Opportunities and Limitations of Decentralization in Decentralized Science

Bence, Lukács[1], Benjamin Heurich[1], Lukas Weidener[2]
[1)] Institute for Applied Blockchain (IABC), Berlin, Germany
[2)] UMIT Tirol, Hall in Tirol, Austria

Decentralization is one of the key attributes associated with blockchain technology. Among the different developments in recent years, decentralized autonomous organizations (DAOs) have been of growing interest. DAOs are currently a key part of another emerging use case, namely decentralized science (DeSci). Given the novelty of the field, an integrative definition of DeSci has not been established, but some inherent concepts and ideas can be traced back to the Open Science movement. Although the DeSci movement has the potential to benefit the public, for example through funding underrepresented research areas or more inclusive and transparent research in general, some negative aspects of decentralization should not be neglected. Due to the novelty of blockchain and emerging use cases, research can and should precede mass adoption, to which this paper aims to contribute.

1. Introduction: The decentralization of scientific processes

Over the last few decades the scientific community and its processes have undergone various phases of change. While the scientific method remained open and accessible for anyone to make use of, institutions started to close their doors and retreat further within their walled gardens. It can be argued that through incremental closing of scientific institutions and its processes, innovation and development was hindered, as there weren't any feedback-mechanisms available for the public and society at large. Additionally, through this insulation, parts of the scientific system became more profit-driven in order to (simply) survive and upkeep the status quo of the previously gained reputation. Most recently, this centralization and in-transparency resulted in major issues, such as the *Reproducibility Crisis* [1], corruption of the peer-review [2] and publication processes [3].

Some countermeasures were taken, starting with the Open Access movement, which generally focused on the accessibility and availability of scientific publications for a broader public through open licensing. Then the Open Science movement further expanded openness principles within the scientific community and started to encourage the building of open structures, fostering collaboration and enabling society and its citizens to take a bigger part of knowledge creation. The most current iteration within scientific processes is based on the principles of decentralization. As we will further expand on in the following pages, technological decentralization offers scientists and the scientific community, as well as society at large, a new way of operating. Because of these new developments and the urgency to solve the aforementioned issues, it becomes especially important for the scientific community to take a scientific approach to these new technological developments, and objectively reflect on what the current state, as well as what the risks and benefits for the field are, i.e. research should precede mass adoption, which this paper aims for.

2. Decentralization Paradigm (DLT and Blockchain technology)

Decentralization, Distributed Ledger Technology (DLT), and Blockchain are interconnected concepts that have gained significant attention from a sociological perspective. Sociologists have recognized the potential of decentralization, DLT, and blockchain to transform social structures and power dynamics. These technologies can promote greater inclusivity, reduce reliance on centralized authorities, and enable direct participation and cooperation among individuals and groups. However, it is essential to critically examine their implementation to address potential challenges and ensure that they align with sociological principles of equity, fairness, and social justice. As these technologies continue to evolve, a social-scientific analysis will continue to play a vital role in studying their societal impact, ethical implications, and potential to reshape social relations.

In sociology, decentralization refers to the distribution of power, authority, and decision-making across multiple nodes or actors within a social system. It is the opposite of centralization, where power and control are concentrated in a single authority or entity. Decentralization aims to empower individuals or smaller groups, promoting autonomy and participation in decision-making processes. Descriptively speaking, decentralization can foster cooperation, collaboration, and democratic practices within various social structures, such as organizations, communities, or governments.

2.1 DLT and Blockchain

Distributed Ledger Technology (DLT) as a technological framework that enables the decentralized storage and management of data across multiple nodes or comput-

ers has the potential to sustainably carry this development, if implemented and governed accordingly. Instead of relying on a central authority or database, DLT distributes the data across a network of participants, creating a tamper-resistant and transparent system. So, from a sociological perspective, DLT can be seen as a manifestation of decentralized organizational principles in technology. By removing the need for intermediaries and allowing direct peer-to-peer interactions, DLT promotes trust and cooperation among network participants, facilitating consensus-building and democratic decision-making.

Blockchain is a specific type of DLT that operates on a chain of blocks. All blocks are linked together in a chronological and immutable sequence, making it virtually impossible to alter previous records without consensus from the network making it a potent tool for achieving transparency and accountability in various domains, including finance, supply chain management, and governance. By ensuring data integrity and decentralization, blockchain can create a more equitable and trustful environment where participants have increased control over their data and interactions.

2.2 Characteristics of decentralized technologies

Thanks to these characteristics, DLT and blockchain have the potential to revolutionize various industries, including science and academia. The decentralized nature of these technologies ensures data integrity, traceability, and immutability, thereby enhancing trust and reducing the need for intermediaries. Applying the decentralization paradigm to scientific research and data management can foster open collaboration, data sharing, and reproducibility, ultimately promoting the advancement of knowledge. Researchers can use blockchain to timestamp and store research data, ensuring its authenticity and preventing data tampering. This creates a transparent and trustworthy record of research findings, enhancing the integrity and credibility of scientific publications. Moreover, decentralized funding platforms powered by blockchain can facilitate direct peer-to-peer funding for research projects, bypassing traditional funding agencies and streamlining the process.

3. Open Science, DeSci and the emergence of DAOs

Open Science (OS), as defined by UNESCO in their 2021 publication aims to alleviate many of the issues mentioned at the beginning of the paper. The OS principles are based on three pillars, which (1) increases collaboration among scientists through sharing research openly, (2) involves the global (scientific) community, as well as citizens, by focusing on accessibility (e.g., multilingual) and (3) extends the scientific process outside of traditional scientific institutions [4]. Among the key words included within the *openness* context for science are open accessibility and availability of research output, open data, open-source software, and open infrastructure.

By promoting transparency on different levels and supporting all approaches toward openness in the research process, OS aims to democratize access to scientific knowledge creation. Through following the aforementioned principles, other researchers can replicate and validate scientific findings, thereby enhancing their reliability and credibility, and give society at large easier access in order to validate the need for research and benefit from it. The OS movement has led to some important changes in the scientific publishing landscape, with an increasing amount of scientific literature being accessible to the public without cost. Furthermore, the OS movement has led to the establishment of preprint servers, enabling researchers to share their findings with the community before undergoing peer review for formal publication.

The principles of OS align closely with those of Decentralized Science (DeSci) since both movements advocate for the democratization of scientific knowledge and the use of (open) technology to facilitate the sharing and collaboration of scientific research. However, while OS primarily focuses on the openness of the research process and increased collaboration, especially the replicability of results, DeSci extends this idea to include the decentralization of the research infrastructure, leveraging blockchain technology, and other Web3 technologies to create a more equitable, participatory, and inclusive scientific ecosystem.

3.1 DeSci as an extension of Open Science principles

DeSci represents a novel movement in the scientific domain, with no universally accepted definition to date. A widely referenced definition, provided by the Ethereum Foundation, describes DeSci as “a movement that aims to build public infrastructure for funding, creating, reviewing, crediting, storing, and disseminating scientific knowledge fairly and equitably using the Web3 stack” [5]. Although blockchain technology is not explicitly mentioned in this definition, it is an integral component of the Web3 stack and plays a pivotal role in the operationalization of DeSci. Blockchain technology and especially the associated features and applications such as smart contracts, governance tokens or NFTs, are fundamental to the current DeSci ecosystem. To summarize, DeSci bears significant parallels with the OS movement, as Web3 technologies serve to extend the principles by incorporating novel technological advancements (i.e. data storage, collaboration mechanisms and funding procedures).

3.2 DAOs as new structures for scientific processes

Essential to the current DeSci movement are Decentralized Autonomous Organizations (DAOs). This type of organization represents a novel form of organizational structure enabled by blockchain technology. While there is no universally accepted definition for DAOs, for the purpose of this publication, we will adopt the definition

provided by the World Economic Forum (WEF): "Decentralized autonomous organizations (DAOs) are structures that use blockchains, digital assets, and related technologies to direct resources, coordinate activities, and make decisions" [6]. The term DAO was first prominently introduced in relation to 'The DAO' in 2016, an ambitious project built on the Ethereum blockchain that aimed to operate as a leaderless venture capital fund [7]. Despite its eventual downfall due to a security breach, The DAO served as a significant milestone in the exploration of decentralized governance models.

In the definition by the WEF, 'digital assets' likely refer to governance tokens, which are utilized in the decision-making process over shared resources (e.g., shared monetary funds as part of a treasury) and activities within the DAO (e.g., funding scientific research). These tokens often represent voting rights, allowing token holders to influence the direction of the organization.

The 'related technologies' within the context of the definition of the WEF likely primarily refer to smart contracts, which are fundamental to the autonomous operation of DAOs. By utilizing smart contracts, DAOs can automate (trans-)actions such as funding research or paying for services, once a decision-making process, typically in the form of on-chain voting, has been completed.

DAOs play a significant role in the current DeSci movement and represent a paradigm shift in organizational structures and governance models, challenging traditional centralized authority with a decentralized, transparent, and democratic approach. However, the practical implementation of DAOs presents a host of challenges and complexities, ranging from technical and security issues to legal and regulatory considerations. In particular, within the context of DeSci, the challenges associated with DAOs will be the context of this publication.

3.3 DeSci DAOs: More than theory – VitaDAO

DeSci-DAOs aim to provide a new method of participation, inclusivity, and accessibility to science. By leveraging the capabilities of the Web3 stack, including blockchain technology, smart contracts, and Non-Fungible Tokens (NFTs), DeSci-DAOs have the potential to revolutionize the scientific landscape. As of the current writing period, a significant proportion of DAOs have predominantly concentrated their efforts on fields such as medicine, natural sciences, and biotechnology. This focus, while offering substantial potential for invigorating research areas that traditionally suffer from underfunding (such as rare diseases), also introduces a new set of challenges and risks (e.g., safety and control of decentralized biological research).

Table 1. Selection of DeSci-DAOs

DeSci DAO	Objectives
VitaDAO	Funding and advancing longevity research
HairDAO	Research support and funding to cure hair loss
ValleyDAO	Financing and democratizing the governance of synthetic biology technologies
BeakerDAO	Decentralized funding of the DeSci ecosystem
CerebrumDAO	Funding solutions to advance brain health and prevent neurodegeneration

At the time of writing, the VitaDAO community comprised approximately 10,000 members, with over 2,000 individuals holding the available governance token ($VITA). These governance tokens play a pivotal role in decision-making processes within the DAO, particularly in matters such as the allocation of funds for longevity research [8]. To date, VitaDAO has successfully raised in excess of $10 million, a portion of which originates from Pfizer Ventures, a traditional pharmaceutical sector entity [9]. This investment from a conventional sector player underscores the growing interest and potential of this novel approach to scientific research and funding. VitaDAO has already funded more than 15 projects, with research areas spanning various aspects of longevity science [10].

4. Risks and benefits of decentralized scientific processes through DAOs

4.1 Benefits for science

This section explores the potential benefits of DeSci ranging from funding underrepresented research areas to enhancing transparency, participation, and interdisciplinarity in the scientific process.

4.1.1 Funding

One potential benefit of DeSci is the funding of underfunded research areas. A prime example of this is HairDAO, a DAO "that is advancing research and development for hair loss treatments in an open-source and democratic way" [11]. Hair loss, specifically androgenic alopecia, is a condition that has been overlooked by traditional pharmaceutical research, despite causing a high level of suffering among those affected. Androgenic alopecia is a common form of hair loss in both men and women, and genetic and hormonal factors play significant roles. Research in this area is crucial, as it not only seeks to provide solutions for those suffering from hair loss, but also contributes to our understanding of human biology and aging.

4.1.2 Transparency and Trust

Increased transparency in the scientific process, which includes research, reviewing, publishing, and access to research, is a cornerstone of the OS movement and a key aspect of DeSci. Transparency is instrumental in fostering trust through better replicability. The replication crisis in various scientific fields has raised concerns regarding the reliability of scientific findings and the validity of policy and action items that were based on certain research. OS and DeSci, with their emphasis on technological, as well as methodological transparency and openness, provide a solution to this crisis. Moreover, transparency in the scientific process can lead to increased participation and access to the overall research process and provides more feedback opportunities for citizens. This is not limited to researchers, but extends to non-researchers as well, such as patients or patient advocacy groups. People interested in a specific topic or research can contribute based on their experiences and skills, even anonymously, without the need for specific degrees. The democratization of participation in the scientific process is a significant benefit of DeSci.

4.1.3 Interdisciplinarity

The concept of interdisciplinarity in the context of OS and DeSci is gaining traction in the academic community. It is increasingly recognized that the complex problems of today's world often require insights from multiple disciplines. However, in traditional scientific research, there are often barriers to such interdisciplinary collaboration, including institutional structures and norms that tend to compartmentalize knowledge within specific disciplines. DeSci, with its emphasis on open collaboration and decentralized governance, has the potential to break down these barriers. By leveraging the capabilities of the Web3 stack, DeSci can facilitate collaboration among researchers with diverse backgrounds and expertise regardless of their institutional affiliations. This can stimulate the exchange and fusion of ideas and knowledge from diverse fields, catalyzing innovative solutions to complex problems.

4.1.4 Protection and Management of Intellectual Property (IP)

Another significant advancement that DeSci can offer in comparison with traditional scientific practices is a novel approach to the protection and management of intellectual property (IP) rights. In conventional systems, the creation and management of IP rights are complex processes that often involve a multitude of stakeholders, including researchers, academic institutions, and corporate entities [12]. This complexity, coupled with the high value associated with IP rights, often results in limited accessibility and transparency for researchers and the public. Furthermore, the existing process can lead to a concentration of IP ownership among certain well-funded entities such as pharmaceutical companies. In contrast to this traditional, time-consuming, and cost-intensive IP management process, DeSci introduces the concept of Intellectual Property Non-Fungible Tokens (IP-NFTs) [13]. These are unique tokens that represent intellectual property assets on the blockchain. Their non-fungibility and ability to tokenize intellectual property rights have significant implications for the funding and conduct of scientific research. By converting intellectual property into a tokenized form, researchers can protect their findings and attract funding in a more cost-effective, time-efficient, and transparent manner. In the context of DeSci, IP-NFTs serve as a bridge between intellectual property and the web3-mediated scientific landscape, allowing scientists to tap into a new source of funding for their research and transact on their discoveries in a novel manner.

4.1.5 Translational research

DeSci holds the potential to expedite translational research, often encapsulated by the phrase "from bench to bedside" [14]. This process involves the application of basic scientific discoveries made under laboratory conditions (the 'bench') to patient care (the 'bedside'). However, the journey from bench to bedside can be slow due to the multi-stage nature of research, which includes clinical trials and the presence of regulatory, administrative, and funding-related barriers [15]. By leveraging the web3 stack, including blockchain technology and DAOs, DeSci can facilitate translational research through increased data and result sharing, interdisciplinary collaboration, and transparency.

4.1.6 Censorship resistance

Another potentially significant benefit of DeSci is its reduced level of censorship in the scientific research process. In the traditional scientific system, universities and grant providers such as the government or pharmaceutical companies significantly impact the current research landscape by providing funding only to research they evaluate as valuable [16]. These entities may choose to fund research that aligns with their own interests or perceived societal value, which can result in underfunding in certain research areas such as rare diseases. This selective funding can also lead to a form of censorship where high-impact research that does not align with the interests of these entities may be overlooked or suppressed. DeSci, with its decentralized and democratic approach, offers a potential solution to these challenges. By decentralizing the funding and decision-making processes, DeSci can ensure a more equitable distribution of resources and reduce the potential for censorship, thereby fostering a more diverse and inclusive scientific research landscape.

4.2 Unique challenges for science

The decentralization of science through DeSci and the web3 stack, while offering numerous benefits, also presents a set of unique challenges and risks.

4.2.1 Accountability

One primary concern is accountability. By their very nature of being potentially fully decentralized and autonomous, DAOs can face difficulties in attributing responsibility in cases of fraudulent or unethical scientific activities. As mentioned in the previous section, the openness of DAOs and the possibility of participating in the scientific process either pseudonymously or anonymously can lower the barriers to entry and increase interdisciplinary collaboration. However, this could also provide an avenue for individuals to pursue personal agendas that could mislead other participants or skew the overall research process. Although the decision-making process in most DAOs is not fully decentralized (yet) and is overseen by elected core members who represent the interests of the organization, there is a risk that these core members could collude to influence the community based on their personal interests.

4.2.2 Decision-making

The token-based voting and decision-making processes inherent to DAOs, while democratizing and inclusive, also present potential risks. The decentralization of decision-making power to token holders can lead to a situation in which the majority's interests may not always align with the broader public or the organization's mission. This is particularly relevant in the context of DeSci, where the research agenda and allocation of resources could potentially be influenced by a minority of token holders with significant voting power. This risk is further amplified in the early stages of a project, when a majority of tokens are often distributed to the public, creating an opportunity for pseudonymous individuals or institutions to accumulate voting rights. This could potentially lead to a concentration of decision-making power, contrary to the democratic ethos of the DAOs. Therefore, it is crucial for DeSci-DAOs to implement robust governance structures and mechanisms to prevent such manipulation and ensure that the decision-making process remains fair, transparent, and aligned with the organization's mission.

4.2.3 (Decentralized) Intellectual Property (IP) Risks

In the context of intellectual property (IP) rights, DeSci-DAOs could potentially own IP rights after funding research, such as through the use of IP-NFTs. Although this approach provides a novel way to fund research and incentivize scientific discovery, it also presents potential risks. For instance, the DAO could potentially limit the use of research findings either by restricting access to the research or by imposing licensing fees. Although this is unlikely, given that the commercialization of IP-NFTs is fundamental to the success of the DAO and the ethos of open science, a significant risk remains if a limited number of individuals (including the founding or “core team”) accumulate tokens. This could potentially lead to a situation in which IP rights associated with a particular research project are controlled by a small group of individuals. Furthermore, the tokenization of IP rights could potentially lead to fragmentation of IP ownership, complicating the licensing and commercialization processes. Another potential risk in the DeSci landscape pertains to the underutilization (or complete lack of utilization) of IP rights owned by a DAO. This could stem from a lack of active participation or voting apathy among the token holders. In a DAO, decision-making processes are typically predicated on a certain threshold of token-holders participating in a vote for it to pass. If this threshold is not met, decisions cannot be made, which could lead to stagnation in the decision-making process and, by extension, under-utilization of IP rights. This could potentially slow down the pace of R&D and discourage members from participating, especially if they view the governance tokens more as a long-term investment rather than an active tool for participation in the DAO's activities. This risk is particularly relevant in the context of DeSci, where the decision-making process can directly affect the direction and pace of scientific research. For instance, decisions related to the allocation of resources for research, the commercialization of research findings, and the licensing of IP rights could be delayed due to voting apathy. This could potentially hinder the progress of scientific research and the realization of its benefits, endangering the overall mission of the DeSci-DAO.

4.2.4 Ethics

Finally, the reduced level of censorship, while being a potential advantage of DeSci, can also pose a significant risk. The absence of traditional governmental or regulatory oversight in the funding and approval process could potentially pave the way for research that is ethically questionable or harmful. For instance, research involving the manipulation of harmful viruses or cloning of humans, which are generally considered ethically and morally contentious, could be pursued without traditional checks in place. In the traditional scientific landscape, research proposals undergo rigorous ethical reviews by institutional review boards or ethics committees that assess the potential risks and benefits of the proposed research. This process was designed to protect the welfare and rights of research participants and ensure that the research was conducted in an ethical manner. However, in DeSci-DAO, where funding and approval decisions are made through a decentralized voting process, it is possible that such ethical considerations may not be adequately addressed.

5. Conclusion: A potential future for/of science

Decentralized Science and its implementation through DAOs present intriguing possibilities for the scientific community. By enabling democratized access to funding and decision-making, DeSci has the potential to revolutionize the scientific landscape. It could foster greater inclusivity, allowing researchers from diverse backgrounds and regions to participate in the scientific process and address a broader range of societal challenges. DAOs, as

self-governing entities, can facilitate collective decision-making in research allocation and project funding. This participatory approach aligns with sociological principles of decentralization and could reduce the dominance of traditional research institutions or powerful funding bodies. Involving a diverse group of stakeholders in the decision-making process may lead to more equitable resource distribution and research prioritization, considering a wider range of perspectives and needs.

However, this transformative potential comes with certain risks that require careful consideration. Governance structures within DAOs may be subject to power imbalances, where certain actors wield more influence than others. Sociologists must examine how decision-making processes within DAOs could be influenced by individual biases, social hierarchies, or external forces. Additionally, the implementation of DeSci must address ethical concerns related to data privacy, data ownership, and accountability. Sociologists should assess how decentralized data sharing and collaboration might impact research ethics, intellectual property rights, and potential misuses of scientific knowledge. Sociological research on DeSci and DAOs is essential to navigate the potential benefits and risks they pose to the scientific community. By addressing issues of power dynamics, accountability, and ethics, sociologists can help maximize the positive impact of DeSci while minimizing potential negative consequences, paving the way for a more inclusive and responsible scientific future.

Acknowledgements / Information on sponsors

Lukas Weidener is a member and investor in multiple DeSci-DAOs and project.

Contact details

Oranienstraße 185, Berlin, 10999 Berlin

Contact persons:

bence.lukacs@iabc.dbuas.de / 0000-0002-3723-6549

Literature references

[1] Baker, Monya (2016): 1,500 scientists lift the lid on reproducibility, Nature 533, 452–454 (2016). https://doi.org/10.1038/533452a.

[2] Petrescu, Maria; Krishen, Anjala S. (2022): The evolving crisis of the peer-review process, J Market Anal 10, 185–186 (2022). https://doi.org/10.1057/s41270-022-00176-5.

[3] Committee on Publication Ethics and STM (2022): Paper mill research, DOI: https://doi.org/10.24318/jtbG8IHL.

[4] UNESCO (2021): UNESCO Recommendation on Open Science, https://unesdoc.unesco.org/ark:/48223/pf0000379949.locale=en, Accessed: 31.07.2023

[5] Ethereum Foundation: Decentralized Science (DeSci). https://ethereum.org/en/desci, Accessed: 31.07.2023

[6] World Economic Forum (2023): DAOs for Impact. https://www3.weforum.org/docs/WEF_DAOs_for_Impact_2023.pdf, Accessed: 31.07.2023

[7] Jentzsch, Christoph. (2017): DECENTRALIZED AUTONOMOUS ORGANIZATION TO AUTOMATE GOVERNANCE, https://lawofthelevel.lexblogplatformthree.com/wp-content/uploads/sites/187/2017/07/WhitePaper-1.pdf

[8] VitaDAO (2021): How VitaDAO Works, https://vitadao.medium.com/how-vitadao-works-61bbf861fe96, Accessed: 31.07.2023

[9] Cumbers, John (2023): Longevity Startup VitaDAO Raises $4.1m, Backed By Pfizer, Balaji Srinivasan, https://www.forbes.com/sites/johncumbers/2023/01/30/longevity-startup-vitadao-raises-41m-backed-by-pfizer-balaji-srinivasan, Accessed: 31.07.2023

[10] DeFrancesco, L., Klevecz, A. (2022): Decentralized investor communities gain traction in biotech.Nat Biotechnol 40, 1310–1315 (2022), https://doi.org/10.1038/s41587-022-01459-z

[11] HairDAO: Landing Page, https://hairdao.xyz, Accessed: 31.07.2023

[12] Fehder, D.C., Murray F., Stern, S. (2014): Intellectual property rights and the evolution of scientific journals as knowledge platforms. International Journal of Industrial Organization (Volume 36) https://doi.org/10.1016/j.ijindorg.2014.08.002.

[13] Molecule: Intro to IP-NFT, https://docs.molecule.to/documentation/ip-nfts/intro-to-ip-nft, Accessed: 31.07.2023.

[14] Feldman AM (2015): Bench-to-Bedside; Clinical and Translational Research; Personalized Medicine; Precision Medicine-What's in a Name? Clin Transl Sci. 8(3):171-3. doi: 10.1111/cts.12302.

[15] Abu-Odah, H., Said, N. B., Nair, S. C., Allsop, M. J., Currow, D. C., Salah, M. S., Hamad, B. A., Elessi, K., Alkhatib, A., ElMokhallalati, Y., Bayuo, J., & AlKhaldi, M. (2022): Identifying barriers and facilitators of translating research evidence into clinical practice: A systematic review of reviews, Health & Social Care in the Community, 30, e3265– e3276. https://doi.org/10.1111/hsc.13898.

[16] Watson, Clare (2021): Health researchers report funder pressure to suppress results. https://www.nature.com/articles/d41586-021-02242-x, Accessed: 31.07.2023.