مبادرات محمد بن راشد آل مكتوم العالمية
Mohammed Bin Rashid
Al Maktoum Global Initiatives

كلية محمد بن راشد للإدارة الحكومية
MOHAMMED BIN RASHID
SCHOOL OF GOVERNMENT

Mohammed Bin Rashid School Of Government
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Summary

This review explores the current landscape of decentralized governance as enabled by blockchain technology, examining its development, implementation, risks, benefits, and applications. We survey key case studies including Bitcoin, Ethereum, Tezos, Cardano and Algorand, assess the governance models of DAOs, and consider emerging regulatory frameworks such as the U.S. Financial Innovation and Technology Act. We also explore how decentralized governance interfaces with AI and operational resilience. The review concludes by identifying future directions and conditions necessary to realize effective decentralized systems.

Network Decentralized Governance: Examples, Risks, Benefits, and Applications[1]

Mark Esposito and Massimo Morini

Introduction

The way we share information and participate to social life has changed dramatically since the advent of the internet. This puts traditional governance frameworks under strong pressure to adapt to digital interconnectedness and technological changes. This happens at the level of nation states, corporations, and other communities. Current governance models are characterized by centralized, rigid and bureaucratic layers of governance that lack adaptability, transparency and capillarity to address the localized and dynamic challenges of a digitally connected society. Participants perceive governance as distant and inefficient and can feel marginal and underrepresented.

The 2030 Agenda for Sustainable Development of the United Nations includes accountable and inclusive governance among its goals. 78 UN member states are also part of the Open Government Partnership[2] to ensure public access to data and more efficient digital governance. For the corporate world, the EU parliament issued in 2022 the Corporate Sustainability Reporting Directive (CSRD), which mandates disclosure on governance bodies to ensure transparency, greater stakeholder engagement, sustainability. In these initiatives, often the stress is towards moving more power from central government structures towards citizens or other stakeholders. A 2021 report from the World Bank says “Decentralization —the transfer of authority, responsibility and resources over public function

from the central government to local governments or other local entities — is one of the most significant public sector reforms pursued by countries around the world"[3].

Decentralization is a term that has recently been used prominently in relation to blockchain technology. Blockchains are web networks using *peer-to-peer* communication and data storage among *cryptographically authenticated* participants, whose rights and wills are verified and enacted by *community consensus*, which differs from traditional web services based on private servers centralizing authentication and permissions. Blockchain platforms already allow direct, disintermediated ownership and management of digital rights (*tokens*) created on the platform, through *consensus algorithms for decentralized validation* of transactions and *smart contracts*, which are a set of codified rules acting digitally over a transparent ledger. Upon their decentralized tech stack, blockchain can achieve three desirable levels of decentralization: operational, economic, and governance. The minimum requirement for the operational level is the decentralization of transactions and transaction validation, but thanks to technological improvement it is being achieved in a growing number of additional applications, such as decentralized finance. Economic decentralization is achieved when no economic group can exert excessive control of the operational activities. These conditions often arise as networks grow and mature. But full decentralization also requires the presence of decentralized governance systems based on blockchain technology that can be used by the community to drive the evolution of the network. This paper explores the potential for blockchain-based decentralized governance, with its achievements, open issues, and possible improvements, to provide a solution to some of the challenges encountered by governance models.

Foundations in Economic Literature

Blockchain technology has been recently suggested as a tool to improve the governance of digital commons[4] - data, processes, knowledge, and assets created in the digital world - and to enhance the democratic process with digital tools.[5] But the debate around decentralized governance has deep roots in the economic literature. Seminal works such as Hardin (1968)'s "Tragedy of Commons"[6] or Olson (1965)'s "Logic of Collective Action"[7] led to a wave of pessimism over the possibility of self-governance outside small, isolated communities with simple economic structures. The disproportion between the cost of commitment towards the community, bore fully by the individual, and the benefit, shared with all other members and vanishing when the community grows, favours free riders and kills the incentives to act for the common good. In such a context, centralized governments that appropriate community resources but contain their individualistic exploit and protect private resources are preferrable.

The Ostrom's principles, expressed in Governing the Commons (1990) book and in several seminal papers,[8] are an energic, well documented reaction to this academic pessimism towards decentralization. Differently from academic assumptions, empirically the information, monitoring and sanctioning capabilities of centralized governments are not perfect and not free from costs. Community individuals can successfully coordinate to share information, monitor behaviour reciprocally, and develop advanced institutional arrangements. But such self-organized collective actions happen when communities manage to "avoid free-riding, achieve high levels of commitment, arrange for new institutions and monitor conformity to a set of rules". This is empirically more likely when a few principles are followed, known as Ostrom principles, and ranging from clear, specific and transparent rules for community participation, to the design of nested, multicentric layers of governance within a solid institutional context.

Economists could not predict the development of a technology like blockchain, where rules are enforced by consensus protocols on peer-to-peer networks that share transparent information and coordinate mutually untrusting players through a system of incentives for collective action. The success of blockchain networks is an empirical proof of Ostrom's principles, yet it still suffers important limitations. Starting from Bitcoin, blockchains manage collectively a platform that protects private digital monetary resources through cryptography and allow peer-to-peer transfer of them, but the extension of the technology to further levels of self-governance is not trivial. For example, the joint management of common monetary digital resources is more complex than just preserving and transferring the private resources of the community members. Tools have been developed by blockchain communities, from multi-signature addresses to smart contracts

that introduce a novel way to commitment and enforcement, but their efficient employment to replace centralization is still subject of empirical experimentation beside theoretical research.[9]

Even more challenging is the extension of the collective maintenance of the platform, already successful in the Bitcoin case, in the direction of the collective management of the evolution and transformation of the platform rules and methods over time. Here some earlier blockchains have shown their limitations in a resounding, and at times self-complacent, way: Bitcoin maximalists oppose any upgrade of the rules, claiming that any attempt would risk bringing the network back to the risk of private appropriation of resources and centralized exogenous control. While the risk is real, the need to tackle it becomes more obvious with the growing popularity of blockchains and the extension of their applications, or when technical innovation such as quantum computing shakes the technological and computational assumptions.

It is natural to follow the same principles that explain the existence of blockchains also in analysing the attempts to extend their functionalities, as shown by the empirical literature of the topic[10].

In this spirit, we start from the empirical evidence, with the advantage of analysing its evolution across the still-unfolding history of various projects. Only after the empirical analysis we will attempt to abstract a few principles from the phenomena observed, offering a conceptual framework for application. Additionally, a red thread running through our analysis will be some attention to economic (or "tokenomic") design and the interplay between governance structures and economic incentives and interests. Such a dynamics drives and twists the development of blockchain governance, as much as it was at the root of the original institutional innovation that made blockchains possible in the first place. The issues we will see bear links with the analysis of Elinor Ostrom about the management of commons, while the empirical solutions often recall the Ostrom principles, empowered by the digital tools of blockchain tech.[11]

Decentralized Network Governance

The most popular example of blockchain decentralized governance in the management world are DAOs (Decentralized Autonomous Organizations), which garnered significant attention around 2022. DAOs are digital entities that share similarities with a traditional company structure but have automatic enforcement of operating rules and operate as collectives in which members make decisions democratically.[12] DAOs illustrate the potential of blockchain technology for governance. Yet, they usually have specialized economic goals, while relying on the technology of a larger, independent, general-purpose blockchain network, a so-called *layer-1*. Their application is still limited, and very specific. A 2023 survey by Chainalysis[13] covers the ten largest DAOs, totalling 14B$ of governance token market cap. Six of them, accounting for 62% of the governance token value, manage apps providing some decentralized financial services running on Ethereum, the second largest Blockchain after Bitcoin. In fact, nine of the DAOs reported run on Ethereum. Only one, ICP, is a full ecosystem independent of Ethereum, and accounts for only 0.9% of the market cap.

The last example is the only one in scope for the analysis in this paper, that focuses on the governance of independent blockchain networks. DAOs are still in their infancy and may not be the most informative example of decentralized technology in 2024. There are already examples of decentralization in the governance of full blockchain networks. These modes of governance include DAO aspects but usually escape the narrow definition of DAOs. They have a wider scope, from changes to the fundamental rules of the network to the management of different community resources.

Today, decentralized governance of layer-1s is still facing challenges, to ensure large, expert, long-term participation, and to avoid conflict of interest and waste of resources. While these may appear typical problems in governance, in the application to decentralized management of blockchain digital commons they take a peculiar shape, and so do the technological solutions devised.

In this paper we first recall some relevant examples of layer-1's decentralizing their governance, and then we analyse what we can learn from these processes. We illustrate what blockchain governance has

achieved and where needs to be improved, looking at the examples as an experimental setting for the design of new governance structures, applicable more widely to digital networks and their commons, and inspiring regulatory requirements.

Examples of Network Decentralized Governance

Bitcoin and **Ethereum**, the two largest chains, have Governance processes only for changes in the protocol code. These were set up years ago and have a lot in common with traditional governance processes, but with strong elements of decentralization. Changes usually start with a public Improvement Proposal document which is then reviewed and discussed by the community. It is accepted only if it reaches large consensus, but most of the decision process happens off-chain. Code changes are then implemented by a specific group of developers, like the so-called Bitcoin Core Developers. Then, the nodes have a final word since they must decide to upgrade their software for the change to take place, but this is the only fully decentralized part.

It is some of the smaller and more recent chains that have focused their efforts on decentralized governance. They try to make full use of the possibilities offered by the technology, such as allowing any public key to cast a vote certified by using the private key and recorded in an immutable ledger.

Dash, a pioneer of decentralized governance, launched in January 2014. In August 2015, Dash introduced a system focused on selecting community proposals to pay out grants. This early example of decentralized governance was hailed as a groundbreaking innovation.[14] However, its implementation faced significant criticism, including from Dash's own management. To ensure committed and expert choices, there were 5000 "masternodes" that could participate to voting, with no involvement of other player. In practice, the actual median participation among these was 807, so most of the proposals were approved by a mere 17% of them. Of the 474 proposals submitted in the first 2.5 years, 67.7% received funding, a high rate of approval that led to rumours of conflict of interest between voters and grant recipients, reinforced by the fact that more than 100 of the approved proposals came from the same two entities. For several approved proposals, the conflict of interest was explicit, since they provided direct benefits to masternodes. More than 60% of the approved proposals fell in the marketing and events category, with topics like governance, research, adoption, development being strongly underrepresented.[15]

Decred, launched in 2016, introduced several innovations. First, voting rights were given not only to validation nodes but to all participants based on their "stake", or the number of tokens held on-chain. This tokenization feature later became a standard for decentralized governance on blockchains. Second, Decred widened the governance scope through the Politeia app, allowing participants to propose and vote on protocol changes to the rules of the system. Decred's ability to avoid contentious hard forks through pre-vote consensus has been well-received. This approach prevents community divisions and ensures smoother implementation of changes compared to other cryptocurrencies like Bitcoin. However, some members of the community lamented that the app was off-chain and therefore at risk of centralization, and that stake-based voting required rewarding the utilization of capital.

Tezos, launched in 2018, is instead designed with a native on-chain decentralized governance mechanism to propose and vote protocol changes. The governance process is structured into five periods: Proposal, Exploration, Cooldown, Promotion, and Adoption. The first governance proposal, Athens A, was proposed, voted, and implemented in 2019. As of November 2024, Tezos has successfully implemented 16 major protocol upgrades. The participation has often exceeded half of the stake, helped by the fact that voters staking their tokens could earn rewards through transaction validation.

Internet Computer (ICP), one of the few blockchain networks to call itself a DAO because of decentralized governance, went further introducing specific rewards aimed at governors.[16]

Algorand was launched in June 2019 and built a decentralized governance system in 2021. Algorand has some features that make its story a compelling example of the interaction of decentralized governance with tokenomics:

- As a pure-proof-of-stake chain, Algorand had no incentives for transaction validation.
- Much of the native crypto assets had been set apart for future community incentives.
- Some resources were used to incentivized decentralized governance, with several evolutions and experimentations.

In Algorand, governors are required to stake tokens and participate consistently over a three-month period to be eligible for voting on governance issues. Since user resources are not locked, compensating committed governors, with rewards received only at the end of the period, served as an incentive for sustained and dedicated participation. Evidence suggests that the magnitude of rewards played a crucial role in driving participation. A gradual 76% reductions of governance rewards over 2 years led to an almost proportional reduction of participation, from 55% to 19% of the available stake.[17] The importance of rewards for stake-based governance is economically rational, since holding resources to prove commitment can compete with other economic activities on-chain or off-chain, but raises several questions. How to deal with conflict-of-interest when governors must decide about their own rewards? What level of rewards can be sustainable? Are there other ways to compensate the opportunity-cost and incentivize long-term participation when voting is based on staking?

In Algorand conflict of interest has been at times addressed through designing decision methods about rewards that made governors share the burden of rewards increases, tying any increase of rewards to increases in governors' commitment.[18] In order to mitigate the opportunity-cost, Algorand set up in 2022 to allow participants in economic activities such as liquidity provision in decentralized exchanges and decentralized lending to participate in governance proportionally to their monetary commitment in these activities. This helped increasing participation. Transaction validation was originally included in the plan to reward the most important form of commitment,[19] but not implemented at that time. The latest step in experimentation, the introduction of validation rewards in early 2025 to replace most of the others, is too recent to judge on its consequences.[20] Algorand also experimented other non-monetary incentives to ensure informed and long-term commitment of voters. In the xGov project, experienced governors that participated consistently in governance for longer periods have unique decision powers for budgeting and selecting different kinds of expenses.

Polkadot, launched in May 2020, is also characterized by interesting experimentation. First, it shows another route to the same need of committed and expert governance that led Algorand to introduced xGovs. With "conviction voting", voluntary locking increased the voting power: accepting to lock tokens in governance for 32 periods could multiply voting power by a factor of 6. Polkadot also introduced a Treasury endowment dedicated to funding community projects, that experienced two different governance models. First, a model with participation happening mostly through elected digital intermediaries called "the Council". Then, since June 2023, an "OpenGov" model with direct vote of token holders. Since then, the size of the Treasury halved in around one year, with some community members considering this a proof of increased allocation efficiency, and others complaining about the expenditure growing to $25M in the second half of 2023 and then doubling to $87M in the first half of 2024.[21]

Cardano, launched in 2017, took a gradual approach to decentralization. The decentralization of validation was completed only in 2020, when Cardano introduced also a decentralized Treasury system, whose design, described in an academic paper[22], predates the Polkadot one. The initiative was taken by the founding entities, and spending of Treasury resources also started gradually, with the support of a growing ecosystem for decentralized analysis of community proposals. From end of 2020 to end of 2024, little less than 20% of the treasury was used, while Voluntary Advisors and Reviewers grew from 50 at the end of 2020 to 4500 in late 2024, with other roles emerging such as Moderators and Milestone reviewers. In this period, around 25% of the proposals have received funding, and half of the funded projects are now completed.[23] These are more reassuring statistics than other ecosystems but worries of conflict of interest and inflation are growing, associated to the accelerations of the rate of spending in recent years. These are reinforced by the fact that the, while the number of votes cast has grown from 23.000 to 292.000, stake did not have a comparable growth, causing worries that interested minorities can exert excessive power on voting, potentially favouring well-connected applicants over the most deserving projects.

These difficulties might be driven by the friction between the original initiative, when centralized leadership and low stake representation were acceptable, and the goal of a more radical decentralization of governance pursued by the ecosystem. In fact, the most ambitious components of Cardano decentralized governance only entered in action in early 2025. After years of preparation, a constitution was approved, triggering a shift from founding-entities-control to decentralized governance.[24] It introduced delegation of voting power, super-majorities for some decisions, and guardrails (hard limits) to some parameter changes. Cardano was built since the beginning as a structured, algorithmic infrastructure depending on precise parameters: 5 technical parameters, 9 network parameters, 11 economic parameters, and several recently introduced governance parameters. Parameters drive for example the release of Community Reserves and how they are distributed between Treasury and validation Rewards, that are also parameterized. Parameterization makes decentralized governance easier, since governors can vote on parameter changes that are automatically implemented. It also allows precise modelling and assessment of the consequences of individual or joint changes of parameters, although it does not address changes to current algorithms that go beyond parametric changes. While this system has run for years, testing of its decentralized evolution has just started. The next few years will be crucial to asses the success of this long-planned devolution of power.

Risks, Solutions, and Benefits

The previous sections outlined trends toward Decentralized Governance in public blockchain networks, with thousands of people involved with proposals, analysis, voting, and debate on improving the quality of decentralized governance. The liveliness of the communities, when coupled with the rate of experimenting new technologies, has no other comparisons in today's societies. It is leading the experimentation of new governance technologies in economically relevant contexts, with decentralized Treasuries administering values of billions of dollars and distributing hundreds of millions. Yet, we have also mentioned several empirical issues. We can group them in 4 main categories:

1. Lack of expertise and commitment
2. Lack of execution/implementation powers
3. Lack of accountability and conflict of interest in resource spending
4. Lack of participation and inclusivity

Notice that the latter two points correspond to the need to implement the Ostrom principles associated to inclusivity, participation, monitoring and gradual sanctioning, while the initial ones echo the traditional perplexities about governance decentralization ("tragedy of commons"). For each of these issues we will propose a few solutions, inspired by the experience from layer-1 decentralized governance systems and driven by principles from the literature on the governance of commons. We will see blockchain solutions implementing not only the fundamental principles just mentioned, but also the principles of nested and multicentric governance based on clear and specific rules.

Expertise and Commitment

Decentralized communities are aware that decentralized governance can lead to suboptimal decision-making compared to centralized systems, if technical experts and experienced leaders are not involved. Some communities criticized decentralization due to concerns about the capability of general users to make sufficiently informed decisions on technical or specific subjects; this was part of the debate surrounding the 2.65M$ marketing expenses voted by the Dash community[25]. The Tezos community argued that the Athens1 proposal was too complex to be judged by its users. Since 80% quorum had to be reached for the decision, many users had to express their views about an issue they did not know in sufficient detail[26].

We have seen a few solutions:

- *Vote Delegation.* Voting power can be delegated to expert members that commit to take the governance mission as a professional role. They can vote instead of less experienced players based on an explicit delegation. Cardano has implemented Delegate Representatives in line with the relevance of staking delegation in the network consensus algorithm.

- *Expert Voting.* The voting power of members can grow with the time of participation, giving more weight to experience members. For systems based on stake, voting power can be proportional to the size of the economic commitment, and to the willingness to lock commitment for longer stimes, ensuring governors have skin-in-the-game that should align their interest with the one of the network. Polkadot and Algorand have similar systems, that are easy to automate within blockchain networks.

- *Decentralized Review*. The experience of decentralized treasuries suggests that growing an ecosystem of decentralized advisors and reviewers improves the outcome. They can also develop tools to assist community members to perform analysis and testing of the consequences of different decisions, particularly if the network functioning is parameterized, a topic we cover in the following. This is part of the broader issue of off-chain entities collaborating with on-chain governance. It presents some difficulties and risks but, in line with the principle of multicentric governance, can work as long as decentralization and transparency are maintained both on-chain and off-chain.

Execution and Implementation

In some cases, blockchain technology allows a decentralized governance decision to trigger automatically its implementation, as it happens in case of choosing across options to distribute grants or changing parameters. This can happen also for some code change decisions. But more generally, on-chain decision power is not matched by on-chain capability of implementation, and off-chain organization must take responsibility for this. Thus, we can consider the following solutions for executing governance decisions:

- *Parameterization*. When the main processes driving the network, for example the tokenomics rules about Reserves and Treasury spending, are parameterized, decentralized governors can vote changes to parameters that are automatically implemented. Parameterization allows also to set guardrails that limit power abuse, a topic covered in the next section.

- *Self-Amendment.* Procedures can be implemented to allow direct changes to the blockchain code, more general than parameter changes. This approach was pioneered by Tezos with its self-amending protocol. Today the development of algorithms for general code changes can also make use of controlled AI systems, as we will mention later in the paper.

- *Off-chain collaboration*. Otherwise, off-chain bodies must be delegated with implementation. One must ensure this does not become a bottleneck, a single point-of-failure giving all powers back to a centralized entity. As we said, when on- and off-chain governance need to interact it is critical that the off-chain delivery remains transparent and accountable to the on-chain governance mechanisms. This remains one of the significant challenges for the blockchain industry, but notable progress has been made, even within the governance structures of the earliest blockchains Bitcoin and Ethereum

Accountability and Resource Spending

A typical concern of decentralized communities is the excessive expenditure of resources managed through decentralized governance.[27] This is due in part to fear of decisions taken without sufficient analysis and planning and can be addressed with a community of reviewers, expert delegation, and granular and parameterized votes supported by analysis when it comes to budgeting expenses.

But fear of excessive expenditure in past examples did not only depend on possible lack of experience or planning. The main worry in some early examples was that, due to low participation, decisions could be taken by a minority of the players, not representing the general network economic interest. An issue reminiscent of traditional free-rider and agency problems in economics, leading to conflict of interest. This is a typical problem also in centralized management, where it is often managed by individual accountability. Decentralized management has a few specific solutions:

- *Built-in trade-offs*. An ad-hoc solution for conflict of interest has already been seen in the specific case of governors deciding on their own benefits: tying any increase of rewards to increases in

governors' commitment.[28] The principle can be extended to other cases of specific conflict-of-interest.

- *Guardrails*. Another technical solution that it is easy to implement in code-based rules is the introduction of limitations and guardrails in decision making. Tokens to be distributed in the future can be secured in digital wallets representing transparent endowments that can be used only for specific purposes, following precise procedures, and for specific amounts. This way precise guardrails can be set to ensure continuity, inclusion, and fair usage, subjecting changes to precise rules, and expenses to granular budgets and temporal limits.

- *High Participation and majority thresholds*. The most radical solution is increasing participation to realign decision making with community interest. This can also function as a solution to some specific risks that can be associated with decentralized technology. In case of decentralized Treasury management, where the primary objective is allocating funds to different projects, rogue players or external attackers may temporarily accumulate or borrow stake to vote and detour resources towards themselves. This attack, however, is feasible only if participation is low. When it starts increasing, this opportunity fades away. Supermajorities, and participation thresholds, can be easily set and be required for certain decisions, and made proportional to their objective relevance, such as the size of expenditures. Both the participation and the control on the management can reach levels impossible in centralized, opaque, and closed traditional systems. This leads us to the next topic.

Participation and Inclusivity

Increasing participation and inclusivity means first increasing the number of voters across different categories, and the amount of stake represented. We have seen why it is an issue, and several solutions.

- *Rewards*. Sustainable and well-designed incentives to participation are a simple solution. The examples we have seen are very clear: the correlation between governance rewards and participation rates is significant. This is related to the role of stake in decentralized blockchain in governance. Stake-based voting means "skin-in-the-game": those with decision power are also those that would suffer more the consequences of bad governance, through a loss of value and usefulness of their stake. This is a game-theoretical incentive to good behaviour, a principle applied by all blockchains in their consensus algorithms, and in governance it is also consistent with the first Ostrom principle. Yet, stake is capital, and the use of capital require compensation, while decentralized communities have limited resources.

- *Committed Governors*. There are alternatives to avoid excessive reliance on stake, or even locked stake, in governance. There are economic actors that have already specific alignments with the interests of the ecosystem, such as transaction validators or participants to economically relevant decentralized applications. Once their commitment is measured fairly, they are natural governors and are usually already compensated for their capital commitment.

- *Multiple Approval*. To ensure participation is matched by diversity, inclusivity, and better decision-making, some decisions may require approval by more than one category or cohort.[29][30] This is consistent with the second and third Ostrom principles for polycentric governance, and provides a form of check and balance, as needed in all well working governance systems. Cardano constitution provides examples of decisions that require not a simple stake majority, but also the support of most Delegate representatives, or most Validation pools, or in some cases both.

Implications for Public Governance and Policy Recommendations

The findings of this analysis underscore profound implications for the evolution of public governance in an increasingly digitized and data-driven world. Decentralized governance models pioneered within blockchain ecosystems provide a real-time experimental field for reimagining how collective decision-making, transparency, and accountability can function beyond the constraints of traditional

bureaucratic systems. They demonstrate how distributed consensus and algorithmic verification can reduce principal-agent problems, mitigate corruption risks, and enhance procedural legitimacy.

In conventional governance, information asymmetry and centralization often slow responsiveness, discourage participation, and create distance between citizens and institutions. By contrast, decentralized systems allow rules, incentives, and outcomes to be transparent, auditable, and enforced automatically through smart contracts. This not only strengthens accountability but also aligns public administration with the principles of inclusion and shared stewardship that underpin the United Nations' Sustainable Development Goal 16 on effective, accountable, and inclusive institutions.

The ability of blockchain networks to record, audit, and verify every decision on immutable ledgers offers a transformative pathway for rebuilding citizen trust in institutions a challenge faced by many governments experiencing declining legitimacy. Trust can be operationalized not through rhetoric but through verifiable digital infrastructure that guarantees procedural fairness and integrity. Governments confronting governance fatigue, bureaucratic opacity, or weak participatory mechanisms could therefore draw valuable lessons from these decentralized governance experiments to design public participation architectures that are transparent by default, traceable in execution, and resilient to manipulation. In this sense, decentralized governance should not be seen as a technological novelty but as a potential constitutional innovation, one that shifts the locus of trust from institutional intermediaries to verifiable, tamper-resistant systems.

Based on these findings, several policy recommendations can be advanced:

1.Pilot blockchain-based participatory budgeting and resource-allocation platforms.

Governments could adopt decentralized digital platforms to enable verifiable citizen voting on local or national spending priorities. Recording every transaction and decision on a public ledger would ensure auditability, prevent misappropriation, and enhance civic ownership of public expenditures. Such pilots would demonstrate how trust and efficiency can reinforce each other when transparency is embedded in the decision process.

2. Institutionalize algorithmic audit trails for public-sector AI and administrative systems.

Public authorities should use blockchain architectures to log and verify algorithmic and bureaucratic decisions, ensuring compliance, accountability, and traceability. This would allow regulators and citizens alike to understand the rationale, inputs, and consequences of AI-enabled public decisions, transforming opaque processes into explainable governance mechanisms.

3. Promote polycentric, nested governance frameworks for digital public infrastructure.

Inspired by decentralized blockchain systems, policymakers should distribute authority across multiple centers that operate under transparent and parameterized rules. Such multi-layered governance can enhance resilience, coordination, and inclusivity while minimizing the concentration of decision power. This would particularly strengthen inter-agency collaboration, transnational governance, and multi-stakeholder initiatives where no single entity should dominate.

4. Establish regulatory sandboxes and living labs for decentralized governance innovation.

Governments and international organizations should create experimental environments to test decentralized mechanisms, such as token-based participation, delegated voting, smart-contract enforcement of policy commitments, or digital identity-based accountability systems, under controlled conditions. These sandboxes would balance innovation and public protection, allowing legal frameworks and technical standards to co-evolve. They would also help regulators develop evidence-based guidelines for scaling successful models while identifying and mitigating systemic risks.

Together, these recommendations suggest that decentralized governance, far from being confined to blockchain communities, could become a foundation for a new generation of public institutions, those that are transparent by design, participatory in operation, and adaptive in regulation. By drawing from the governance architectures of decentralized networks, policymakers can begin to craft more trusted, efficient, and equitable systems of public decision-making suited to the complexities of the digital age.

Conclusions and Future Applications

In this work we have illustrated several examples of decentralized governance of layer-1 blockchain platforms, analysing both the issues faced and the solutions experimented. For independent blockchain networks, the presence of a decentralized governance system has also been proposed as a regulatory requirement, in the "Financial Innovation and Technology for the 21st Century Act", approved by the USA Congress with bipartisan support in September 2024. The policy states that financial securities regulations will not apply for blockchains or digital ledgers that are "decentralized and functional systems". Much less demanding commodity regulation will apply if these requisites are accepted. The Act prescribes lighter regulations for blockchains or digital ledgers that have a 'decentralized governance system', defined as a "rules-based system permitting persons using the blockchain or the digital assets related to such blockchain system to form consensus or reach agreement in the development, provision, publication, management, or administration of such blockchain system". The disclosure requirements include, beyond supply, issuance, and consensus, also "an explanation of governance mechanisms for implementing changes to the blockchain system or forming consensus among holders of such digital assets"

The purpose of our analysis has been studying the examples of decentralized governance of blockchain networks as an experimental setting, to understand their potential but also their limitations, and propose solutions for improvement and standardization.

We can conclude that, even with the observed limitations, the collective governance of blockchain networks has made big technical progresses since the DAO hack in 2016 and the hard fork that followed. That was a crucial lesson to improve the standards of decentralized development, testing and auditing.[31] As we have seen, over the past several years decentralized systems have demonstrated the ability to operate with remarkably few technical issues, organizing their governance and experimenting several improvements.

If we compare with traditional systems, blockchain technology has consistently proven to offer greater operational resilience, transparency, and auditability, a point that the blockchain community has started to make with financial regulators.[32] Decentralized systems are open access and log all governance actions on immutable ledgers, ensuring that every decision and action can be traced and verified. This increases both fault-tolerance and trust, reducing the risk of errors or frauds, compared to opaque traditional systems that still rely on completely centralized points of failure.[33] Traditional governance models frequently struggle with transparency issues that undermine their effectiveness and public trust. The opacity in centralized systems manifests in decision-making processes that remain hidden from stakeholders. This lack of visibility creates a disconnect between governing bodies and constituents, leading to the disempowerment of citizens. When citizens cannot observe how or why decisions are made, the legitimacy of governance is compromised. The transparency inherent in decentralized systems reduces the risks of fraud, mismanagement, and hidden agendas,[34] making blockchain an increasingly compelling choice for governance and operational integrity.

A second observation is that the current state of the art may be rapidly revolutionized by the interplay between blockchain decentralized governance and artificial intelligence (AI). This offers some unique opportunities. On one hand, AI can become a powerful tool in blockchain governance, providing enhanced analysis and predictive modelling. By processing vast amounts of data, AI can help stakeholders make more informed and strategic decisions, reducing inefficiencies and enhancing collaboration in decentralized systems. AI can process blockchain transaction histories and governance proposals to predict outcomes and optimize resource distribution. Moreover, AI systems automatically update governance protocols when detecting new legal requirements through global regulatory databases.[35]

Even more importantly, blockchain itself is uniquely positioned to address critical challenges in the governance of AI algorithms. Opaqueness and lack of accountability in AI can have dramatic ethical, economic and legal implications.[36]

Blockchain technology and immutable ledgers can provide transparency to AI systems, by recording and certifying algorithmic steps for increasingly complex algorithms, enabling robust audits and accountability. Decentralized systems can automate and enforce ethical guidelines or regulatory frameworks in AI applications, to help detect and prevent biases, misuse or manipulation of AI engines. AI training data, uniquely identified in a succinct way by hashing, can also be validated and certified, to ensure they remain unbiased and adhere to ethical standards. With cryptographic technologies like zero-knowledge proofs and homomorphic encryption, blockchain can facilitate privacy-preserving mechanisms, allowing sensitive data to be used in AI systems without compromising individual privacy.

As of now, the integration of blockchain governance tools and AI productivity presents significant technical challenges, but the stakes are equally high. By integrating AI into decentralized governance, and blockchain into AI governance, it is possible to create systems that are not only more effective, resilient and transparent, but also more accountable, equitable, and privacy-preserving.

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Author(s) and Citation

This Policy Brief was authored by:

Mark Esposito
Professor of Economic Policy
Mohammed Bin Rashid School of Government

Massimo Morini
Bocconi University, USI University of Lugano, and ADIA Lab - Abu Dhabi

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MOHAMMED BIN RASHID SCHOOL OF GOVERNMENT

Mohammed Bin Rashid School of Government
Convention Tower, Level 13, P.O. Box 72229, Dubai, UAE
Tel: +971 4 329 3290 - Fax: +971 4 329 3291
www.mbrsg.ae - info@mbrsg.ac.ae