science research is heavily concentrated in the United States and Western Europe, with the US and United Kingdom exhibiting the highest betweenness centrality values. The visualization demonstrates strong collaborative clusters among North American and European countries, while nations from other regions occupy more peripheral positions with fewer connections. This pattern underscores the significant geographical concentration of policy-relevant complexity science research in the Global North.

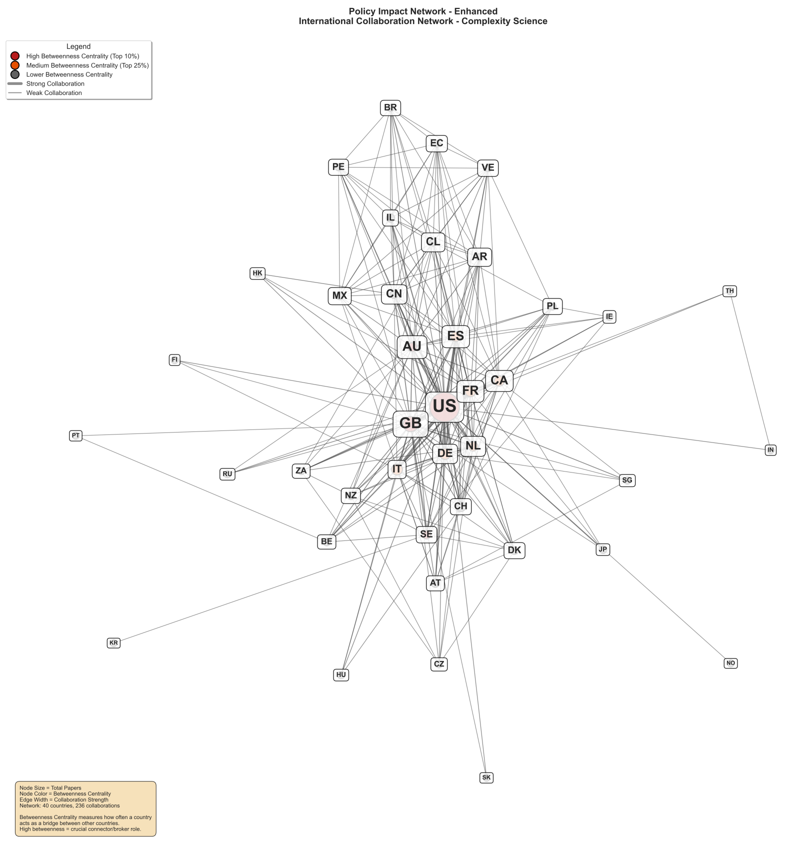

Figure 5: Collaboration Network for Policy Cited Papers by Country
Source: Own construction using OpenAlex and Altmetric bibliometric data.

5 Discussion: Reflections and Challenges

This section discusses the results presented previously and highlights some of the most interesting findings. This paper presents an exploratory approach to studying the impact of complexity science on policy and media. Building from concepts of bounded rationality, design-oriented policymaking, and complexity-driven adaptive capacity, we showcase the impact of complexity literature—pioneered by the Santa Fe Institute and two other complexity science institutions—across policy, media, and academic domains.

Delving deeper into our results, we identify interesting emerging patterns. Figure

A.11 suggests a strong positive correlation between the overall impact by SDG (summing academic, policy, and media citations) within Complexity Science and the total papers related to each SDG. In other words, academic production by SDG appears highly correlated with its potential impact. Nevertheless, as discussed in section 4, the effectiveness of complexity science in penetrating policy is quite heterogeneous.

First, SDGs tied to governance, shared prosperity, and ecosystems demonstrate the strongest policy penetration (e.g., Decent Work and Economic Growth; Peace, Justice and Strong Institutions; and Climate Action), with higher representation in the policy domain than in the academic domain. Second, SDGs dominated by more technical topics (e.g., Good Health and Well-Being and Life on Land) may have substantial academic production but lower policy citation rates, as these tend to be highly technical papers discussing subjects such as biochemistry or virology with policy and practical implications that are difficult to communicate. These papers tend to be related to laboratory work or highly technical models. Despite their high representation in complexity science, they have weak policy penetration.

When analyzing the top 10 papers associated with the SDGs Good Health and Well-Being and Life on Land, we note these papers articulate complexity in terms of emergent states, networked interactions, thresholds, and feedbacks. They employ sophisticated methods such as network modeling, temporal and spatial dynamics, and evolutionary theory, providing powerful insights into relevant phenomena that enrich the conceptual foundations of complex-systems thinking. Yet, despite their high academic citation counts, they exhibit limited direct influence on policy, partly because their insights remain at a theoretical scale and their policy implications are difficult to grasp. Many operate at the level of molecular or microbial systems (in the case of Good Health and Well-Being) or abstract ecosystem models (in the case of Life on Land). Policymakers usually require population-level models, clear intervention pathways, and actionable indicators—elements that are lacking in these papers. Some studies explicitly note gaps between their scientific models and management or policy applications [Rietkerk et al., 2004].

Although these studies provide rich theoretical insights, they lack the translation layer that would establish actionable metrics for integration into policy frameworks. This translation gap—beyond the research content itself—may explain the limited penetration into policy citations of highly academically cited papers, despite their conceptual relevance for SDG targets.

As shown in Figure 3, media coverage heavily focuses on SDG Good Health and Well-being. This aligns with previous research on media coverage and scientific quality during the pandemic. Mach et al. [2021] documented the increase in news outlet reporting in 2020 and analyzed the scientific quality across different outlets in the political spectrum. They found that scientific quality was particularly low—especially regarding validity, precision, and context—among populist-right outlets in the countries analyzed.

Among the top 10 most policy-cited papers, we observe key aspects of complexity successfully translated into easy-to-communicate and policy-relevant research. Tversky and Kahneman [1974] identified three core heuristics that shape judgments under uncertainty, marking a shift away from assumptions of full optimization toward a framework grounded in bounded rationality and adaptive decision-making. By replacing the idealized rational actor with empirically observed cognitive processes, their work enabled governments to design more effective, complexity-aware policies in domains such as taxation, environmental regulation, and financial oversight.

Moreover, papers such as the influential "The Strength of Weak Ties" by Granovetter [1973] introduce an easy-to-communicate and interesting finding using complex network dynamics analysis: weaker social connections are more valuable than strong ones for accessing novel information and opportunities, such as finding a new job. This insight, while intuitive upon reflection, has had substantial impact on how negotiations and policymaking are conducted.

Hidalgo et al. [2007] apply network dynamics to demonstrate network constraints and structural barriers in the context of "product space"—the specialization patterns across different development levels among countries. In other words, this work uses complexity science methods to understand how countries produce the products they trade: highly technological products are produced in the core, while less sophisticated products are produced in the periphery, explaining why developing countries struggle to build more competitive export portfolios.

These three examples showcase how these papers draw clear and relevant results for policy analysis and policymaking. Complexity science represents not only a set of analytical tools but also a framework for structuring policy reasoning under uncertainty, interdependence, and bounded rationality. The methods and conceptual architectures that made these top papers influential mirror the qualities that enable complexity approaches to meaningfully inform policy design.

6 Limitations and Potential Next Steps

This work explored the impact of complexity science on policy research. Although we discovered interesting insights regarding how different complexity concepts translate into policy applications, this work has several important limitations.

Although we successfully constructed the complexity science corpus using metadata and citation metrics from OpenAlex and Altmetric, this process required considerable time. Consequently, further work could investigate these results more deeply to characterize not only how this corpus influences policy literature through citations, but also how this cited knowledge is actually used in policy, whether as mere proposals and ideas or as the foundation for actionable interventions and key components of policy design.

Additionally, like any bibliometric work, this study is limited by the constraints of the datasets employed. We plan to test the robustness of our findings by retrieving metadata from other policy-specialized datasets, such as Overton.

Moreover, further stages of this work could develop typologies to guide policymakers on how to best apply complexity science methods throughout the policy cycle. Specifically, it would be valuable to examine how different complexity science concepts permeate different policy stages—such as ideation, design, implementation, and evaluation—and how this process could be optimized through a policy implementation guideline or handbook for complexity science. Additionally, we plan to conduct a more rigorous analysis of the properties of the co-citation and bibliographic coupling networks derived from our complexity science corpus. The current analysis is primarily descriptive, and exploring network properties (such as propagation dynamics) represents a promising avenue for future research.

Another limitation concerns the methodology used to construct the "Golden Standard" corpus in complexity science, which relates to the institutional and geographical concentration findings in our work. Our seed corpus was intentionally built from papers available in OpenAlex authored by scholars from the Santa Fe Institute, the Vermont Complex Systems Center, and the Complexity Science Hub Vienna. This selection may have concentrated the papers citing them in the Global North, which represents the academic and geographic area most exposed to these institutions' work.

Finally, we identified several fields and subfields where complexity science has gained influence in the policy domain. However, given the structure of the dataset, more careful analysis is needed to identify which specific complexity science methods (and not necessarily just concepts) most permeate policy, as these two dimensions are currently conflated in our dataset.

7 Conclusion

This study systematically mapped the intersection between complexity science research and public policy impact. By integrating co-citation network analysis with policy mention data and SDG classifications, we find that academic influence and policy impact operate as divergent dimensions of scholarly influence. Our proposed Policy Effectiveness Index reveals substantial heterogeneity across SDGs, with papers addressing socioeconomic prosperity and governance (Decent Work and Economic Growth, Peace and Justice, Climate Action) achieving higher policy penetration than technically specialized domains like molecular biology and ecology (associated with Life on Land and Good Health and Well-Being SDGs), despite the latter's strong academic citations.

The most policy-influential papers are characterized by accessible, policy-relevant research addressing decision-making and frameworks for structuring policy reasoning under uncertainty, interdependence, and bounded rationality. In contrast, papers with limited policy impact tend to focus on highly technical and specialized topics with difficult-to-communicate policy implications.

These findings underscore that successful policy translation of complexity science requires more than methodological sophistication—it demands clear, portable mechanisms that balance simplicity with explanatory power. Papers that effectively bridge the research-policy divide articulate intelligible structures applicable across contexts. However, significant challenges remain: geographic and institutional concentration of complexity science production and policy penetration in the Global North, translation gaps between technical insights and actionable policy frameworks, and the need for rigorous typologies guiding complexity method application throughout policy cycles. This research provides actionable insights for scholars seeking to maximize policy impact and for policymakers navigating complexity science approaches under conditions of bounded rationality and systemic uncertainty.

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A Appendix

A.1 Parameter Tuning

To systematically evaluate the impact of network filtering parameters on corpus quality, we tested all combinations of m (maximum edges per node, ranging from 4 to 11) and k (k-core threshold, ranging from 2 to 5). For each parameter combination, we measured three key metrics: the resulting number of nodes (network size), modularity (quality of community structure, ranging from 0 to 1), and gold standard coverage (fraction of highly influential papers retained, ranging from 0 to 1). Figure A.1 presents heatmaps visualizing how these metrics vary across the parameter space. Lower values of m and higher values of k produce smaller, more selective networks, while the inverse produces larger networks. The systematic exploration of this parameter space informed the selection of filtering thresholds that balanced network size, preservation of thematic structure, and retention of influential publications as reported in Section 3.

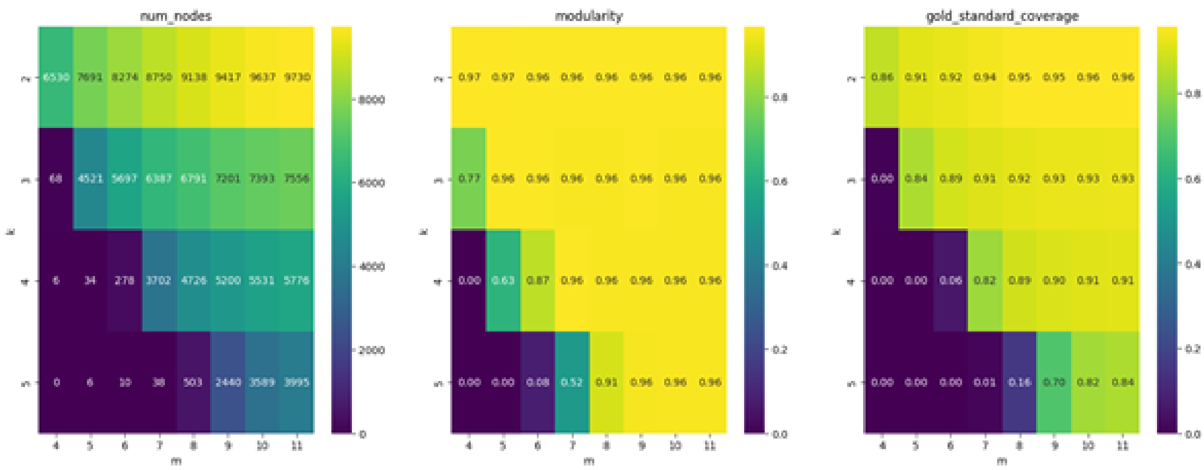

Figure A.1: Parameter tuning analysis for network filtering.
Heatmaps show the effect of varying m (maximum edges per node) and k (k-core threshold) on three key metrics: number of nodes (left), modularity (center), and gold standard coverage (right). Darker colors indicate lower values, while brighter colors indicate higher values for each respective metric.

A.2 Co-Citation Network

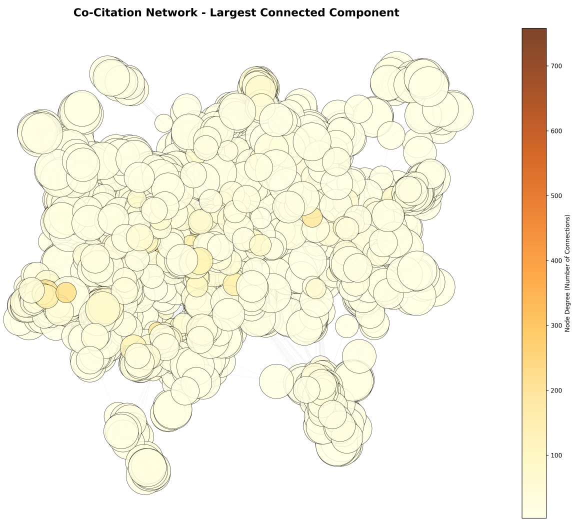

Figure A.2: Co-citation network visualization of the complexity science core corpus.
Node size represents the average weight between the node and all its neighbors; node color represents node degree.

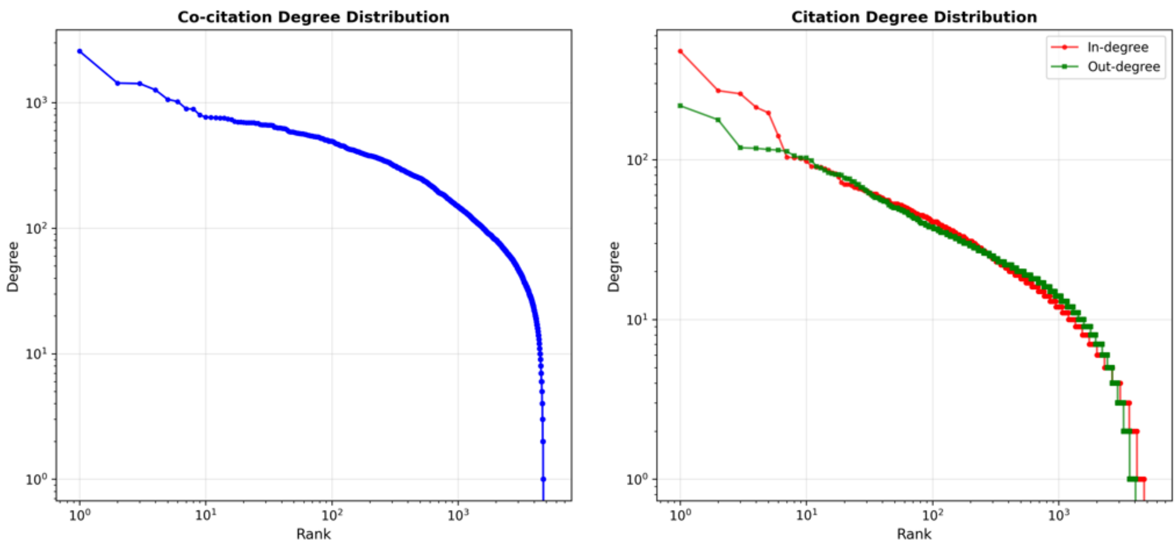

Figure A.3: Zipf plot of the degree (number of citations or co-citations) versus rank within the complexity science core corpus.

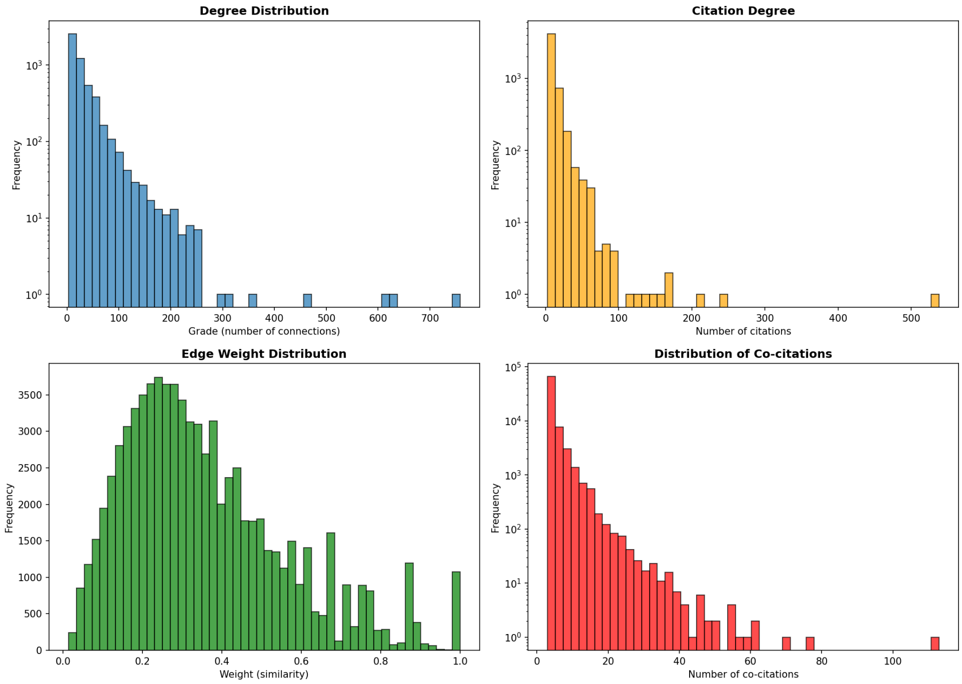

Figure A.4: Distributional properties of the co-citation network:
(a) degree distribution, (b) citation degree distribution, (c) edge weight distribution, and (d) distribution of co-citations. Interestingly, the heavy-tailed degree distribution appears to show scale-free properties, characteristic of scientific citation networks.

A.3 Policy and Media Impact

Table A.1: Descriptive Statistics of Impact Indicators from Merged OpenAlex-Altmetric Dataset

Category	**Indicator**	**n>0**	**%>0**	**Mean**	**Median**	**SD**	**Q25**	**Q75**	**Q90**	**Q95**	**Total**
Academic	Citations (OA)	3,651	100.00	1,620	372	5,470	137	1,053	3,044	5,635	5,915,566
Academic	Citations (Alt)	3,625	99.29	1,292	315	4,553	117	857	2,472	4,441	4,716,715
Academic	Peer Reviews	25	0.68	0.02	0	0.9	0	0	0	0	87
Policy	Policy Mentions	1,199	32.84	4.6	0	21.7	0	1	7	18	16,625
Media	Mainstream Media	1,120	30.68	7.9	0	82.3	0	1	7	21	28,752
Media	Blogs	1,394	38.18	2.3	0	8.9	0	2	5	9	8,245
Media	Videos	216	5.92	0.2	0	1.3	0	0	0	1	567
Media	Podcasts	211	5.78	0.1	0	0.9	0	0	0	1	443
Social	Twitter/X	2,349	64.34	63.4	2	777.2	0	10	41	96	231,314
Social	Facebook	636	17.42	0.8	0	5.7	0	0	1	3	2,846
Social	Reddit	182	4.98	0.2	0	1.3	0	0	0	0	570
Social	Bluesky	291	7.97	0.3	0	2.1	0	0	0	1	940
Readers	Mendeley	3,602	98.66	728	222	2,581	76	580	1,448	2,566	2,656,582
Other	Wikipedia	1,665	45.60	3.6	0	21.9	0	3	8	15	13,036
Other	Q&A Sites	529	14.49	0.4	0	2.0	0	0	1	2	1,360
Other	Patents	849	23.25	8.7	0	141.1	0	0	6	19	31,794
Other	Guidelines	50	1.37	0.04	0	0.7	0	0	0	0	144

Note: N = 3,652 complexity science publications from merged dataset. OA = OpenAlex; Alt = Altmetric; SD = Standard Deviation; Q25/Q75/Q90/Q95 = respective percentiles. Academic citations show near-universal coverage (99-100%), while alternative metrics vary substantially in prevalence.

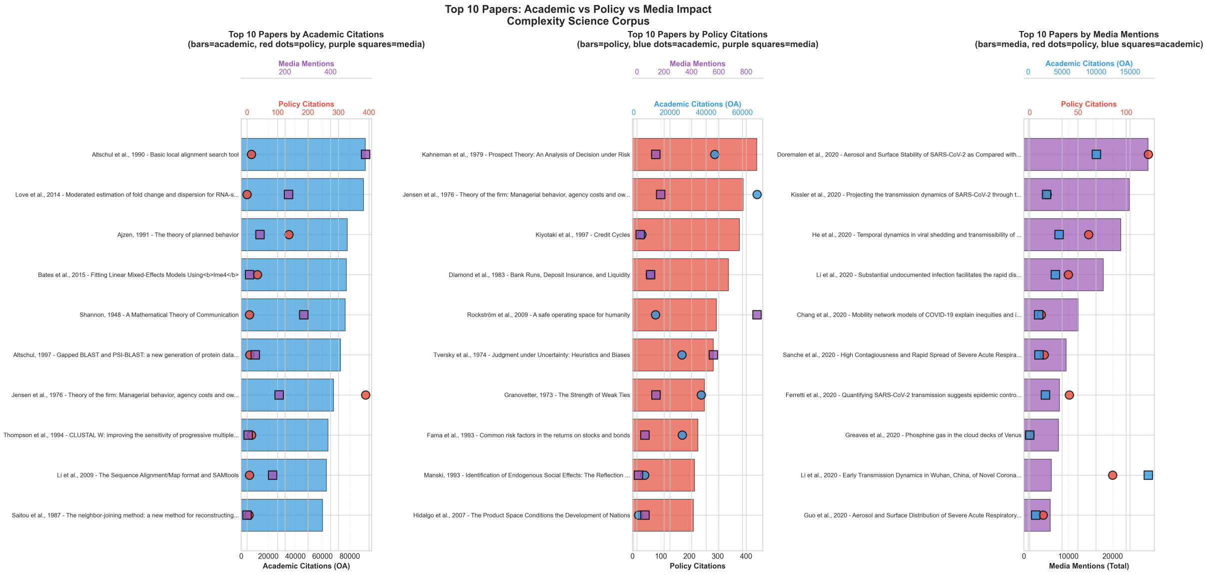

Figure A.5: Top 10 Papers in Academic, Policy and Media Citations.

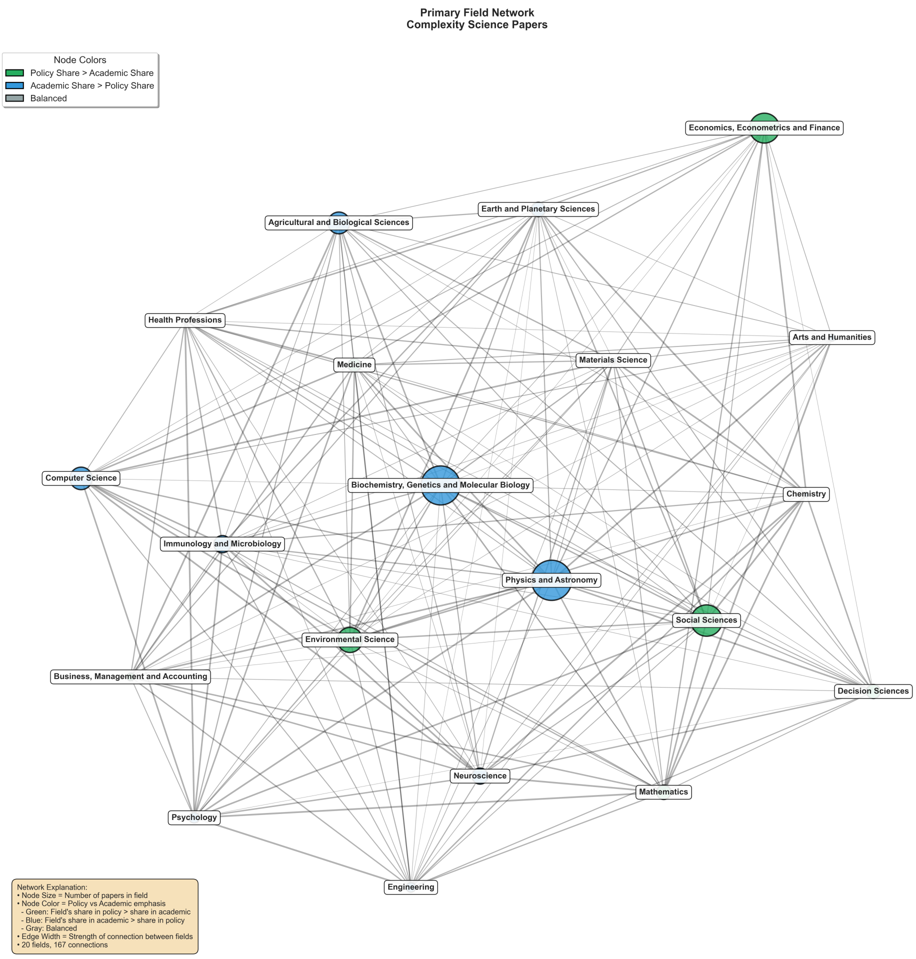

Figure A.6: Primary Field Network in Complexity Science

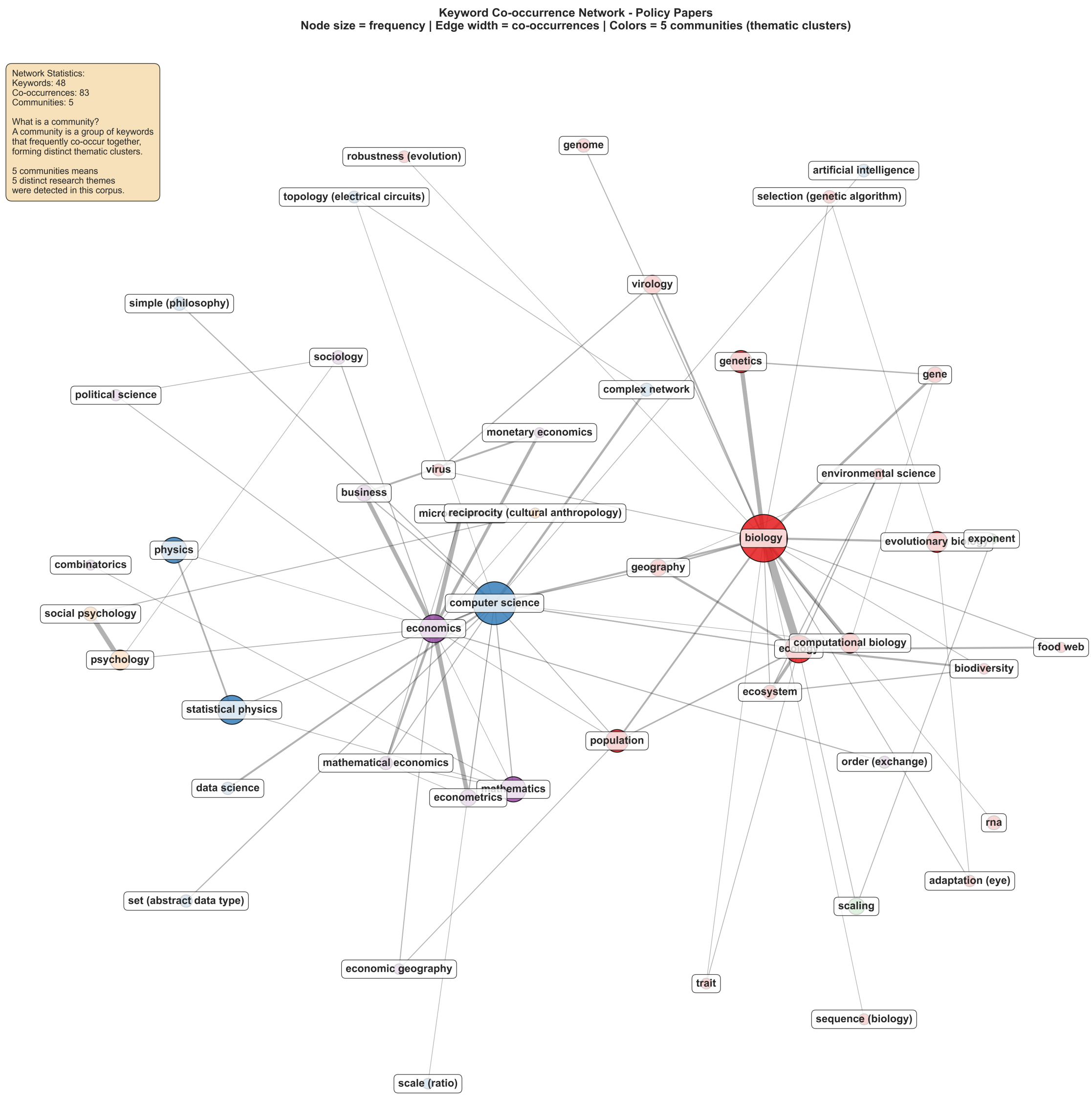

Figure A.7: Keyword co-occurrence in the Policy cited Complexity Science.

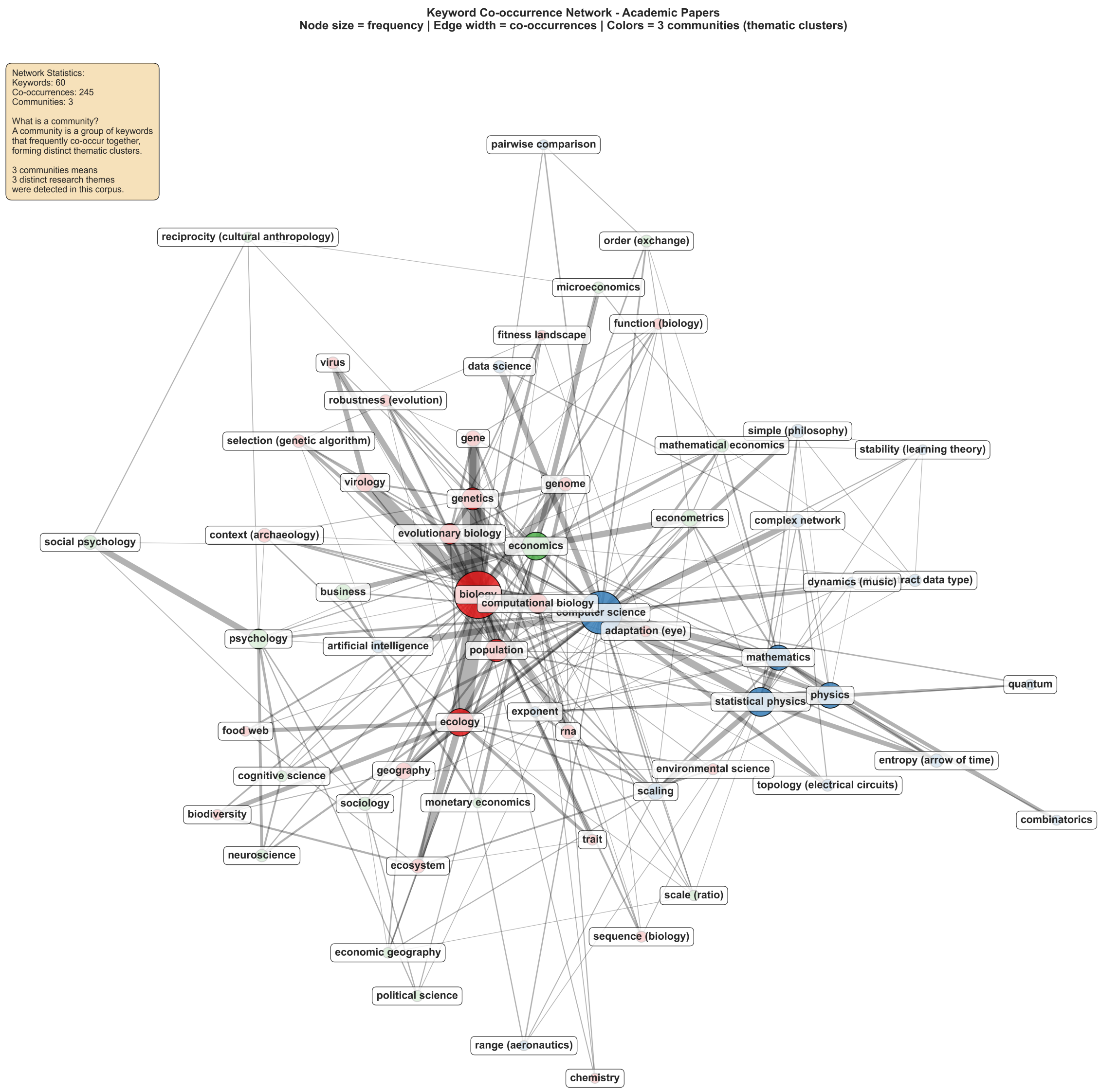

Figure A.8: Keyword co-occurrence in the Complexity Science Corpus.

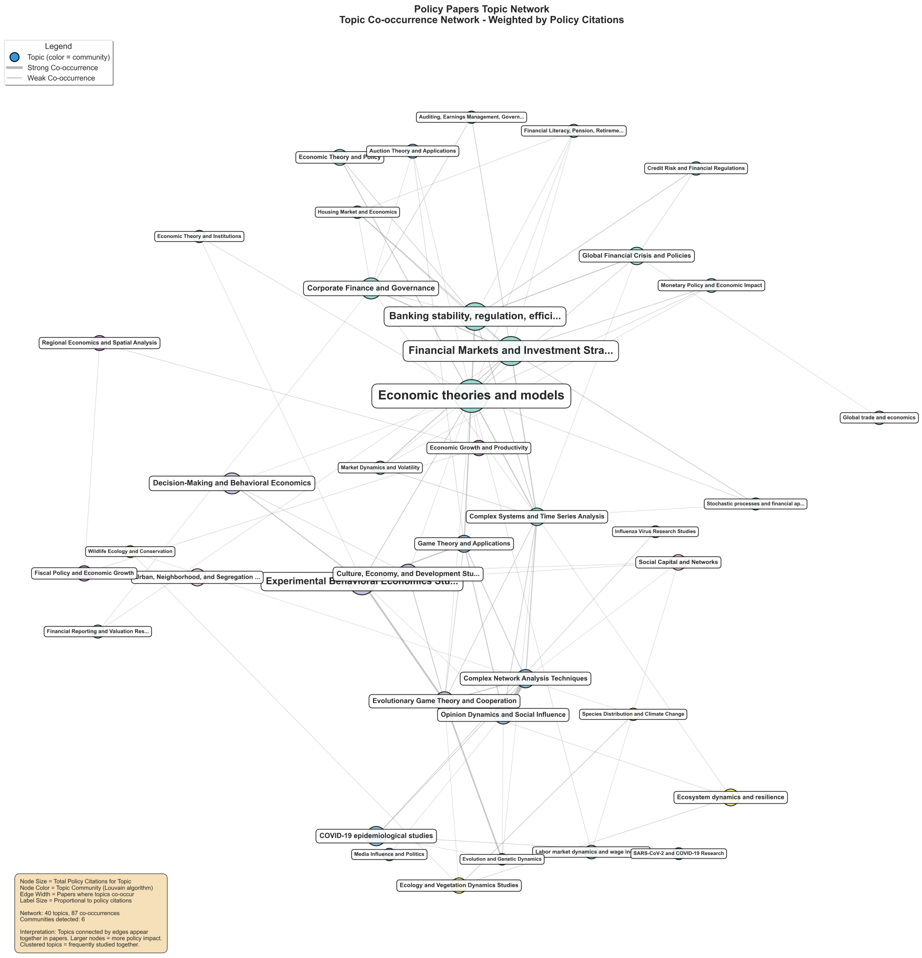

Figure A.9: Topic Co-occurence Network

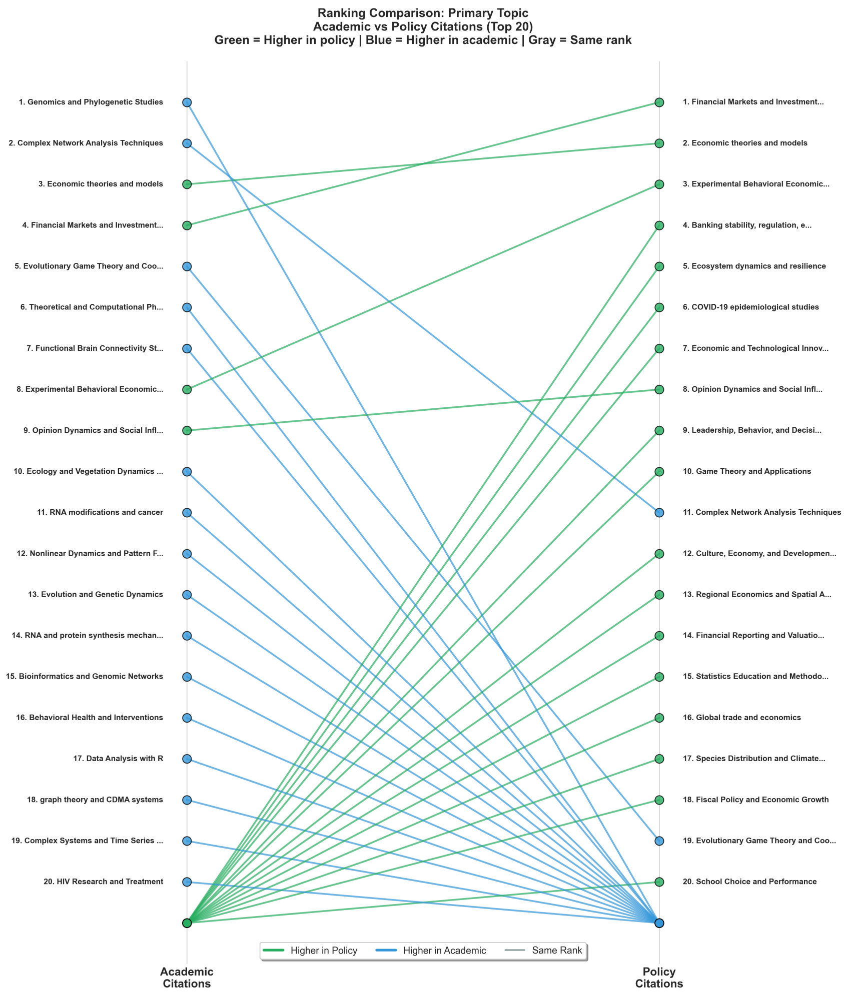

Figure A.10: Primary Topic Rank Comparison

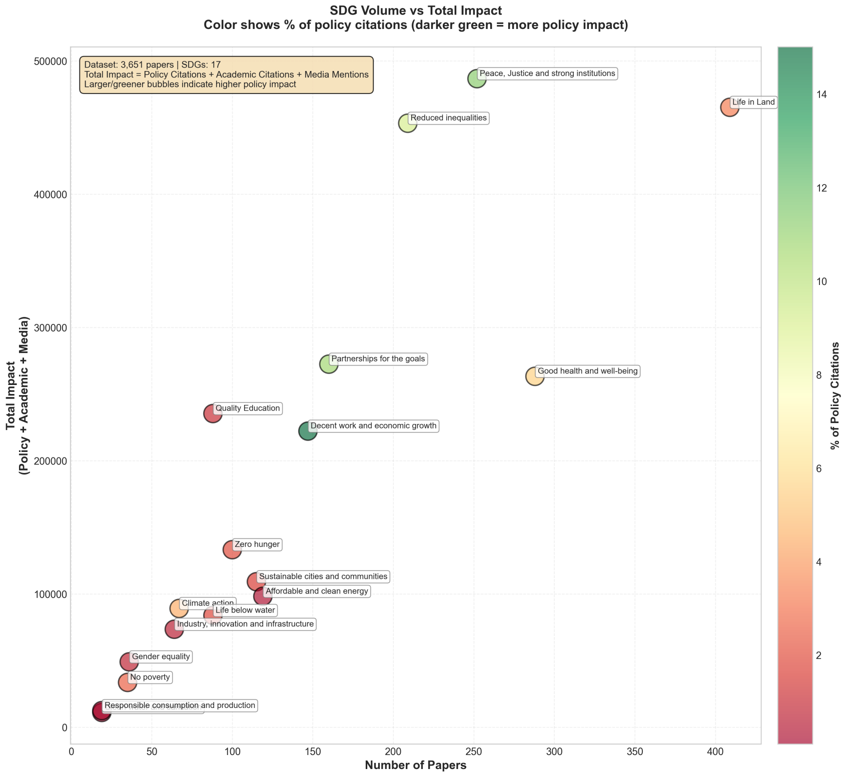

Figure A.11: General Impact by SDG

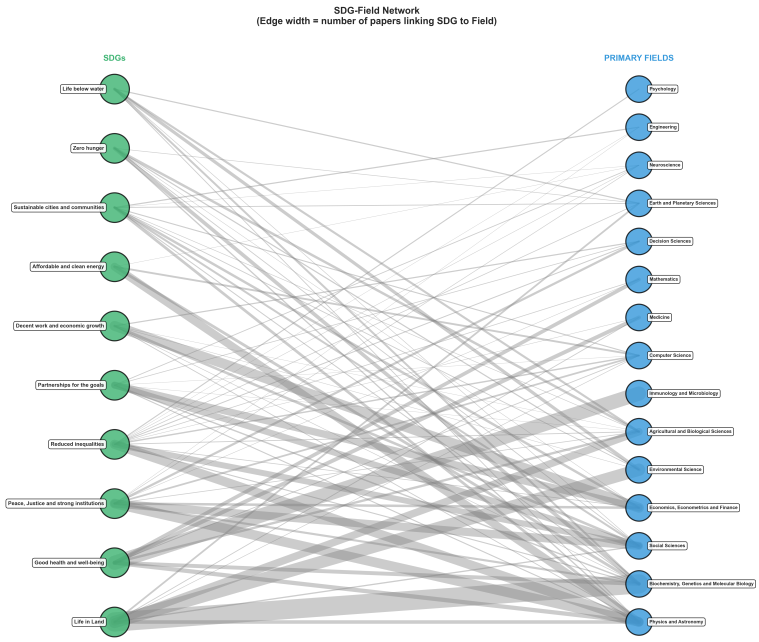

Figure A.12: SDGs-Field Network

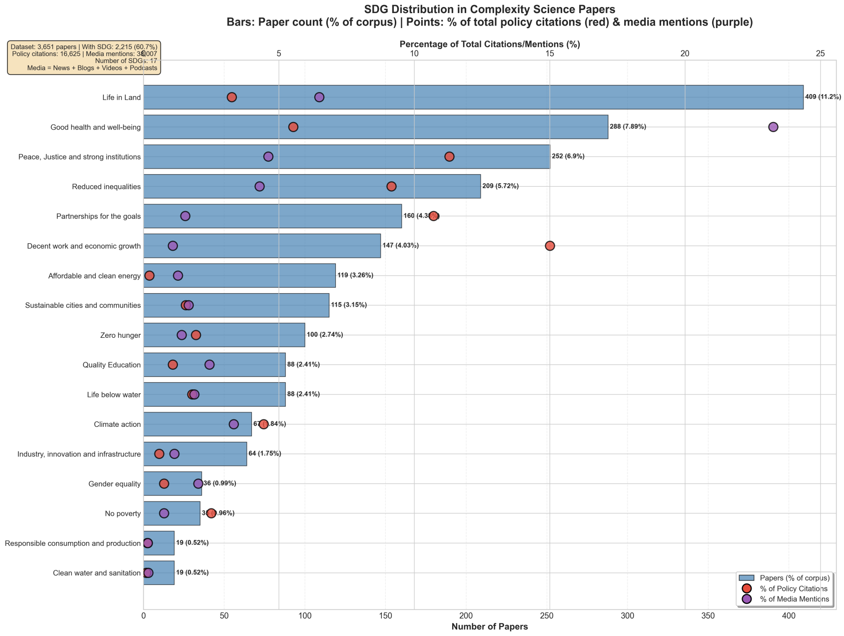

Figure A.13: SDGs distribution in Complexity Science Papers