Reconfiguring knowledge creation in decentralized science with blockchain

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ABSTRACT

The production of scientific knowledge remains largely governed by centralized infrastructures, which generate inefficiencies along the knowledge value chain, including information asymmetries, opaque validation processes, and limited accessibility. In this context, blockchain technology has emerged as a potential enabler of alternative coordination mechanisms, giving rise to Decentralized Science (DeSci). This paper investigates how blockchain reshapes the knowledge creation process through a combined qualitative and quantitative analytical framework. First, the DeSci ecosystem is mapped through a multilayer architecture that distinguishes blockchain infrastructures, protocols, and applications, with the latter further divided into a Research Layer and a Knowledge Layer, in order to identify how blockchain-enabled features affect different stages of the knowledge value chain. Second, the analysis introduces a network-based measurement approach to assess decentralization across DeSci platforms. Each project is modeled as a graph, and two complementary indicators are computed: a centralization index (C_x) and a decentralization index (D_x). The results reveal a heterogeneous landscape characterized by hybrid coordination structures. Projects in the Knowledge Layer tend to exhibit higher levels of centralization due to infrastructural and governance constraints, despite maintaining distributed interaction patterns. Overall, the findings show that blockchain does not eliminate centralization but rather reconfigures it, enabling new trade-offs between coordination efficiency and distributed participation within the scientific ecosystem.

Keywords: *Blockchain, Coordination Mechanisms, Decentralized Science, Knowledge Value Chain, Network Analysis.*

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Highlights of this paper

- This study maps the Decentralized Science (DeSci) ecosystem through a multilayer architecture that distinguishes a Research Layer from a Knowledge Layer, and it links blockchain-enabled features to the stages of the knowledge value chain.
- By modeling each project as a network, the study introduces two complementary indicators—a centralization index (Cx) and a decentralization index (Dx)—to measure how coordination is structured across DeSci platforms.
- The results show that blockchain does not eliminate centralization but reconfigures it: Research Layer projects display the most distributed interaction patterns, while Knowledge Layer projects tend to remain more centralized due to infrastructural and governance constraints.

1. INTRODUCTION

Over the past few decades, the production of scientific knowledge has been profoundly transformed by the digitalization of research processes and the increasing interdependence among disciplines, computational infrastructures, and global collaboration networks. However, the knowledge value chain remains largely governed by centralized architectures: access to research outputs is often mediated by editorial intermediaries and proprietary databases, funding decisions are concentrated within a limited number of evaluation bodies, and validation is delegated to peer review mechanisms that, while ensuring quality, introduce bottlenecks and information asymmetries (Larivière, Haustein, & Mongeon, 2015). Such rigidities translate into delays in the circulation of results, duplication of effort, and difficulties in the systematic reuse of data and contributions, ultimately reducing the impact of research and its ability to translate promptly into social, economic, and technological value (Borgman, 2012).

In parallel, recent years have seen the consolidation of a set of initiatives associated with the Open Science paradigm, aimed at making research outputs (articles, data, code, protocols) more transparent and accessible, while promoting greater reproducibility (OECD, 2015). Despite these advances, many structural challenges persist: coordination processes remain costly, quality is often inferred through bibliometric proxies, and the governance of digital infrastructures tends to be concentrated among the actors that control access, metadata, and usage rules (Borgman, 2015).

This results in a paradox: knowledge may be technically available, but not necessarily verifiable, interoperable, or efficiently reusable across the entire scientific pipeline. It is in this context that blockchain technology has emerged, combining distributed ledgers, consensus mechanisms, and cryptography to ensure data integrity and traceability in low-trust environments (Catalini & Gans, 2020). The programmability introduced by smart contracts, together with the possibility of tokenizing rights and economic incentives, enables alternative coordination mechanisms in which resource allocation, intellectual property (IP) management, and participation rules can be explicitly defined, verifiable, and automated (Cong & He, 2019; Freni, Ferro, & Moncada, 2022). These features have supported the emergence of Web3 ecosystems and, more recently, a specific application domain known as Decentralized Science (DeSci).

DeSci can be described as a set of protocols and platforms that leverage blockchain to reconfigure key functions of the scientific ecosystem: research funding (e.g., through community-driven models and DAOs), project and output governance, the attribution and compensation of contributions, data versioning and provenance, and the controlled exchange of scientific assets. DeSci aims to reduce dependence on centralized intermediaries and mitigate well-known issues in the knowledge value chain—such as information asymmetries, opaque validation processes, the risk of contributions being lost, and slow dissemination—while enabling broader participation and greater transparency in the assessment of scientific outputs.

However, the transformative potential of blockchain in the scientific domain cannot be taken for granted. Decentralization *by design* does not necessarily imply decentralization *in practice*: distributed ledgers may coexist with highly centralized operational architectures, and tokenization may generate effective incentives or, conversely, distortions that undermine scientific quality. It is therefore necessary to develop an analytical framework capable of distinguishing between technological promises and observable configurations and of evaluating how architectural choices concretely affect different stages of the knowledge creation process.

Against this background, this study aims to identify, from a qualitative perspective, how blockchain influences the scientific knowledge value chain and to measure, in a comparable way, the degree of decentralization achieved by the main DeSci platforms currently in operation. The methodological approach of this paper is twofold. The first part identifies the most relevant weaknesses of the knowledge value chain and outlines how blockchain affects the different phases of this process. Building on this, we explore the DeSci ecosystem to identify active platforms and map them through a multilayer flowchart that distinguishes blockchain infrastructures (Base Layer), protocols and standards (Protocol Layer), and applications (Application Layer), with the Application Layer further divided into a Research Layer and a Knowledge Layer. The flowchart serves as an analytical tool, useful both for formalizing the reconfiguration of the value chain induced by blockchain and for linking existing challenges with technology-enabled solutions.

The second part extends the analysis using network analysis and graph theory. For each identified platform, we map stakeholders as nodes and their operational relationships as elementary cooperation relationships. Based on the resulting graphs, two complementary indicators are computed: a centralization index (C_x), derived from Freeman's centralization measure, and a decentralization index (D_x), interpreted as a proxy for the level of distributed interaction and coordination (Freeman, 1978; Jackson, 2010). The joint interpretation of C_x and D_x allows the relationship between power structure and cooperation density to be assessed across different stages of the knowledge production process, highlighting recurring configurations and hybrid cases.

The main contribution of this paper is therefore to provide an integrated framework—both theoretical and data-driven—for analyzing DeSci, moving beyond purely normative descriptions and offering observable criteria for discussing the trade-offs between decentralization and operational efficiency.

The remainder of the paper is organized as follows. Section 2 introduces the knowledge value chain. Section 3 presents the DeSci ecosystem and the qualitative results. Section 4 reports the quantitative results. Finally, Section 5 critically discusses the results and concludes the paper.

2. THE KNOWLEDGE VALUE CHAIN

The knowledge value chain can be defined as the set of processes through which data and information are transformed, managed, and applied to generate organizational and societal value. This process consists of a sequence of activities, including knowledge creation, validation, storage, distribution, and application, which collectively enable organizations to leverage knowledge as a strategic resource (Alavi & Leidner, 2001; Davenport & Prusak, 1998). Rather than a linear pipeline, the knowledge value chain unfolds through iterative cycles in which raw signals, dispersed data, and individual experiences are progressively transformed into structured knowledge capable of informing decisions, improving processes, and fostering innovation. Figure 1 illustrates the knowledge value chain.

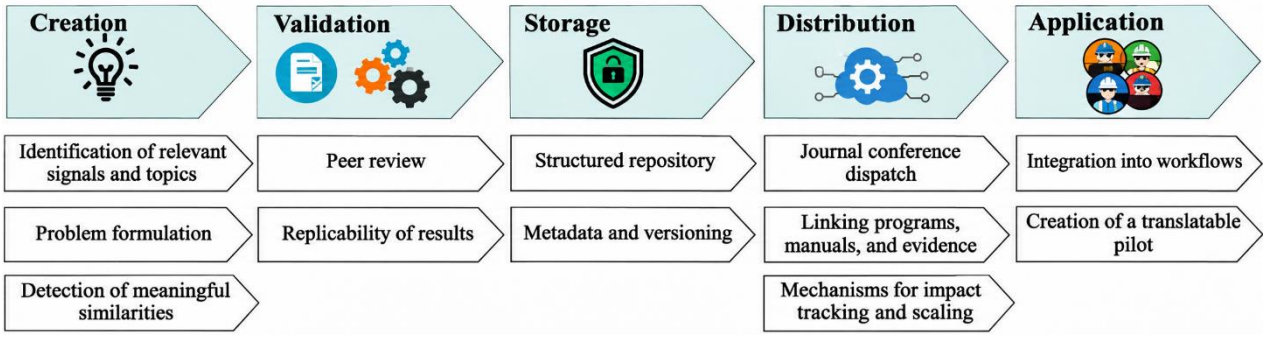

Figure 1. The knowledge value chain.

The transition from information to knowledge is achieved through learning processes involving the construction of models and theories. In this context, knowledge is not merely the accumulation of information but its interpretation within a coherent analytical framework. A key distinction can be drawn between tacit and explicit knowledge: while the latter can be codified in documents, datasets, and formal representations, the former remains embedded in individual experience and is difficult to articulate or transfer. The conversion of tacit into explicit knowledge is therefore essential for scalability and collective learning.

Validation is a central stage in the knowledge value chain. In scientific contexts, this process is typically implemented through peer review and replication, which aim to ensure the reliability and robustness of results. Once validated, knowledge must be stored and organized to ensure long-term accessibility and reuse. This involves not only the archiving of explicit knowledge in repositories and databases, but also the preservation of organizational memory, including routines and practices.

Closely related to storage are knowledge retrieval and transfer, which pertain to the distribution stage. Knowledge transfer extends beyond simple dissemination, as it requires recipients to be able to interpret and apply the information received. This process occurs through both formal channels (e.g., publications, databases, training programs) and informal mechanisms (e.g., communities of practice, mentorship, collaborative interactions). The final stage is application, in which knowledge is integrated into decision-making processes, operational practices, and innovation strategies. It is at this stage that knowledge generates tangible value. However, effective application depends on the alignment between available knowledge, organizational capabilities, and incentive structures. Without such alignment, knowledge may remain underutilized, limiting its potential impact.

Across these stages, several structural weaknesses emerge. First, the creation phase is characterized by asymmetries in ownership and control, with knowledge outputs often concentrated in the hands of a limited number of intermediaries, such as publishers and platform providers. This concentration can reduce incentives for open sharing and restrict participation. Second, validation mechanisms, while ensuring rigor, tend to be slow, opaque, and biased toward established paradigms, potentially limiting innovation. Third, funding processes introduce additional bottlenecks, as resource allocation is mediated by centralized evaluation systems that rely heavily on bibliometric proxies, which have been widely criticized for their limited ability to capture true scientific quality.

Further weaknesses arise in the storage and dissemination phases. Knowledge fragmentation across heterogeneous platforms, the lack of interoperability, and inconsistent metadata standards hinder effective retrieval and reuse. At the same time, economic barriers such as paywalls restrict access, contributing to unequal participation in knowledge ecosystems. Finally, the entire value chain is affected by structural latency. Editorial delays, fragmented infrastructures, and the high cognitive costs of searching for and integrating information all slow down the circulation of knowledge.

Taken together, these weaknesses point to a systemic imbalance in the governance of the knowledge value chain. Rather than isolated inefficiencies, they reflect deeper coordination problems related to incentives, access, and infrastructure design. Addressing these issues requires rethinking both individual stages of the process and the mechanisms that connect them, thereby opening up space for alternative coordination models.

3. DESCI ECOSYSTEM AND QUALITATIVE RESULTS

To represent the current DeSci landscape, we propose a multilayer flowchart that distinguishes the main technological and functional components of the ecosystem (Figure 2). The first is the *Base Layer*, which includes blockchain infrastructures such as Ethereum, Solana, and Polygon. Above it sits the *Protocol Layer*, where protocols define interoperability standards, transaction rules, and shared mechanisms for managing assets, rights, and exchanges. The top level is the *Application Layer*, which can be further divided into two sub-layers: the *Research Layer* and the *Knowledge Layer*.

The Research Layer includes projects focused on funding, governing, and coordinating research initiatives, especially in biotechnology and biomedicine. In this context, blockchain mainly acts as a coordination infrastructure, enabling collective financing, transparent governance, and shared ownership of scientific outputs. The Knowledge Layer, by contrast, includes projects centered on the circulation, valorization, and exchange of scientific data. In this context, blockchain supports traceability, verifiability, and incentive alignment in decentralized data marketplaces. This distinction highlights that DeSci is not a monolithic whole but rather a structured ecosystem in which different layers contribute to reshaping both research production and scientific data management.

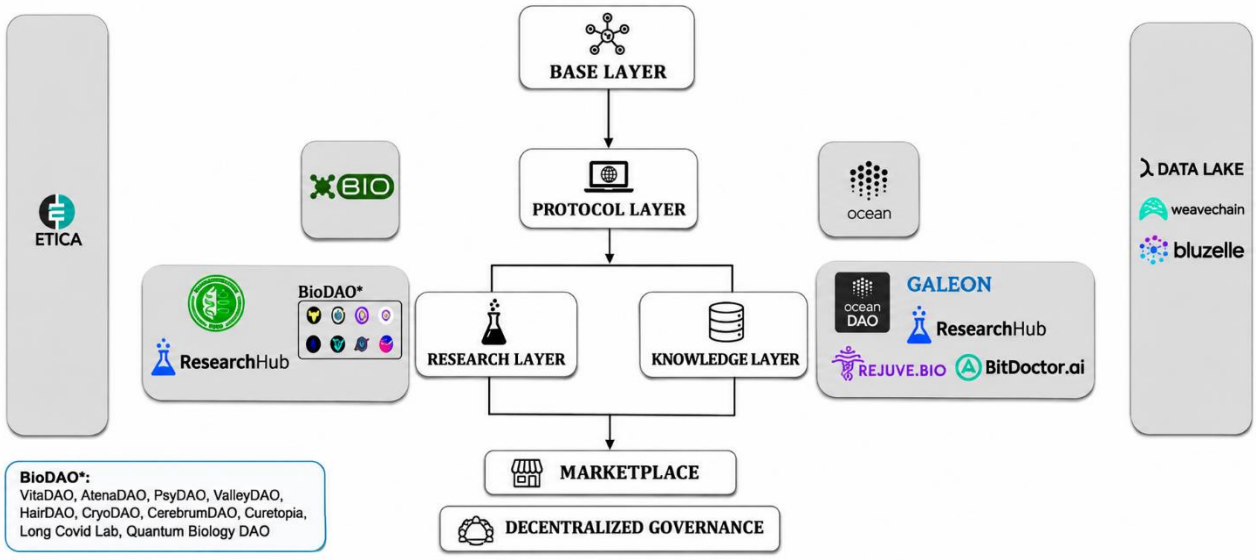

Figure 2. DeSci ecosystem flowchart.

In the flowchart, projects occupy different positions depending on their technological design. Some actors, such as Etica and Bluzelle, operate as native blockchain infrastructures and therefore span the base, protocol, and application layers simultaneously. Others, such as Ocean Protocol or BioProtocol, act as specialized protocols that provide common standards for interoperability, access rights, governance, and incentive design. Finally, at the application level, projects may either rely on external protocols or implement proprietary economic logics through smart contracts. A paradigmatic example is provided by BioDAOs such as VitaDAO, which operate as decentralized

applications (dApps) for funding and governing biomedical research while relying on BioProtocol to standardize IP, governance rights, and technology transfer mechanisms.

At the application level, a further distinction emerges between *decentralized governance* and *marketplace* functions. In the Research Layer, governance is often central, as communities participate in selecting projects, allocating resources, and monitoring scientific progress. In the Knowledge Layer, by contrast, the marketplace dimension becomes structurally essential. However, the notion of marketplace should not be interpreted in a conventional sense. In most DeSci projects, what is exchanged is not the raw dataset itself, but rather a conditional right of access or computation, regulated through smart contracts. In more advanced configurations, users do not obtain the data directly but only the ability to run authorized queries in secure environments, preserving privacy and regulatory compliance while still enabling scientific use. As a result, these marketplaces are better understood as infrastructures for orchestrating access, permissions, and controlled data use rather than as simple venues for selling data.

Building on this ecosystem mapping, the qualitative analysis shows that blockchain affects the knowledge value chain through a set of recurring outcomes that address the weaknesses identified earlier. First, blockchain enables the *inclusion of non-traditional actors*, such as patients, citizens, communities, and independent contributors, who can participate through funding, data provision, peer review, or governance. This broadens the creation phase of the value chain, making the identification of relevant signals and the formulation of problems more open and participatory. Second, blockchain introduces *verifiable provenance of contributions*. Financial support, reviews, datasets, and validation activities become traceable and attributable, improving transparency and accountability, especially in the creation and validation stages.

Third, DeSci ecosystems rely on *structured incentive mechanisms*, in which tokens and smart contracts make it possible to reward scientific contributions that are often neglected in traditional systems, such as peer review, replication, data sharing, and curation. In this way, blockchain does not merely support exchange but acts as a programmable governance device capable of aligning incentives with epistemic and organizational objectives. Fourth, *unique addressability and immutable versioning* strengthen the storage and distribution phases of the value chain, as datasets, papers, and intermediate outputs can be persistently identified, historically reconstructed, and verified over time. This directly supports replicability and reduces the risk of knowledge being functionally lost. Finally, *reduced time-to-publish and permissionless access* accelerate the circulation and application of knowledge. By relying on tokenized access rights, on-chain licenses, and decentralized marketplaces, DeSci platforms reduce traditional bottlenecks associated with editorial intermediation and centralized gatekeeping. Figure 3 illustrates the impact of blockchain on the knowledge value chain.

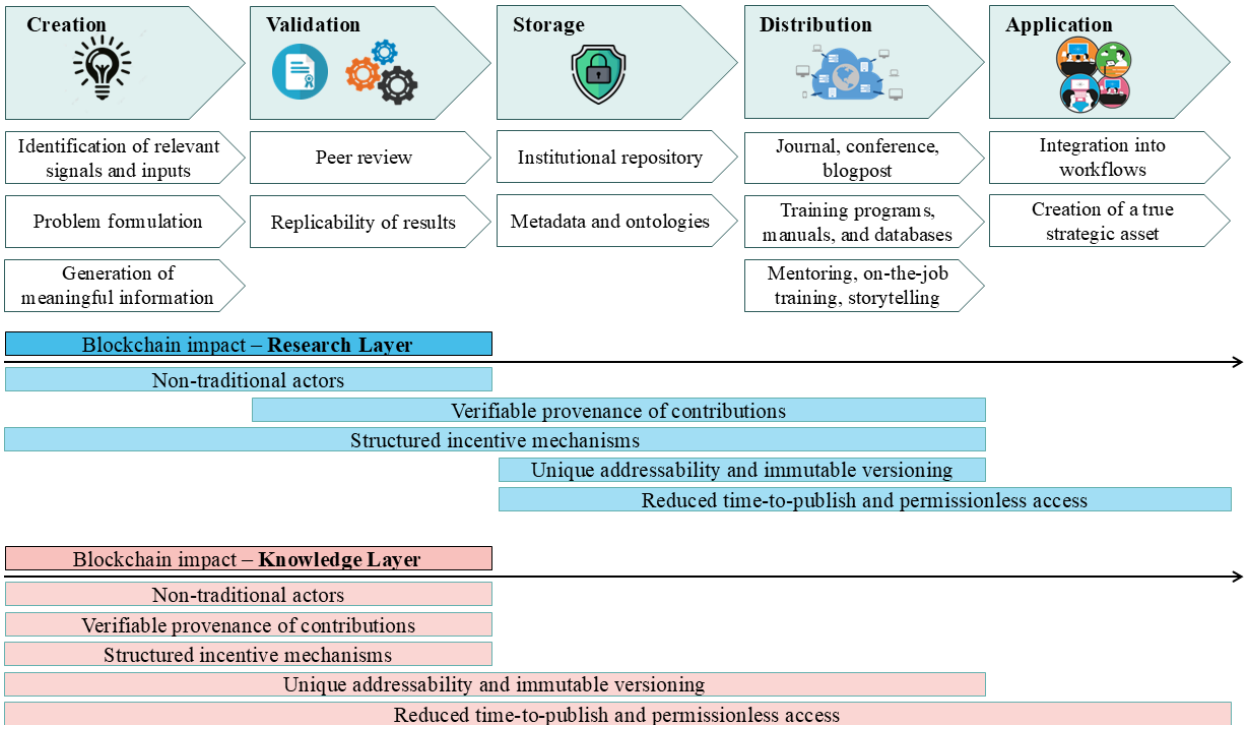

Figure 3. Knowledge value chain and blockchain impact in DeSci – Research and Knowledge Layers.

Figure 3 complements the ecosystem flowchart by making explicit how the blockchain-enabled outcomes discussed above are distributed along the value chain of the two application layers. In both layers, the inclusion of non-traditional actors affects the upstream phases of creation and validation, where participation and quality attestation are generated. Beyond this common pattern, the two layers differ. In the Research Layer, verifiable provenance of contributions and structured incentive mechanisms extend from the upstream phases to distribution, reflecting the role of blockchain in funding, governing, and attributing research activities throughout the process, while unique addressability, immutable versioning, reduced time-to-publish, and permissionless access affect the downstream phases of storage, distribution, and application. In the Knowledge Layer, by contrast, provenance and incentives remain confined to creation and validation, where data are generated and attested, whereas unique addressability and immutable versioning extend from creation to distribution, and reduced time-to-publish and permissionless access span the entire value chain, as access to data is orchestrated through marketplaces from the moment datasets are created.

4. QUANTITATIVE RESULTS

The quantitative analysis builds on the ecosystem mapped in Section 3. Each identified platform is formalized as a graph $G = (N, E)$, where N denotes the set of actors (nodes) and E the set of elementary cooperation relationships (edges). This enables the application of network analysis tools to investigate how coordination and control are structured across different platforms.

The goal of the analysis is to measure the degree of decentralization by disentangling two complementary dimensions: the concentration of structural power and the distribution of cooperative interactions. To this end, two indices are computed for each platform: a centralization (C_x) and a decentralization index (D_x).

C_x is derived from the concept of network centralization introduced by Freeman (1978), which measures the extent to which a network is organized around its most central nodes. Formally, it is defined as:

$$C_x = \frac{\sum_{i=1}^{N} [C_x(p^*) - C_x(p_i)]}{H} \quad (1)$$

where $C_x(p_i)$ denotes the centrality of node i (i.e., the number of outbound relationships with other nodes), $C_x(p^*)$ is the maximum centrality observed in the network (i.e., the maximum number of outbound relationships), N is the total number of nodes, and the denominator $H = (N-1)^2$ corresponds to the normalization factor. The index takes values in the interval $[0,1]$, where higher values indicate a stronger concentration of influence within a limited subset of actors, reflecting more centralized configurations.

D_x, in turn, captures the extent to which cooperative interactions are distributed across the network. Its formal definition is:

$$D_x = \frac{|E|}{N(N-1)} \quad (2)$$

where $|E|$ is the number of observed edges and $N(N-1)$ represents the total number of possible edges in a network with N nodes. The index spans the interval $[0,1]$, with higher values indicating a greater density of interactions and a more distributed pattern of cooperation among actors.

The joint interpretation of C_x and D_x allows for a nuanced characterization of DeSci platforms. Their combined use makes it possible to identify different coordination regimes, ranging from highly centralized systems with low interaction dispersion to more decentralized configurations in which coordination emerges from a broader and more distributed set of relationships.

For each identified DeSci project, we produced a combination of graphical and tabular representations, summarized in project sheets. Each sheet includes: (i) a table listing all the cooperation actions, i.e., the edges; (ii) a graphical representation of the network structure, where nodes correspond to actors and edges to elementary cooperation relationships; (iii) the computed values of C_x and D_x; and (iv) a brief description of the project and its main functionalities. Figure 4 reports the project sheet of BioProtocol as a representative example.

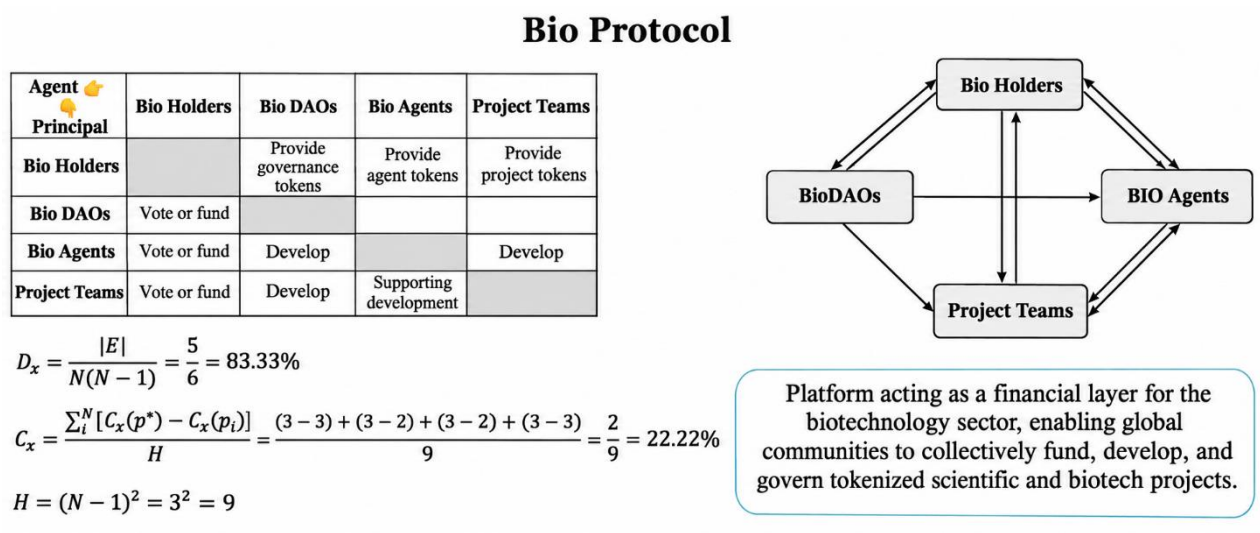

Figure 4. BioProtocol – Project sheet.

Building on these individual representations, Table 1 reports the aggregated results across all analyzed projects. The table summarizes the distribution of the two indices, enabling a comparative assessment of

centralization and interaction density across the DeSci ecosystem. These results allow us to identify differences between projects operating in the Research Layer and those in the Knowledge Layer, as well as to highlight the presence of heterogeneous organizational configurations within each group.

Finally, Figure 5 presents the joint positioning of all case studies in the (D_x, C_x) space. This representation provides a synthetic view of the coordination structures observed across the ecosystem. The scatter plot can be interpreted as a coordination design space, where each project occupies a position reflecting the trade-off between concentration of control and distribution of cooperative interactions.

Table 1. DeSci ecosystem overall results.

Group	Project	D_x	C_x	H	N	Actors	In. Rel.	Out. Rel.	Layer
1	BioProtocol	83.33%	22.22%	9	4	Bio Holder	3	3	R
						Bio Agent	3	2	
						Project Team	3	2	
						BioDAO	1	3	
	Rejuve	66.67%	0%	9	4	Contributor	2	2	K
						Researcher	2	2	
						Platform Operator	2	2	
						Healthcare Provider	2	2	
	WeaveChain	66.67%	0%	9	4	Data Provider	3	2	K
						Data Consumer	3	2	
						Network Node	2	2	
						Validator	0	2	
	Transhuman Coin	83.33%	25%	4	3	Researcher	2	2	R
						Governance Committee	2	2	
						Community Members	1	1	
	Genomes.io	83.33%	25%	4	3	Data Owner	1	2	R
						Researcher	2	2	
						Institution	2	1	
	Etica	58.33%	11.11%	9	4	Proposal Creator	3	2	K
						Voter	1	1	
						Core Team	2	2	
						Organization	1	2	
2	Ocean Protocol	58.33%	55.56%	9	4	User	3	2	K
						Data Provider	2	1	
						Compute Provider	2	1	
						Ambassador	0	3	
	Data Lake	66.67%	44.44%	9	4	Researcher	2	2	K
						Data Provider	3	2	
						Patient	3	1	
						Ambassador	0	3	
	Bluzelle	66.67%	33.33%	9	4	Researcher	3	3	K
						User	1	1	
						Investor	1	1	
						Community Members	1	1	
3	ResearchHub	40%	43.75%	16	5	Author	4	1	R/K
						Curator	0	3	
						Reviewer	2	1	
						Editor	1	2	

					Funder	1	1	
	Galeon	50%	22.22%	9	4	Patient	2	1	K
						Nurse	0	2	
						Healthcare Institution	3	1	
						Researcher	1	2	
	BitDoctor	40%	24%	25	6	Contributor	2	1	K
						Aggregator	2	3	
						Data Consumer	3	2	
						Operator	2	2	
						Medical Specialist	3	1	
						Ambassador	0	3	

Note: The In. Rel. column shows inbound relations for each actor, while the Out. Rel. column shows outbound relations. The Layer column identifies the Research (R) or Knowledge (K) layer in which the project is located.

From this perspective, Figure 5 not only summarizes the empirical findings but also offers a visual tool to compare different architectural approaches within DeSci and to assess the extent to which blockchain-based systems effectively achieve decentralized coordination, taking as a benchmark a traditional setting in which, by definition, actors occupy the fully centralized position $(0, 1)$ in the (D_x, C_x) space.

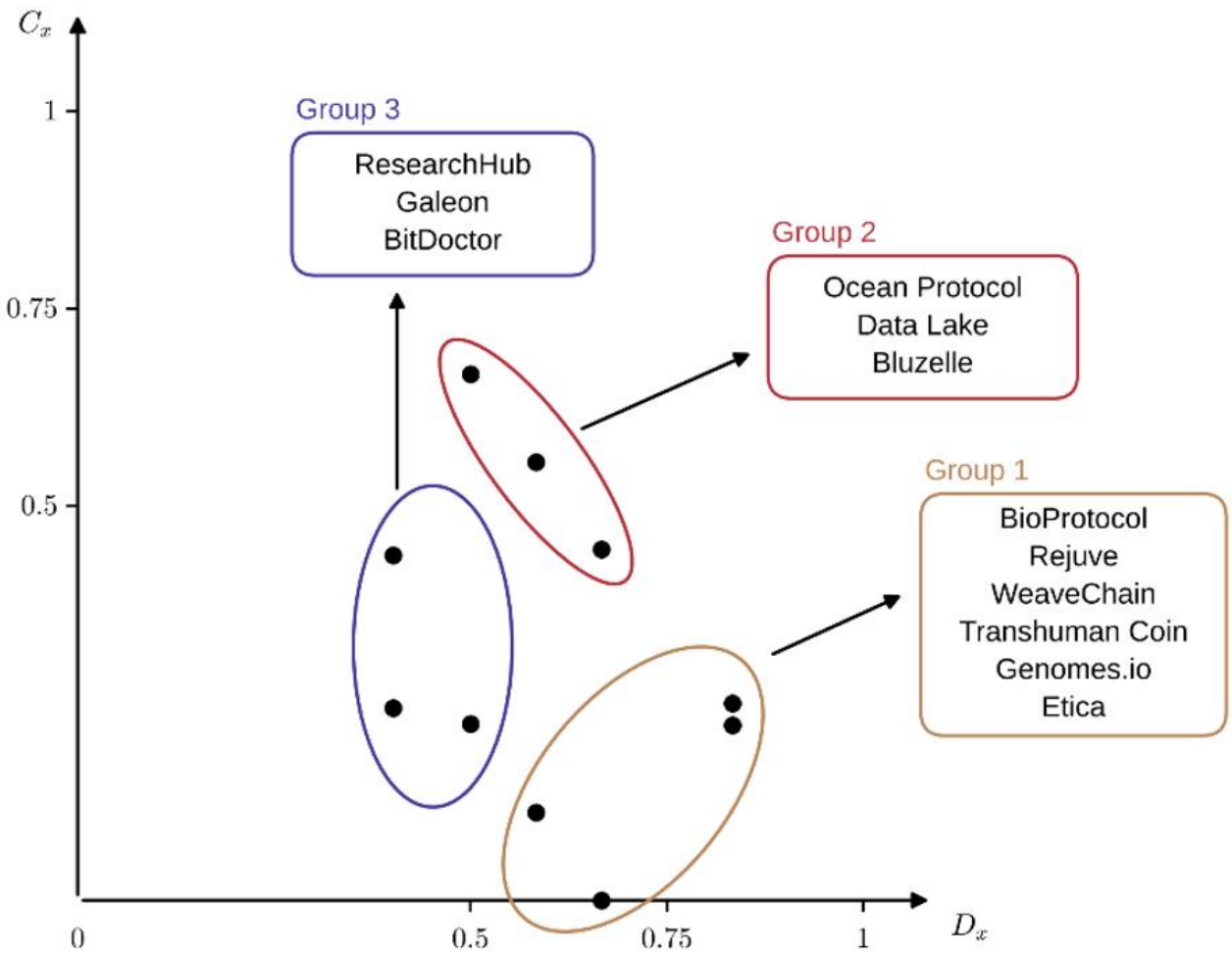

Figure 5. Positioning of the case studies in the (D_x, C_x) space.

5. DISCUSSION AND CONCLUSION

Our analysis shows that blockchain adoption does not translate into a uniform or automatic redistribution of power and coordination. The joint evaluation of C_x and D_x highlights a heterogeneous landscape in which projects exhibit different organizational configurations, ranging from highly centralized structures to more distributed interaction patterns. A first key result concerns the distinction between the Research and the Knowledge Layer. The latter tends to display higher levels of centralization due to the need to coordinate access, governance, and compliance over sensitive data infrastructures, even when interaction patterns remain highly distributed. In these contexts, although participation is broadened through token-based mechanisms, decision-making power often remains concentrated in a limited subset of actors. By contrast, projects in the Research Layer generally exhibit higher values of D_x, reflecting the need to coordinate complex activities such as project selection, funding allocation, and governance.

A second important finding is the presence of hybrid configurations, in which relatively high levels of interaction coexist with moderate or high centralization. These cases indicate that decentralization should not be interpreted as the absence of structure, but rather as a reconfiguration of coordination mechanisms. In particular, blockchain enables broader participation and traceability of contributions, while still allowing for focal points of control that ensure operational efficiency. This trade-off between inclusiveness and coordination emerges as a defining feature of the DeSci ecosystem. This phenomenon is exemplified by the projects in the second group of Table 1 and Figure 5.

More broadly, the results confirm that decentralization is a multidimensional phenomenon that cannot be captured by a single metric. The distinction between concentration of power (C_x) and distribution of interactions (D_x) proves essential for avoiding misleading interpretations, especially in contexts where technological decentralization coexists with organizational centralization. From this perspective, the proposed framework contributes to a more nuanced understanding of how blockchain reshapes the knowledge value chain, not by eliminating intermediaries altogether, but by redistributing roles, incentives, and access conditions across its different stages.

In conclusion, DeSci should be regarded not as a fully decentralized alternative to traditional science but as an evolving coordination paradigm in which different degrees of decentralization emerge depending on the function considered. Future research may extend this analysis by incorporating dynamic perspectives, larger samples, and alternative measures of coordination, in order to investigate further how these configurations evolve over time and under different technological and institutional conditions, especially as the DeSci ecosystem matures and gains wider adoption.

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