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Exploring blockchain technologies for collaboration and partnerships

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GO Lab is a research and policy centre based in the Blavatnik School of Government, University of Oxford. GO Lab investigates how governments partner with the private and social sectors to improve social outcomes.

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Executive summary

Blockchain technology has emerged as a promising solution for collaboration and partnerships, providing a secure and transparent way for multiple parties to interact and transact without intermediaries. Despite its wide-ranging utility and applications, an overreliance on technical jargon and buzzwords has hindered the technology's outreach to a broader audience, including the public sector. Recent market developments related to cryptocurrencies have also tarnished the technology's image.

To address these challenges, this report offers practical guidance on applying blockchain to facilitate broader collaboration and partnerships, with a particular focus on its relevance to government and other public sector bodies that seek to improve social, economic and environmental outcomes. Drawing from a rapid review of literature, expert interviews, a survey of practitioners and stakeholders, and two case studies, the report discusses key concepts and frameworks, explores opportunities and challenges and presents a decision-making framework for public managers contemplating the adoption of blockchain technologies in collaborative initiatives.

This report finds that blockchain technology possesses key features such as *immutability, decentralisation* and *programmability*, which enable the creation of decentralised networks that have the potential to do the following:

- **Support relationships and trust** by enhancing data security, enabling democratic sharing of information, creating smart contracts and reducing costs associated with building and maintaining relationships.
- **Facilitate coordination:** in areas with multiple reporting mechanisms, blockchain offers a new way to achieve information consistency in project management, eliminate manual reconciliation in financial and sustainability reporting and enhance coordination.
- **Enhance transparency and accountability:** improve understanding of programme effectiveness and combat corruption in public spending and procurement by enabling transparent tracking of outcomes and funding sources, thereby enhancing accountability.

While blockchain technology holds potential benefits in various areas, it is not a panacea and has limitations that need to be considered.

These limitations may include the following:

- **Immutability at the expense of flexibility:** while immutability ensures the integrity of transactions, it also means that once a transaction is recorded on the blockchain, it cannot be changed or deleted.
- **Decentralisation and power dynamics:** decentralisation can create power dynamics within the network, where certain participants may have more influence or control over others.
- **Trust and the blockchain paradox:** a heavy reliance on trust in the underlying technology and the network's participants, despite the technology being touted as a way to eliminate the need for trust between parties.

Furthermore, the report presents a decision-making framework for public managers considering the adoption of blockchain technologies for collaborative initiatives. The framework emphasises the need for clear objectives, appropriate governance arrangements and stakeholder engagement, among other factors, to ensure successful implementation.

In conclusion, while the potential benefits of blockchain technology in enhancing collaboration and partnerships are recognised, its adoption must be approached with care and forethought to maximise its potential and address associated challenges.

It is important to note that existing evidence does not support the hype surrounding blockchain, particularly with regard to its supposed disruptive nature. Instead, the technology plays a complementary role and relies on other technologies, with specific and narrow-use cases, at least in the short term. Therefore, it is important to evaluate the application of blockchain technology on a case-by-case basis, considering factors such as cost, scalability and compatibility with existing systems.

Key policy implications:

1. Policymakers should approach the adoption of blockchain technology cautiously and carefully weigh its potential benefits against its limitations and potential drawbacks. Using evidence-based decision frameworks such as the one presented in this report can help ensure objective decision making.
2. Improving interoperability between different blockchain systems and existing technology infrastructure is crucial to realising the full potential of blockchain. As blockchain relies on other technologies, better integration can enhance its effectiveness.
3. Blockchain technology shows potential for addressing some of the challenges in healthcare, such as data integration and risk management, as well as promoting climate action by enhancing carbon accountability and traceability.
4. Blockchain technology can potentially benefit collaboration between different stakeholders in the public sector, particularly in areas such as procurement, public financial management and outcome-based contracting.
5. Policymakers should invest in research and development to better understand the potential applications of blockchain technology and how it can be effectively integrated into existing systems.

Glossary

Application Programming Interface (API): A set of protocols, routines and tools that allows software applications to communicate and exchange data with each other, making different sets of data and functionality programmatically accessible.

Blockchain: The International Organization for Standardization (ISO) defines blockchain as "a distributed ledger ... organised in an append-only, sequential chain using cryptographic links."[70] In this report, the term 'blockchain technology' is used to refer to the generic technology behind various types of blockchains.

Consensus mechanism: Since there is no centralised authority on the blockchain, an update is made based on a pre-defined consensus mechanism among participants approving the change. There are various ways to design the mechanism based on needs and trade-offs. Common examples include *proof of work*, which entails an energy-intensive process of solving a computational puzzle, and *proof of authority* through which a number of pre-approved participants validate the record.

Consortium blockchain: Consortium blockchain is managed by a group of individuals and organisations with varying privileges and can be considered a hybrid of public and private blockchain.[71] See also *Public and private blockchain* below.

Cryptography: Blockchain is a combination of various technologies and principles, one of which is cryptography.[8] ISO defines cryptography as a "discipline that embodies the principles, means, and methods for the transformation of data in order to hide their semantic content, prevent their unauthorized use, or prevent their undetected modification."[70]

Distributed ledger: Blockchain is a type of distributed ledger, which is a "ledger that is shared ... and synchronised ... using a consensus mechanism."[70] Blockchain is distinguished from other types of distributed ledger by its data structure (block) and cryptographic links (chain).

Node: A node refers to an independent computer within the blockchain network.[72]

Permissionless versus permissioned blockchain: The distinction between permissionless and permissioned blockchain refers to who can contribute to and maintain the data.[39] Anyone can add data to a permissionless blockchain, while only certain users can contribute data to a permissioned blockchain.

Public and private blockchain: The distinction between public and private blockchain is about who can access the data.[39] Along with the difference between permissioned and permissionless blockchain, it is a key design component of a blockchain. Anyone can access a public blockchain, while only certain participants can view the data stored on a private blockchain.

Smart contracts: The idea of smart contracts was developed in the 1990s as a set of digitally specified promises, with a feature to automatically execute the contract upon meeting criteria. The advent of blockchain technology is often associated with the reification of the idea of smart contracts due to the immutability and transparency afforded by the technology.[12]

Oracles: Oracles act as a bridge between blockchain and the external world, injecting information from the physical (hardware oracles) and web-based (software oracles) sources.[12]

Outcome-based contracting: One of the methods of incorporating an outcome orientation in public service delivery by linking (parts of) payments directly to the achievement of outcomes (GO Lab).[73]

Zero-knowledge proofs: A cryptographic protocol that allows one party to prove to another that they know a particular piece of information without revealing the information itself.

Introduction

Tackling today's social and environmental challenges requires action from more than one sector, let alone one organisation. The global agenda advanced by the UN Sustainable Development Goals (SDGs) underscores the need for multi-stakeholder engagement. Despite the demonstrable benefits of coordinated action[1], initiating, monitoring and managing complex contracts and relationships can be costly and burdensome.[2]

Blockchain technologies can facilitate partnerships by enabling the efficient and secure exchange of information.[3] Recent market developments relating to cryptocurrencies have tarnished the image of the technology, despite its wider utility and applications. However, an overreliance on technical jargon and buzzwords have not helped the sector reach a wider audience, including the public sector.

This report offers practical guidance on the application of blockchain to facilitate wider collaboration. It introduces key concepts and frameworks and explores the opportunities and challenges of applying the technology to collaboration and partnerships. The discussions are informed by a rapid review of literature, expert interviews and a survey of practitioners and key stakeholders.

Two case studies provide practical illustrations of how blockchain has been applied within existing initiatives relating to both an outcome-based approach in healthcare and carbon emissions data for climate action. This report also presents a decision framework for public managers considering adopting blockchain technologies in collaborative initiatives.

Although the research identifies best practices that may be transferable to other sectors, the focus is on the relevance of blockchain to government and other public sector bodies seeking to work with partners to improve social, economic and environmental outcomes.

Methodology

The rapid review of literature was conducted using keywords including 'blockchain in public-private partnerships', 'blockchain in cross-sector collaboration' and 'blockchain and outcome-based contracts' on ScienceDirect, Google Scholar and via a web search. Both academic and grey literature were consulted. Recent publications were strongly prioritised, and the review favoured policy-relevant evidence, while excluding purely technical literature in engineering and computer science as well as evidence exclusively focused on cryptocurrencies.

Interviews were conducted between September 2022 and January 2023. Fifteen participants were selected using purposive sampling to identify stakeholders involved in design and/or implementation of blockchain-enabled projects across a range of domains and sectors. In addition, snowball sampling was used to gain insights into the technology's diverse applications. All interviews were held virtually and conducted as panel interviews[i], with more than one member of the research team present to facilitate note-taking and probing to clarify responses by participants.

An online anonymous survey of practitioners and relevant stakeholders was conducted between December 2022 and February 2023 using an online survey software tool (Qualtrics). The survey instrument was disseminated across the GO Lab, CIPFA, World Commerce & Contracting (WCC) and Apolitical networks to maximise the reach of the study.

There were 110 respondents in total, with 62 of them finishing more than 75% of the survey (our threshold for inclusion). As the design and dissemination of the survey were not based on a person's prior knowledge of blockchain or other emerging technologies, the risk of bias was moderate to low. Results from the survey were used to evaluate the practical implications of theories and proposed use cases of blockchain.

As per the recommendations of recent academic articles[4, 5], case studies should adhere to a uniform approach to optimise evidence generation. This approach comprises four essential components for reporting, namely the justification for employing blockchain technology, the access point and code base of the application, the blockchain protocols employed, and a discussion of the benefits and challenges associated with the blockchain application for the given use case.

An international peer learning event Blockchain technologies for partnerships and outcome-based approaches was held on 11 November 2022 to further facilitate group discussions with a wider audience and stimulate knowledge exchange. The discussion was co-chaired by GO Lab and CIPFA and included four speakers with a range of experiences in applying blockchain technologies, followed by a Q&A session. There were 41 attendees (excluding the project team) representing government, business, academia and the third sector.

This study has some key limitations. First, the small survey sample (62 completed responses) may not be representative of the wider population, which limits the generalisability of findings. Second, the study draws on existing evidence from literature and expert interviews, which may introduce pro-innovation and survivorship bias. The failures of blockchain-based projects are less well documented and therefore less visible, which may skew the findings towards a more positive view of blockchain technology.

i Panel interviews consisted of more than one member of the research team and one or more interviewees. When there was more than one interviewee present, they were either from the same organisation or working on a joint initiative related to the research topic.

Blockchain 101

What is blockchain?

Blockchain is a type of data structure in which sequenced *blocks* of data are cryptographically *chained*.[6] Cryptography secures data by incorporating several features such as the conversion of an input into a randomly generated combination of alphabets and letters. The information is synchronised across multiple computers, providing each 'node' with simultaneous access to the same data. Since there is no master copy or single point of control, each participant in the network shares joint management of the data. Blockchain obviates the need for reconciliation to ensure consistency.[7]

What makes blockchain different from other technologies?

Blockchain has the potential to enable innovative ways of managing contracts and relationships. Some of the most salient features would include the following:

- **Immutability:** Each block of data is chained to a previous block in a sequential manner and the data is 'append only'. In principle, this means that blockchain is a ledger that anyone can view but no one can arbitrarily modify. The novelty of the technology therefore lies in its potential to produce "final, definitive and immutable records."[8] To illustrate, immutable records stored on blockchain can be contrasted with a spreadsheet being shared via email as an attachment (or even data saved on cloud-based services, eg SharePoint), resulting in multiple versions over time as recipients make modifications and later needing a time-consuming reconciliation.[9]
- **Decentralisation:** Rather than relying on intermediaries and central authorities to verify the data, participants in the network uphold the data integrity themselves through pre-established consensus mechanisms.[3] While there is a variety of consensus mechanisms ranging from proof of work (an energy-intensive process of solving computational puzzles to earn the right to add data) to proof of authority (only limited participants with proven identities can add data), its core objective is to establish the rules of the network and make fraudulent behaviours costly, thereby deterring such behaviours from the outset.[10]
- **Programmability:** Another important feature of blockchain is that it is written in programming languages. Its programmability complements and realises the concept of *smart contracts*, enabling "agreements built in computer code and stored on a blockchain."[11] By linking 'if-then' code (for adding conditionality) with external (off-chain) information sourced from software (eg websites) and hardware (eg monitoring sensors and other 'internet of things' devices generating data), smart contracts can be automatically executed upon meeting a set of pre-defined criteria.[12] While automated transaction itself is not at all new, blockchain enables smart contracts to execute without intermediaries and automatically creates tamper-resistant records.[13]

What are the types of blockchain?

Blockchain is a term that is sometimes used interchangeably with cryptocurrencies like Bitcoin,[14] but this overlooks the many variations in how blockchain technology is designed and used in practice. Applying blockchain requires making several design choices, and for any blockchain-based solution, it is important to identify, establish and maintain the desired properties.[15] Therefore, while Bitcoin is an example of blockchain technology, it is just one of many.

One of the most important design choices is how open a network is and who can read and write the data.[9] Public blockchains such as the one that underpins Bitcoin are open to anyone, but the technology can also be permissioned based on requirements and authentication by a consortium of participants across organisations or made entirely private.[6] Private blockchains can be a response to the handling of sensitive information hosted within public sector bodies and compliance with General Data Protection Regulation (GDPR) and related privacy concerns.[8]

There are different types of blockchain, including public, private and consortium blockchains. Public blockchains are open to anyone, while private blockchains are restricted to authorised users.

Consortium blockchains are a hybrid of the two, with a group of organisations collaborating to maintain and use the blockchain. Developing blockchain-based solutions for partnerships requires mapping key objectives and desired outcomes to these design choices. Although it is possible to build a bespoke blockchain, there are many existing general-purpose platforms that could facilitate access such as Ethereum (public permissionless) and Hyperledger (private permissioned). Many technology firms also provide customisable cloud services for developing blockchain-based solutions, or blockchain-as-a-service (BaaS).

The current state of blockchain adoption

Blockchain can be divisive. While proponents of the technology may claim it as a solution to almost everything, naysayers criticise it as 'the solution in search of a problem.' The reluctance for wider engagement with blockchain may stem from its roots as an enabler of digital currencies such as Bitcoin. Recent volatility in the cryptocurrency market, headlines on the collapse of one of its largest exchanges and wicked behaviours (like hacks and scams) have not helped to shore up confidence either.[16]

Despite these challenges, blockchain-based solutions have proliferated across a multitude of industries and sectors. Based on Fortune Business Insights, the global market for blockchain is forecast to grow from $4.7bn in 2021 to $164bn by 2029. There is the potential for many of these applications to work synergistically with existing tools and mechanisms of public governance.[17] However, the mainstreaming of this technology will require a degree of transparency and accountability that may benefit from some degree of externally imposed regulation. This is why many governments are experimenting with various applications of blockchain.

For example, the Bank for International Settlements (BIS) estimates that more than 80% of central banks have or are considering the launch of a central bank digital currency (CBDC)[18] (see also a live tracker on Atlantic Council). According to PwC,[19] an accountancy firm, some notable CBDC cases developed for the public include:

- the eNaira by the Central Bank of Nigeria, Africa's first CBDC
- the Sand Dollar by the Central Bank of the Bahamas, which is recognised as legal tender
- an ongoing CDBC pilot programme across 12 cities in China, including Beijing and Shanghai.

In recent years, use of blockchain technology has increased in the world of bond issuance. For example, the World Bank made history in 2018 by creating, allocating, transferring and managing the world's first bond using distributed ledger technology (DLT).

Similarly, the European Investment Bank (EIB) partnered with Banque de France in 2021 to issue its first digital bond on a public blockchain. On a national level, Poland's Ministry of Finance launched a blockchain-based reporting system in December 2020 to track savings bonds issued by the Polish treasury. Governments are also exploring how DLT can be applied to bond issuance. The UK government is considering this approach; HM Treasury has been investigating blockchain technology to enhance public services since 2016.

At a local level, the public authority of Lugano, Switzerland issued a six-year bond worth up to CHF 100m (roughly £88m/US$108m) via blockchain in January 2022. This move is being touted by all parties involved as a 'public sector first'. Additionally, 'digital identification' systems built on blockchain technology are gaining traction globally due to their potential to create secure and decentralised digital identities.

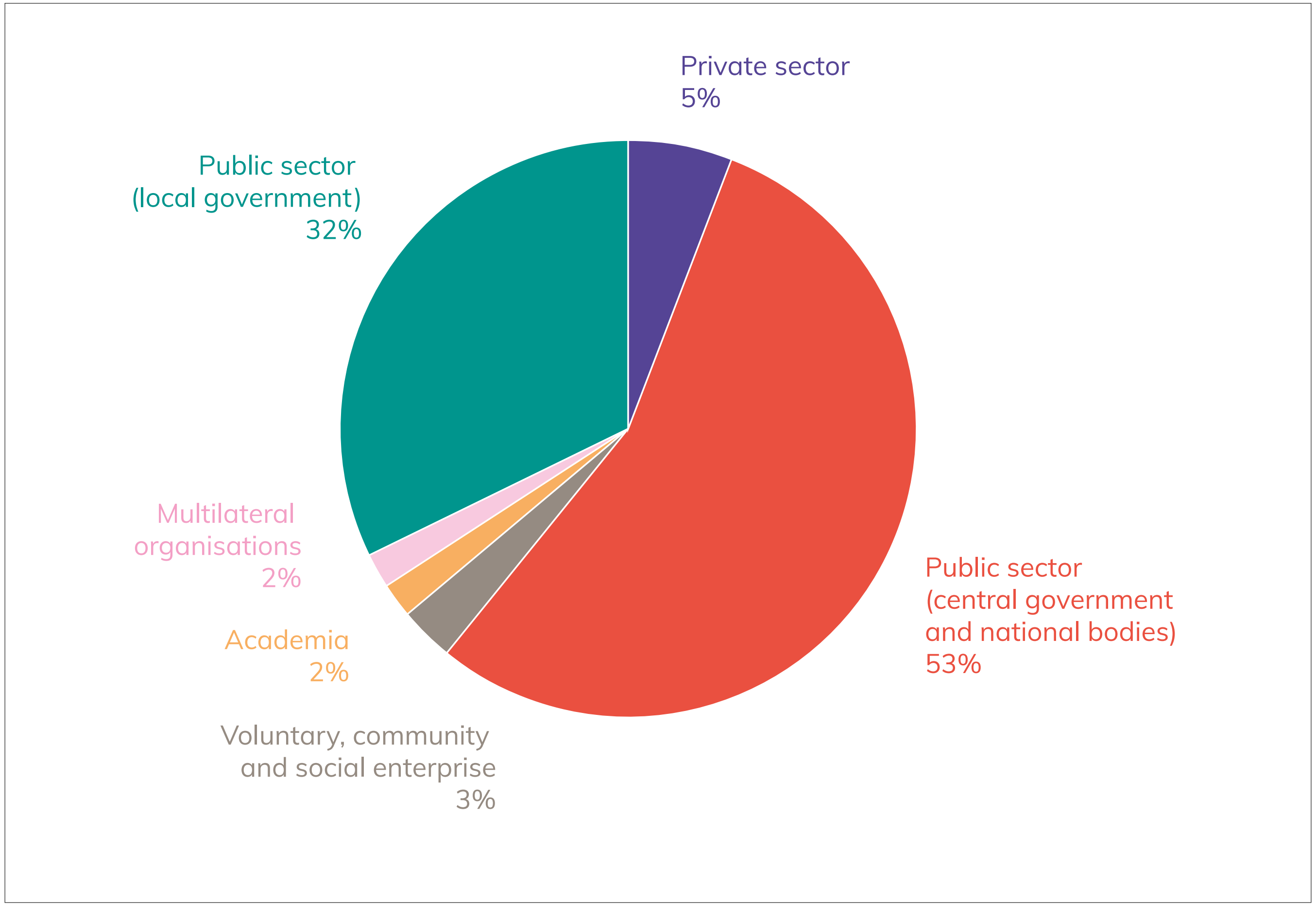
Some of the existing initiatives that use blockchain-based digital identification systems include the Estonian e-residency programme, which enables anyone in the world to establish a trusted digital identity backed by the government of Estonia. In India, the government has launched the Aadhaar programme, a biometrics-based digital identification system that uses blockchain to provide secure, tamper-proof identity verification. In Finland, a new digital ID solution based on the concepts of self-sovereignty and government-issued core identity is in development.

While far from being mature, the evolution of blockchain since its advent in 2008 has influenced the way societies record and distribute data. By redefining how data are structured and managed, the technology has the potential to transform complex landscapes such as commercial contracting and public procurement. At the very least, this can support transparency by way of continuity in transactional information. For public sector bodies, this may improve service delivery and 'value for money'.

Through a survey of practitioners and related stakeholders, we assess the level of familiarity with blockchain and perceptions across sectors. Given the focus of this study, we prioritised reaching the public sector, which resulted in 85% of respondents being from either local or central governments (Figure 1).

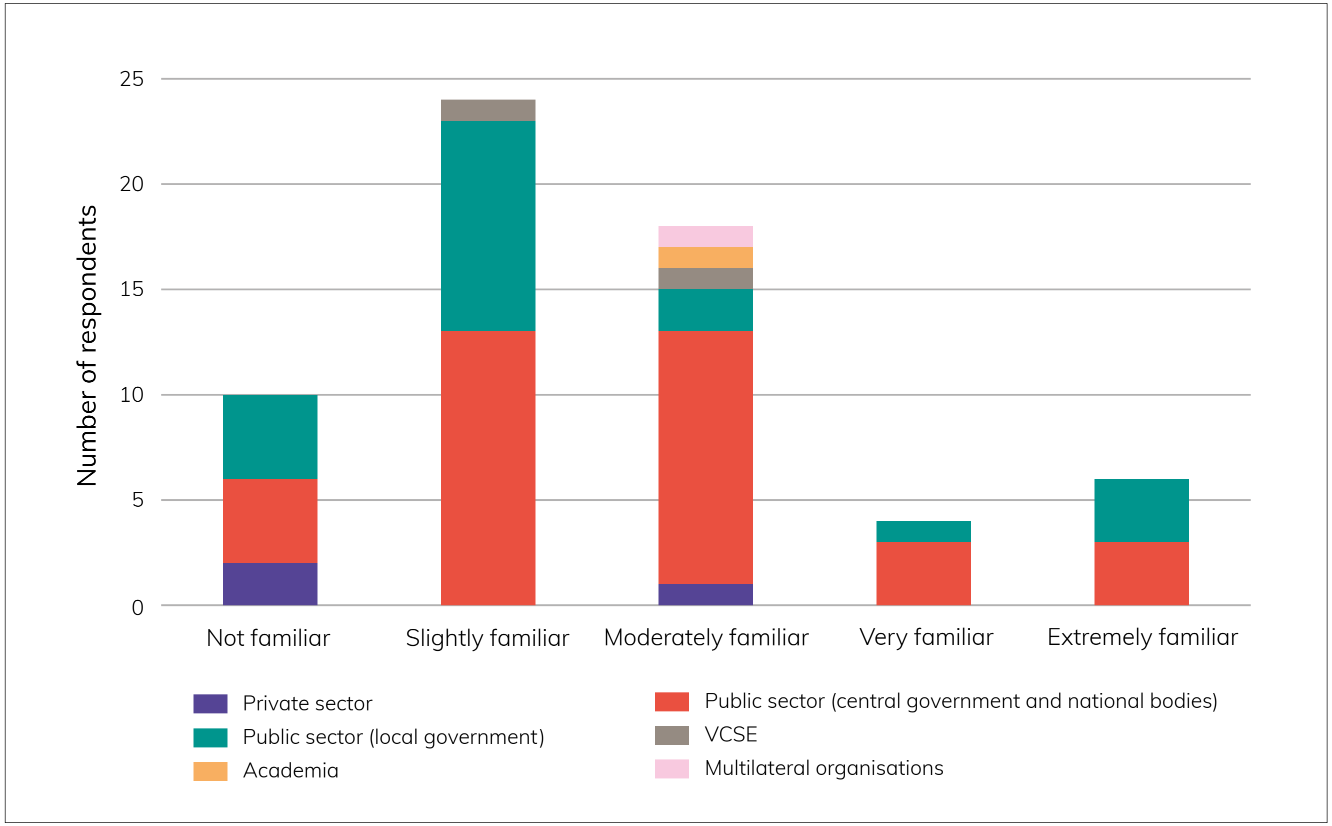
With respect to familiarity with the technology, slightly less than half of all participants (45%) were at least 'moderately familiar' with blockchain technologies. Although this view was held by a third of private sector respondents[ii] compared to 44% for those in the public sector, 18% of respondents (all from the public sector) stated they are 'very' or 'extremely' familiar with the technology.

Figure 1: Sector affiliation of respondents



ii Given the substantially small sample size for the private sector, interpretations are indicative and should be taken with caution.

Figure 2: Familiarity with blockchain



Given the potential of blockchain to transform various aspects of business and governance, it is crucial that more efforts are made to enhance evidence generation and understanding of the technology among the general public. Public awareness and understanding can also help to inform the development of policies and regulations that balance innovation with risk management.

There exists a fair degree of scepticism around the added value of blockchain. A respondent from the public sector (central government) expressed the lack of an accountability mechanism:

> This technology remains too opaque to be considered for anything useful outside of gambling. The complete lack of effective ownership and accountability renders it untrustworthy.

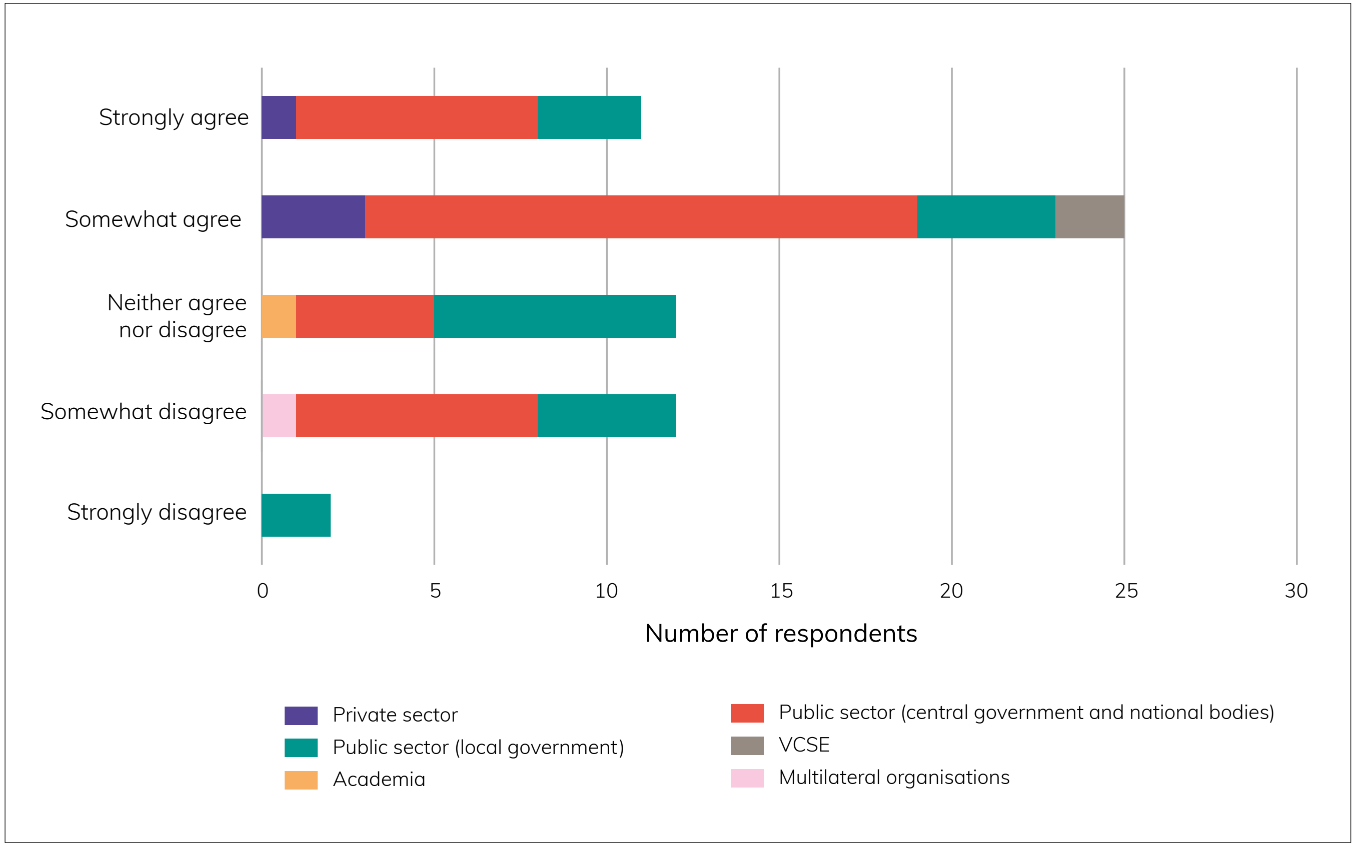
Meanwhile, a local government respondent held quite the opposite view and referred to blockchain as a solution to devolution and local government empowerment:

> A public blockchain where transactions can be viewed is true transparency… decentralisation and blockchain technology are aligned with devolution. If the risks are managed, the adoption of blockchain could bring massive transformation to the sector. With the development of the metaverse/Web3, it is important that the public sector keeps up to date to appeal to a changing demographic.

From a sample of 1,488 senior executives and practitioners across 14 countries, the 2020 Deloitte Global Blockchain Survey found that 55% of respondents considered blockchain technology as a top-five strategic priority (versus 53% and 43% in 2019 and 2018 respectively), and 83% believed that blockchain technology would become more scalable, secure and interoperable in the future.

Our survey asked respondents whether they see blockchain as a disrupting technology (Figure 3). The fact that 58% of survey respondents view blockchain as a disruptive technology (responding either strongly agree or somewhat agree) highlights the significant impact it can have on various industries and sectors. This disruption can potentially lead to greater efficiency, transparency and security, among other benefits.[21] However, it is important to recognise that disruption can also lead to unintended consequences and risks. For instance, the implementation of blockchain could lead to job displacement in certain industries through changing the rules of employment and the requirements of competences, knowledge, skills and attitudes of employees.[22] This is the case for any new technology with disruptive potentials; another recent example is ChatGPT. Such effects could exacerbate existing inequalities.

Figure 3: Sentiments around the disruptive role of blockchain



It is interesting to note that those in central government are more likely to view blockchain as disruptive compared to their counterparts in local government (67% versus 35%). This could be due to differences in the scope of responsibilities and the level of involvement with blockchain-related projects. Central governments may be more focused on large-scale implementation of blockchain such as in the case of digital currencies or supply chain management, whereas local governments may be more focused on smaller-scale applications such as land registration.

Ultimately, the question of whether disruption brought about by blockchain is good or bad depends on how it is harnessed and implemented. It is crucial to engage in a thoughtful and inclusive discussion about the opportunities and risks of blockchain to ensure that the technology is developed and implemented in a responsible and equitable manner. The following two sections discuss these in detail.

Opportunities to enhance collaboration using blockchain

Collaborative activities can be both frustrating and exhilarating,[23] and *"There is a fine balance to be struck between gaining the benefits of collaborating and making the situation worse."*[24] This balance is a common characteristic of partnerships, which often face challenges that can lead to high failure rates.

Researchers have identified numerous challenges associated with partnerships across sectors, including environmental constraints, divergent organisational aims, communication barriers and difficulties in developing joint modes of operation, managing power imbalances, building trust and working with geographically dispersed partners.[23, 25] With the growing dependence on multiple partners from different sectors, organisations must adopt a new mindset towards partnerships, recognising that success often depends on how the collection of alliances fit together.[26]

Figure 4 presents the results when respondents were asked to identify the challenges they faced (multiple choices were allowed) in setting up, monitoring and evaluating collaborative activities. According to our survey, 82% of respondents identified 'building and maintaining relationships' as a major challenge, followed by 'drawing up and negotiating terms of contracts' and 'cultural differences', both at 54%.

Collaborative activities are often complex and involve multiple stakeholders with different interests and expectations. Building and maintaining relationships is critical for the success of these activities, as it helps to establish trust, promote communication and manage conflicts. However, developing and sustaining relationships can be challenging, especially when there are cultural or organisational differences among stakeholders.

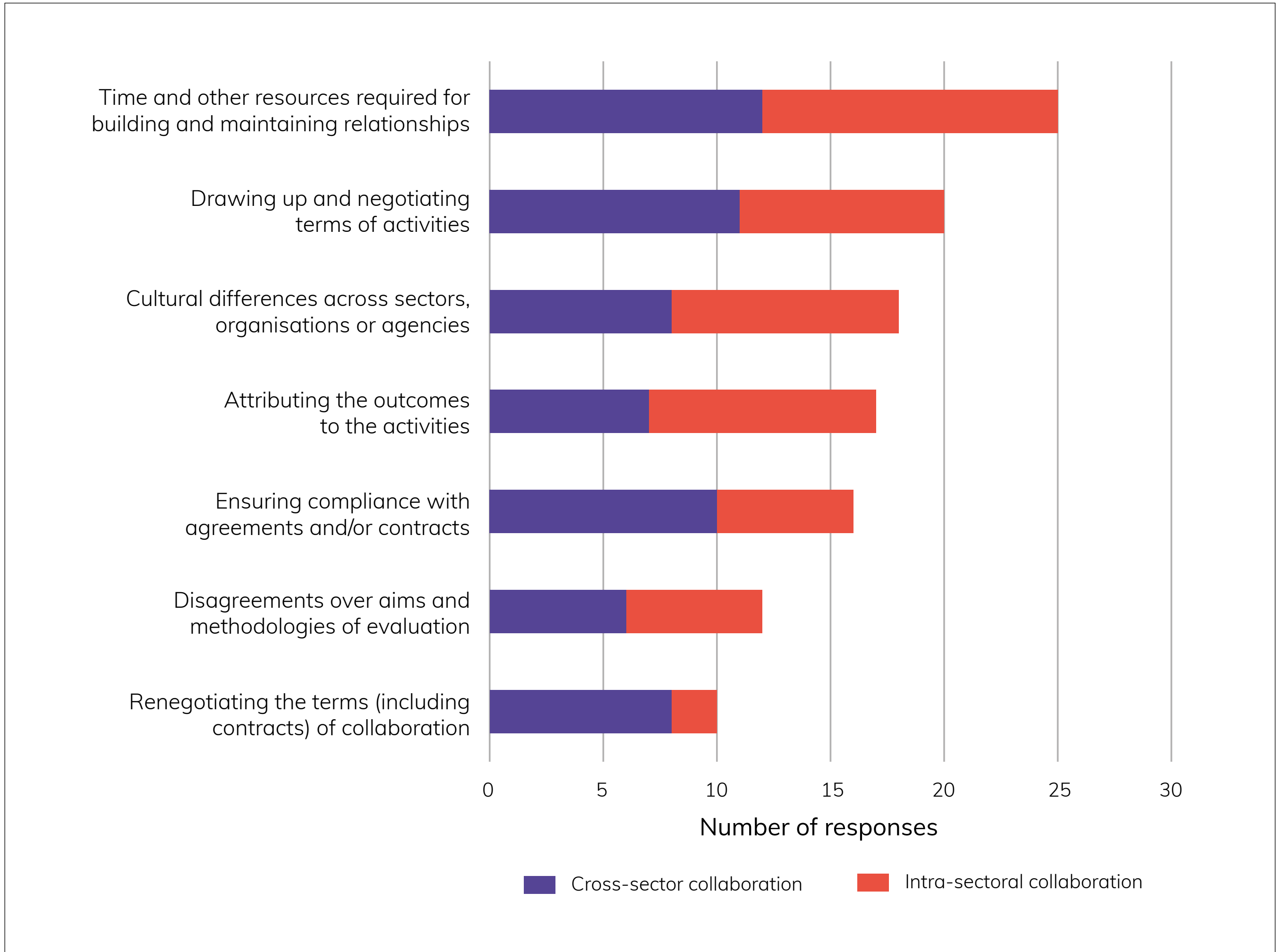
Negotiating contracts and agreements is another key challenge in collaborative activities, as it involves balancing the interests of different stakeholders and ensuring everyone is committed to the same goals and objectives. Drawing up and negotiating contracts requires a clear understanding of roles and responsibilities, as well as the ability to identify potential risks and challenges.

Collaboration also requires effective communication and coordination among diverse stakeholders with varying interests, values and goals. As a result, collaborative activities can be time consuming and resource intensive, especially when involving multiple organisations and sectors. This can result in delays, conflicts and costs that were not initially anticipated or planned for.

Moreover, the success of collaborative activities is often difficult to measure and evaluate, which can create additional challenges for monitoring and accountability. 'Outcomes attribution' is another highly ranked challenge requiring a shared understanding of success and focus on longer-term outcomes of initiatives instead of shorter-term outputs and activities. Such a turn in focus can introduce new challenges around identifying, measuring and evaluating those outcomes.[27] The synergies between outcome-based approaches and the potentials of blockchain is further explored in Blockchain's implications for outcome-based approaches and described in practice in the first case study.

There is a fine balance to be struck between gaining the benefits of collaborating and making the situation worse.

Figure 4: Challenges in setting up, monitoring and evaluating collaborative activities



The potential for blockchain technology to reduce collaboration challenges is significant in theory. As mentioned earlier, blockchain boasts several key features such as immutability, decentralisation and programmability. These features are highly relevant in addressing some of the most pressing challenges in collaboration.

Immutability ensures that data entered on the blockchain cannot be altered or deleted, making it highly secure and resistant to tampering. *Decentralisation* enables collaboration among parties without relying on a central authority, which reduces the risk of data manipulation and increases trust between parties. *Programmability* allows for the creation of smart contracts, which can automate the execution of predefined conditions, streamlining collaboration and reducing the need for intermediaries.

Table 1 demonstrates how blockchain functions can potentially address collaboration challenges identified by survey respondents, highlighting the technology's potential to reform processes and increase efficiency and transparency across various sectors. The table is based on existing evidence and the authors' interpretations.

Table 1: Blockchain's potential in addressing the challenges of collaboration

Collaboration challenges	Key blockchain features		
	Immutability	Decentralisation	Programmability
Relationship management		x	
Contract negotiation	x	x	x
Cultural differences		x	
Outcomes' attribution	x	x	
Ensuring compliance			x
Conflicts and disagreements		x	
Renegotiations		x	x

We then asked if the survey respondents' corresponding organisations have ever tried using blockchain to address any of the above barriers. A low share of our respondents' organisations (8%) have so far used blockchain to address challenges of collaboration, reflective of the low uptake of the technology in day-to-day business, especially in the public sector.

With innovation comes new risks. Apart from the financial risks, governments that invest in innovation or new technologies take a reputational risk. This risk may be less pronounced when the status quo is maintained, even if they are ineffective. As John Maynard Keynes famously said: "Worldly wisdom teaches that it is better for reputation to fail conventionally than to succeed unconventionally."[28]

A survey respondent highlighted their risk aversion through resisting change in the public sector:

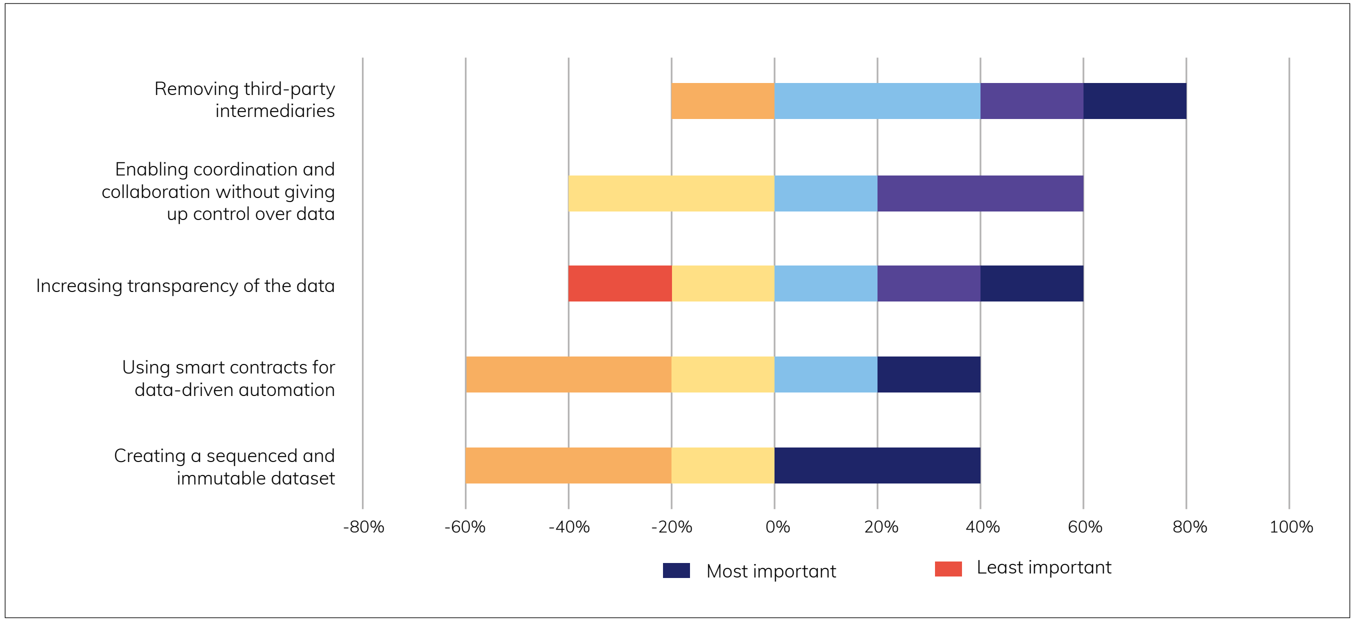
Our organisation is very solid and resistant to change. Even several tasks that can be automated are still done manually. Infrastructure and IT changes are very expensive and take ages to happen, and when implemented, the technology is already outdated. I cannot even imagine that blockchain technology becomes part of our practice when we still live in the Stone Age in government (some sectors still ask to receive data on CDs, to be mailed to them)!

To better understand the motives behind implementing the technology, we asked for the reasons behind adoption. As illustrated in Figure 5, the most significant consideration was the removal of intermediaries, which is particularly important in collaborative efforts. Transaction costs associated with setting up, managing, monitoring and evaluating projects can be considerable, making the elimination of intermediaries an attractive proposition.

This finding underscores the potential economic benefits of blockchain technology. The second and third most cited reasons for adoption were enhanced coordination and transparency, both of which are key features of blockchain technology. These findings suggest that the potential benefits of blockchain technology go beyond simple cost savings and extend to improved collaboration and greater transparency.

Interestingly, the use of smart contracts was ranked lowest among the reasons for adopting blockchain technology. This may be due to the composition of our sample, which was biased towards the public sector. Smart contracts are more widely appreciated in the private sector, particularly in the context of supply chain management.[29]

Figure 5: Motives for adopting blockchain



We also tried to understand how respondents perceived the role of blockchain technology in addressing those challenges. Most respondents (80%) identified blockchain's role as 'valuable' (ie providing added value), while 20% identified it as 'viable' (ie it was suitable for purpose) but not 'vital' (ie only blockchain could solve the specific challenges they faced).

Many respondents believe that existing tools can fulfil the same tasks as blockchain technology. While this could suggest a certain level of doubt regarding the buzz surrounding blockchain and a preference for technologies that have a track record of success in tackling problems, it's also possible that this view stems from a limited grasp of the promising potential of blockchain and its capacity to deliver distinctive solutions that other technologies may not be able to match. When used effectively, the unique features of blockchain – its immutability, decentralisation and programmability – have the potential to facilitate innovative solutions and drive progress in various fields.

Informed by existing studies and our expert interviews, some of the unique mechanisms through which blockchain could enhance collaborative initiatives include the following:

Supporting relationships and trust

Many existing frameworks on collaboration speak to the importance of priming conditions and contexts such as the level of trust in counterparties in achieving successful collaboration.[23, 30] Traditionally, existing relationships and reputational cues play a role in identifying potential partners. However, it takes considerable time and effort to search for such information and build and maintain trusting relationships.[31]

Lack of visibility and established reputation may also erect barriers for smaller and newer stakeholders and firms to participate in processes such as public procurement.[32] Blockchain can play a significant role in reducing the expenses associated with searching for information and building relationships, as:

- *immutability* and anonymity features can enhance data security, reduce expenses related to investigations or searches and discourage malicious participation by providing tamper-resistant and transparent data management and protecting individuals' privacy[10]
- *decentralisation* enables democratic sharing of information and authority through consensus mechanisms, which allows for the exchange of information without needing each party to relinquish control over their proprietary data[7]
- *programmability* enables the creation of smart contracts, which allow for the automation of data exchange and verification processes, further enhancing control and security over proprietary data[7]. These qualities may broaden the search for potential partners for collaboration.

In fact, blockchain-enabled applications have been used to facilitate collaboration between some of the unlikeliest of partners, such as competitors in the pharmaceutical industry (eg MELLODDY), to pool data for rare diseases for their research and development efforts.[15]

Facilitating coordination

Active monitoring and management of projects is a key consideration for all organisations regardless of sector or industry. While such activities normally take dedicated staff, time and other resources to perform, collaboration with external parties requires additional effort to maintain consistency, which may lead to coordination fatigue.[31] A shared understanding can be further hindered by cultural and linguistic differences across organisations and sectors.

In this context, blockchain's decentralised records offer a new way to achieve information consistency.[10] The potential of blockchain may be substantial in areas where multiple reporting and coordination mechanisms exist. In financial reporting, this would obviate the need for manual reconciliation for reporting conducted anew at various levels of governance and in organisations.[33] Similarly, the immutability of blockchain-based solutions could reconcile carbon emissions data for sustainability reporting where multiple scopes and measures of carbon emissions across organisations can lead to inconsistencies and duplicated efforts.[34, 35]

The ability of blockchain to enhance coordination allowed the World Food Programme's Building Blocks initiative to release US$59m in immediate assistance after the Beirut port explosion in August 2020.

Enhancing transparency and accountability

Ensuring accountability in collaboration can be complicated by the lack of clarity over whom and what the parties are accountable for. Collaborative activities are found to have a better chance of success when underpinned by an accountability mechanism that tracks and measures outcomes.[36] However, monitoring performance can be burdensome and costly, and opportunistic behaviours are notoriously difficult to address.[37]

Since information on a blockchain is time-stamped and chronologically ordered (immutability), transparency and the auditability of data are enhanced.[10] For instance, outcomes of aid spending can be tracked, providing insights into the multipliers and secondary impacts of programmes.[38] This may have significant implications for public spending and its evaluation more broadly, as blockchain can establish a link between achieved outcomes and the funding sources and arrangements, enhancing our understanding of effectiveness and value for money.[33]

By shifting the focus away from auditing transactions and towards programme and policy design, blockchain contributes to a whole system approach.[39] Applications to improve transparency in spending are already emerging, with the US Treasury piloting a grants payment process. Blockchain-based solutions in public procurement are also put forward to combat corruption throughout complex and manual processes. In a recent study,[40] authors put forth a blockchain-based solution to tackle the rampant corruption in Nigeria's procurement system, which amounts to 15% of contract values.

Risks and challenges

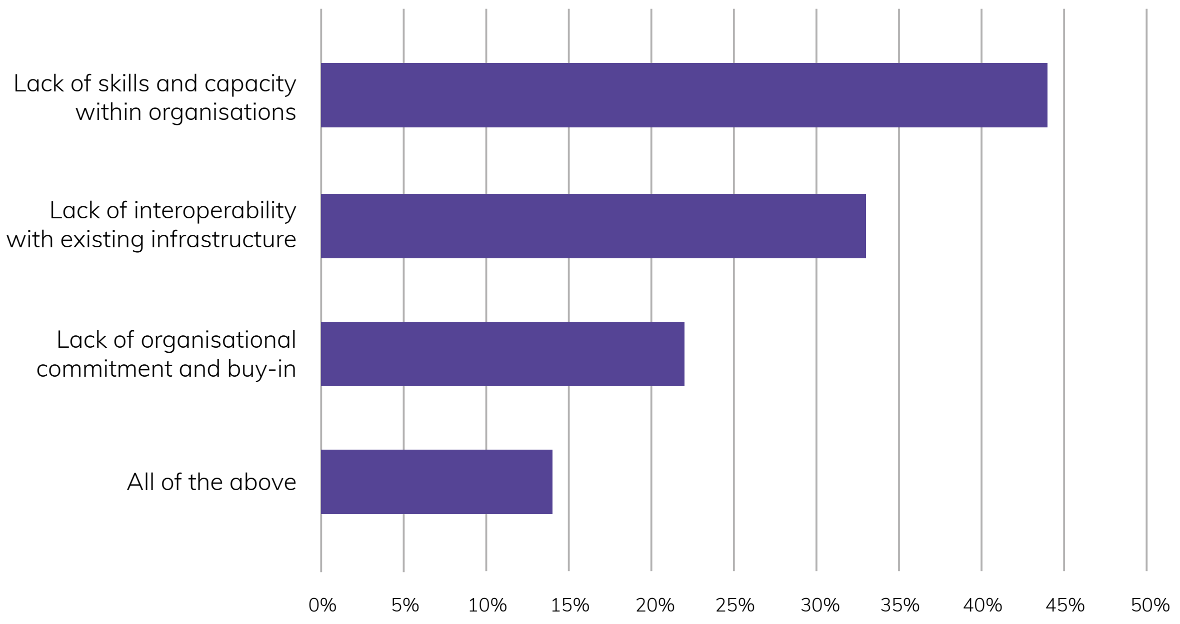
While applying blockchain technology has potential benefits, it comes with significant trade-offs. For example, current blockchain systems are slower and less efficient than conventional databases based on standard performance metrics.[8, 14, 16] The security and consensus mechanism inherent in blockchain requires additional time and resources, as data is saved across multiple computers instead of a single location. It is important to recognise that blockchain is not a panacea for addressing all challenges in partnerships and collaboration, and, prior to adoption, a careful consideration of the trade-offs is necessary.

Our survey identifies three key challenges that could potentially impede the implementation and growth of blockchain amongst those who have previously applied the technology (Figure 6). A 'lack of skills and capacity within organisations' was flagged as the most prominent by 44% of respondents. This was followed by the 'lack of interoperability with existing infrastructure' (33%) and 'lack of organisational commitment and buy-in' (22%).

Barriers appear to be most prevalent in the public sector, where it may be more difficult to deviate from established norms and practices. Reflecting this risk-averse culture, a respondent from the public sector commented:

I am yet to be made aware of a blockchain proposal for government that has moved out of the demonstration phase. Government needs solutions that work now and deliver results now. We have grant-funded programmes to pilot new technologies, but government procurement shouldn't be used to supplement business R&D programmes.

Figure 6: Main challenges with adopting blockchain



Respondents were allowed to select multiple challenges.

Even if capacity, skills and interoperability were not problematic, the lack of evidence on the effectiveness and 'value for money' can be a deal-breaker for many public sector bodies. Currently, there is not sufficient evidence on the performance and economic validity of blockchain to broker its wider adoption. As another survey respondent observed:

> A lack of knowledge of the technology, combined with few real-world implementations means it (blockchain) is not actively considered.

In addition to the implementation challenges that were pointed out by survey respondents, we have identified three significant areas that are susceptible to risks and misunderstandings when it comes to utilising blockchain technology for collaboration.

Immutability versus flexibility

Immutability is a key feature of blockchain technology, but it comes at the cost of flexibility in managing collaboration. Blockchain is not immune to the problem of 'garbage in, garbage out'. Fraud and errors in data entry may defeat the benefit of having an immutable record.[41] While consensus mechanisms can partially address this issue, the risk cannot be eliminated entirely.

Programmability, or the codified nature of blockchain, shifts key technical and legal decisions to the initial design stage of initiatives, creating new challenges and trade-offs at various levels of governance.[42] This is particularly acute for smart contracts, which require the translation of rules and standards into a coding language. Nuanced norms such as 'reasonableness' exist on a spectrum and cannot be easily represented in code. Immutability further complicates the matter since imprecise syntax – a misplaced comma or a space – can invalidate the code.[43]

While smart contracts may provide efficiency from a purely technical standpoint, they can create new inefficiencies, as immutable codification comes at the cost of flexibility and the 'interpretative richness' of traditional contracts. This has the potential to limit the informal resolution of disputes that can preserve relationships.[11] As a result, codification leaves no room for discretion, since there is no choice other than that prescribed by a pre-defined algorithm.[6]

While simple and transactional contracts may translate easily into formulaic 'if-then' algorithmic expressions, it may be impractical, if not impossible, for more complex contracts.[44] In the case of public-private partnership projects that can span decades, contracts will typically include clauses to reflect higher degrees of uncertainty.[37] The costs involved with setting up such contracts would therefore be presumed to be higher.

Decentralisation and power dynamics

The benefits of blockchain can be exaggerated.[6] For example, decentralisation may not necessarily result in more equal relationships, particularly if it creates a gulf between the 'code savvy' and the 'code naïve.'[11]

Contrary to the claims about distributing power, some use cases demonstrate that the technology recentralises power to third parties as well as to those with IT expertise and capacity.[45] As a result, decentralisation can lead to the emergence of new power structures such as 'distributed dictatorships' that are even less accountable than the ones they seek to replace.[46]

Trust and the blockchain paradox

Trust is a critical component of collaboration, requiring ongoing efforts to build and maintain.[36] The term 'trustless trust' associated with blockchain suggests that parties can operate without trust, but this can be misleading, as it simply shifts the need for trust rather than eliminating it altogether.[8]

The 'blockchain paradox' refers to a contradiction in the understanding of blockchain technology. Blockchain is often presented as a revolutionary technology that can eliminate the need for centralised control and governance, as it allows participants to interact directly with each other without intermediaries. Blockchain networks require a certain level of governance to function effectively. For instance, the rules that determine which transactions are accepted into the blockchain, the validation of transactions and the management of the network's resources all require some level of governance. Without proper governance, blockchain networks can suffer from inefficiencies, errors or even security breaches.

Meanwhile, if governance issues are resolved, allowing the network to function smoothly, then the need for blockchain itself may diminish. In other words, once the governance problem is solved, the original purpose of blockchain as a tool for decentralised and trustless interactions may no longer be necessary. Therefore, blockchain doesn't completely remove the need for trust and governance, but rather transforms them into decentralised and distributed systems.[14]

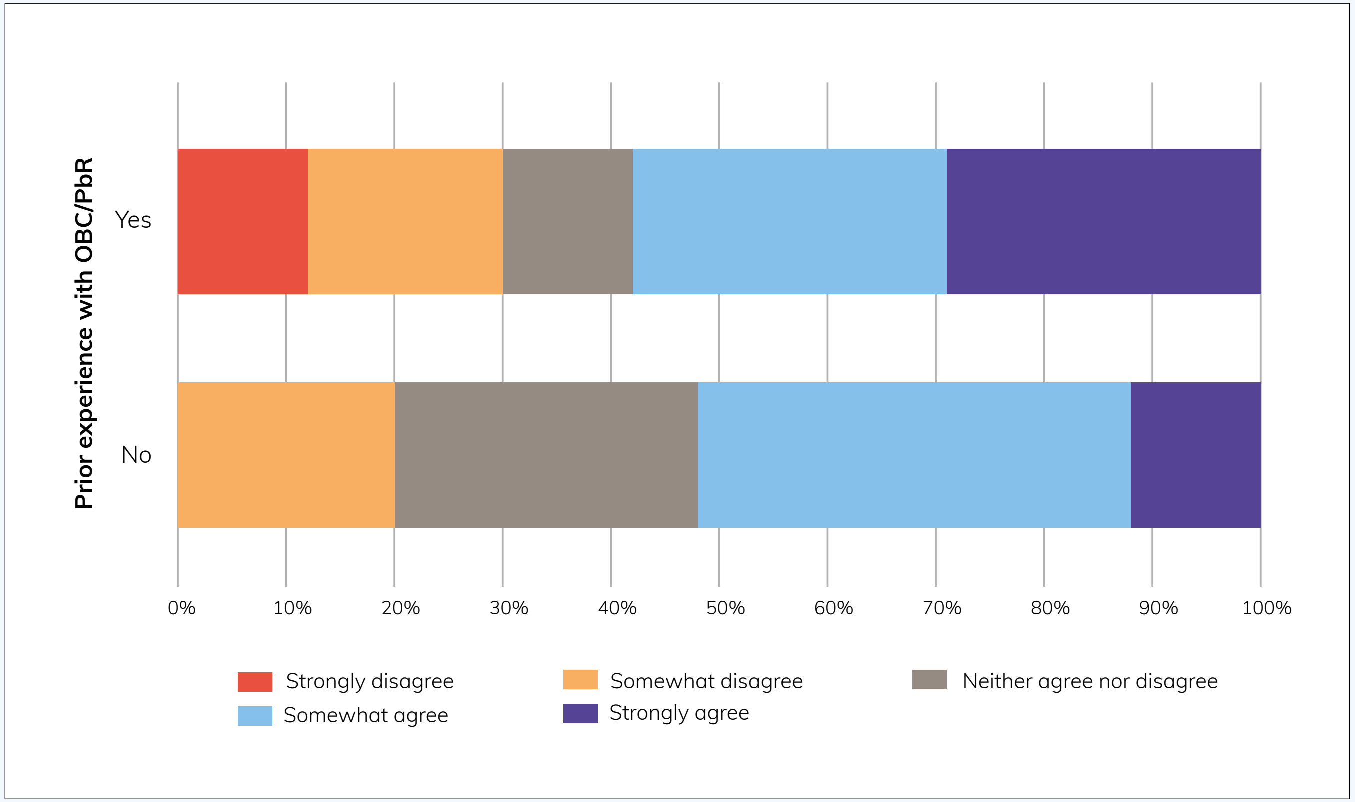
Blockchain's implications for outcome-based approaches

In contrast to traditional models that pay for inputs and activities, outcome-based contracting (OBC) links payments to the achievement of pre-defined outcomes.[iii] While various models such as social impact bonds have emerged, determining the impact of the public programmes and effectiveness of a commissioning mechanism has proven difficult.[27, 47] For example, the traceability of information stored on blockchain can help to overcome challenges with impact attribution.

Equal access to consistent and verifiable records can pave the way towards outcome-based payments, as blockchain helps overcome the need for consensus on whether an outcome has been achieved.[48]

The transparency embedded within the technology supports a shared understanding across stakeholders, thereby lowering the risks associated with perverse incentives. Moreover, the conditionality of payment upon outcome verification provides suitable grounds for using blockchain with innovative financing methods.[49]

Figure 7: Sentiment around the disruptive role of blockchain



iii For more information on various approaches and the key debates on outcomes-based contracting, see GO Lab's introduction on the topic.

The promising landscape of implementing blockchain technology in OBCs has attracted attention among the pay-by-result (PbR) community (see case study 1 below). Across our survey respondents, those with previous experience with OBC and/or PbR tend to have higher hopes for blockchain: 59% versus 52% somewhat or strongly agree that this technology has a disrupting role (Figure 7).

The complementarity of blockchain to outcome-based approaches should not be overstated. While codifiable outcomes that can be measured digitally may lend themselves to blockchain-based approaches, more complex social and economic outcomes may require manual instruments or processes for verification. Hence, blockchain cannot fully replace the measuring and understanding of the more nuanced attributes of outcomes.

Case studies

Case studies exploring the potential applications of blockchain are scarce and anecdotal. To address this evidence gap, we have developed two case studies centred on blockchain-enabled solutions for collaboration in the healthcare and climate change sectors.

Case 1: Blockchain in healthcare

The COVID-19 pandemic has brought into sharp focus the importance of coordinated management of sensitive data in healthcare. While the pandemic accelerated the adoption of digital technologies, healthcare digitalisation has achieved mixed success in the past. For instance, medical records are fragmented across thousands of organisations in the UK, with just over half of NHS trusts indicating that their staff can trust digital records to find patient information.[50]

Blockchain-enabled innovations have shown promise in healthcare records management and research collaboration. Although not well suited for handling personal data due to privacy concerns,[51] it is possible to combine on- and off-chain methods to desensitise and anonymise data while assuring verifiability.[52] For example, blockchain has enabled research collaboration among competitors in the pharmaceutical industry to share clinical data on rare diseases for peer learning (eg MELLODDY, MediLedger).

Another challenge in healthcare is an ageing population. Many systems are struggling to keep pace with rising costs and increased demand. Due to the high costs of developing new medicines and uncertainties over their real-world applications, some public and private payers have resorted to risk-sharing mechanisms that tie part of a payment to the clinical outcomes achieved. This helps to reduce the delay in patient access to medical breakthroughs.[49]

Such an outcome-based approach allows for value-based pricing, which has the potential to maximise patient health, enhance cost effectiveness on pharmaceutical spending,[53, 54] incentivise innovation across pharmaceutical companies and provide faster access to innovative treatments.[55] A particular interest of value-based pricing relates to the field of gene and cell therapies,[56] as the long-term benefits of these drugs may be difficult to quantify due to insufficient data at the therapy launch.

While there is a growing interest in using OBCs in the pharmaceutical and drug payer market, there remain obstacles that hinder its adoption. For instance, one significant barrier is the existence of data silos in the healthcare system that limits interoperability and data sharing.[57, 58] Another challenge is the complex and resource-intensive data collection and monitoring processes, which not only increase contract management costs but also delay the outcome payment process.[59, 60]

The allocation of risk can further inhibit the wider adoption of OBCs. Outcome payers such as the pharmaceutical industry and health insurance companies are typically not well equipped to handle the risk associated with performance-based payments.[61] To address this challenge and accelerate OBC adoption, it may be necessary to attract private investors who are willing to take on greater risk but at a higher premium. Two conditions can help to accelerate this trend:[61]

- The development of a technical data infrastructure capable of accurately pricing contracts.
- The ability to bundle multiple OBCs with varying degrees of risk into financial derivative products.

Miraculum software

Immutability, decentralisation and programmability position blockchain as a promising solution for the promotion of security, provenance, transparency, trust and better data management. To explore how the technology can be applied to OBCs for drug treatment, we examine a blockchain software based on Lydion Data Economics Operating System (Lydion DEOS) called Miraculum.[iv]

The case study is structured around a description of the software's technical features and its potential benefits and limitations in outcome-based contracting for drug treatment.

Decentralised data infrastructure is the backbone of the software that enables the creation of a private contract adjudication network. The network is designed to connect individual contract parties' private Lydion Vaults[v] and Banks,[vi] providing them with a secure and reliable platform for managing their private data (see Figure 8, right side). In this network, data privacy and security are of paramount importance. Each Vault can create a 'contract Lydion' that contains the specific partial results required to adjudicate a contract from their private data. These contract Lydions are distributed to the Vaults owned by other contract parties. The benefit of this approach is that the contract Lydions do not reveal the private input data used to construct these answers. Instead, they carry an encrypted audit trail back to the Vaults.

Moreover, data reliability and validity are ensured by the encrypted audit trail. Each party's Vault/Bank can independently calculate the results of the contract using their own, and everyone else's, contract Lydions without having to reveal or examine private data. This feature provides an added layer of security, and contract parties can have confidence in the validity and reliability of the data used for the adjudication of their contracts. In addition, the software provides an automated transaction process. Contract parties no longer need to rely on external verification of the achievement of patient outcomes. Instead, the transaction is automated[vii] when the pre-specified drug outcome is achieved. This ensures that the contract parties have a hassle-free and efficient transaction process that saves time and eliminates the need for external verification.

iv The case study was drafted with support from Jenny Hinkel and Arka Ray, who specially advised on the technical details of the application.
v Each Vault stores, organises and manages a single class of asset.
vi Lydion Data Banks contain several Lydion Data Vaults.
vii The software relies on a patented consensus mechanism for confirming transactions and generating blocks called Transactional Proof of Work.

Figure 8: Comparison of outcome-based contracting adjudication networks (left: centralised; right: Miraculum software)

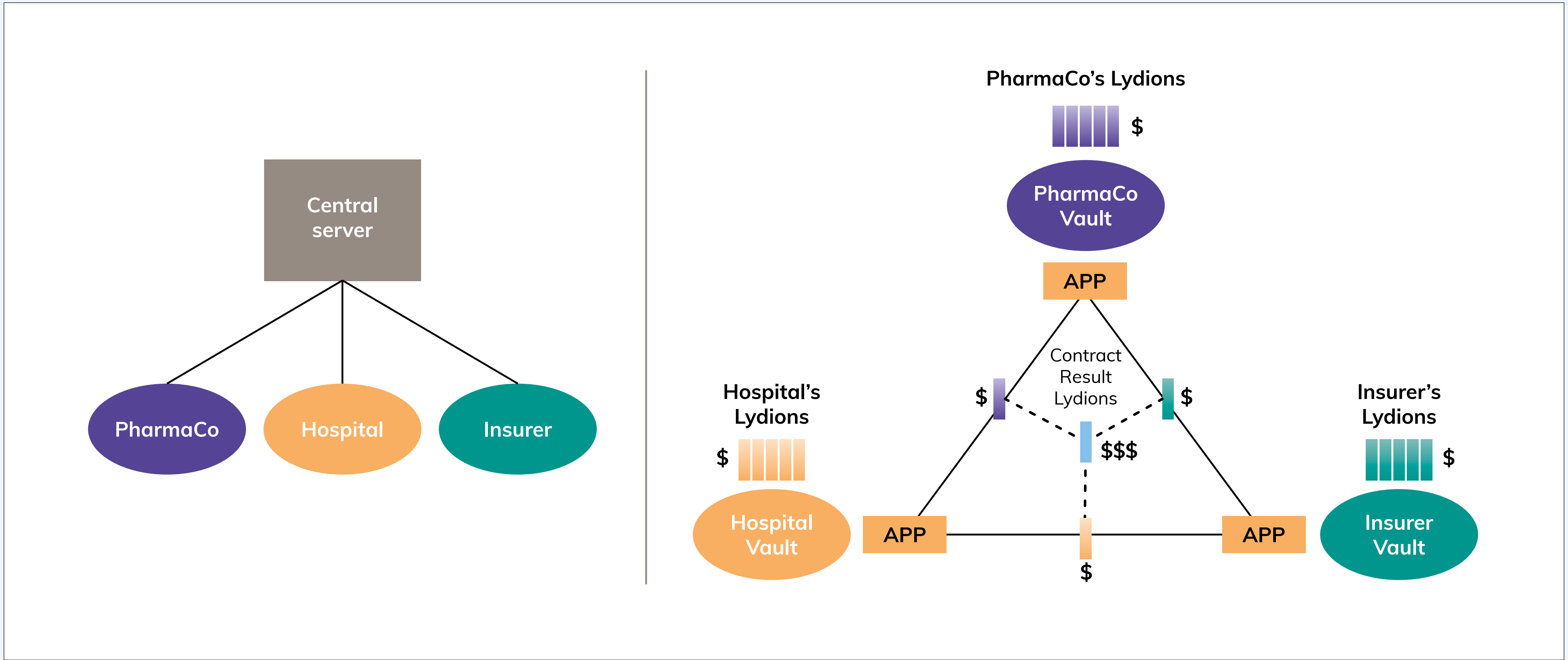


Table 2 summarises the benefits and limitations of using Lydion-based blockchain software. The table focuses on Lydion's features such as its ability to track outcomes over time, decentralise data infrastructure, enhance data privacy and security and enable automated transactions. While the technology offers many benefits such as increased efficiency and transparency, there are limitations to consider such as the need for technical expertise and infrastructure, potential inaccuracies in source data and ethical concerns around private investor power.

Table 2: Benefits and limitations of Miraculum software

Challenge to OBC in drug treatment	Features	Benefits	Limitations
Underdeveloped ability to outcomes pricing	Track outcomes from distributed datasets over a long period of time, while generating consensus across contract parties.	**Impact-driven outcomes pricing:** Ability to determine the true impact of drugs over a long period of time by collating data across different data pools.	Technology can facilitate but not always solve the need for the requirement for experts to define their desired valuable outcomes and agree on the value of those outcomes and contracting terms.
	Different financial modelling opportunities are displayed in dashboard.	Facilitate consensus building on outcome pricing.	
Decentralised data infrastructure	Each participant can independently examine the proofs of work and arrive at a consensus with the rest of the network.	**Increased transparency:** No one participant must implicitly trust another participant or a central authority – all "play by the same rules" and are held accountable by peers.	Cannot protect against real-world source data having gaps or inaccuracies.
Data privacy and security	Data does not leave the data owners' control and oversight.	**Increased data sharing:** Data owners have more incentives and guarantees to make their data available to the network – overall greater availability of data for applications. Monitored usage of data for authorised purposes only.	Each Data Bank must be protected against intrusion.

Challenge to OBC in drug treatment	Features	Benefits	Limitations
Data reliability and validity (ie lack of aggregated data to allow for evidence-based reimbursement decisions – potential patient selection bias)	Allows private patient-level data to be stored and to contribute to cross-network calculations through a zero-knowledge proof[viii] without transferring or revealing the private details.	**Increased data protection and adaptable data privacy protection features:** Data fidelity and provenance, ability to adjudicate a contract for a specific population or sub-population, and data protection and ability to permanently 'turn off' or 'forget' access to any specific data point (eg GDPR compliance requirements).	Relies on data inputs from real-world operations. Does not prevent the actions of a malicious actor intentionally submitting fraudulent billing claims or other fraudulent data.
Claims management	Automated transaction when pre-specified drug outcome is achieved for patient.	**Enhanced reliability and greater cost efficiencies.** Avoidance of human error. Eliminates the need for an external verifier. Closer to real time and eliminates need for costly retrospective analysis.	
Financial engineering	Lydions can serve as securitised scorecard that allows for resale to transfer to, or investment from third parties, insurance or other forms of hedging	**Market growth.** Outcome contracts for drug treatments as impact investment product.	Ethical concerns regarding private investor power.

viii Zero-knowledge proofs are a cryptographic protocol that allows one party to prove to another that they know a particular piece of information without revealing the information itself.

Key takeaways:

- By utilising multiple data pools, Miraculum enhances transparency in the long-term outcomes of drug treatment, making it easier to establish a financial model for pricing drug outcomes.
- The software employs zero-knowledge proof methods in cross-network analysis, which significantly bolsters data privacy and security, particularly with respect to the sensitive health data of patients.
- The software still requires consensus building across contract parties to agree on a financial model, even though it facilitates the process. Additionally, Miraculum cannot protect against gaps, inaccuracies or fraud in the real-world data source.

Case 2: Blockchain in climate action

Despite growing awareness of the urgency of climate action, the world is significantly off track in achieving the 45% reduction in greenhouse gas emissions by 2030 required to meet the Paris Agreement targets. To limit the rise in global temperatures to below 2°C, a global and system-wide transformation is necessary.[63] In this context, the Paris Agreement's bottom-up approach through nationally determined contributions (NDCs) can present challenges. While the NDCs acknowledge countries' varying capacities, priorities and pathways toward achieving climate goals through a principle of common but differentiated responsibility, it may result in fragmentation and inefficiencies without global coordination and cooperation across sectors.

Blockchain technology's potential to enable transparent data sharing and enhance collaborative efficiency for environmental sustainability is increasingly recognised. Pilot initiatives in electricity and supply chain management across different jurisdictions demonstrate blockchain's ability to promote transparency, traceability and accountability.[64]

For instance, IBM and Maersk launched a blockchain pilot programme in 2018 to improve supply chain management and reduce waste and emissions in the shipping industry. The platform enabled real-time tracking of goods and documents across the supply chain, with information recorded on the blockchain to ensure transparency and traceability. Despite successful implementation, this initiative was recently withdrawn due to lack of global industry collaboration.

Another example is the Brooklyn Microgrid, which uses blockchain technology to enable peer-to-peer energy trading between consumers. The platform allows users to buy and sell excess solar power generated by rooftop solar panels, with transactions recorded on the blockchain to ensure transparency and accountability.

Voluntary carbon markets are another emerging application of blockchain. Article 6 of the Paris Agreement permits engagement in the use of internationally transferred mitigation outcomes (ITMOs)[ix] to achieve NDCs cost effectively. According to a 2019 study by the Carbon Pricing Leadership Coalition and International Emissions Trading Association (IETA), carbon markets have the potential to save $250bn by adopting NDCs.

Meanwhile, there are substantial concerns relating to greenwashing and double counting in voluntary markets such as carbon credits and offsets. This is largely due to the lack of evidence in achieving additionality and permanence.[x, 6] These risks cast doubt over the quality of climate projects using carbon offsets, whose verifiability of effectiveness in reducing emissions has been questioned.

Carbon emissions data have several features that may make them suitable for blockchain-based solutions. For instance, measurement units are generally standardised for carbon dioxide (metric tonnes) and other greenhouse gas emissions (carbon dioxide equivalents). There are also existing internet of things (IoT) technologies such as sensor devices that can measure and generate relevant data.

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ix ITMOs are a mechanism under the Paris Agreement on climate change that allows countries to transfer and receive credits for greenhouse gas emission reductions achieved in one country that are then used to meet the emissions reduction targets of another country.

x Additionality refers to the idea that carbon credits or offsets must represent real emissions reductions or removals that would not have occurred without the incentive provided by the market. Permanence refers to the idea that the emissions reductions or removals represented by the carbon credits or offsets must be permanent and not subject to reversal or leakage.

The reporting and verification of emissions reductions, which have traditionally incurred high transaction costs due to manual processes involving multiple stakeholders (including on-site monitoring and data verification), can be made more transparent and efficient with blockchain.

The following example looks at data infrastructure created to harmonise carbon registries through the application of blockchain.

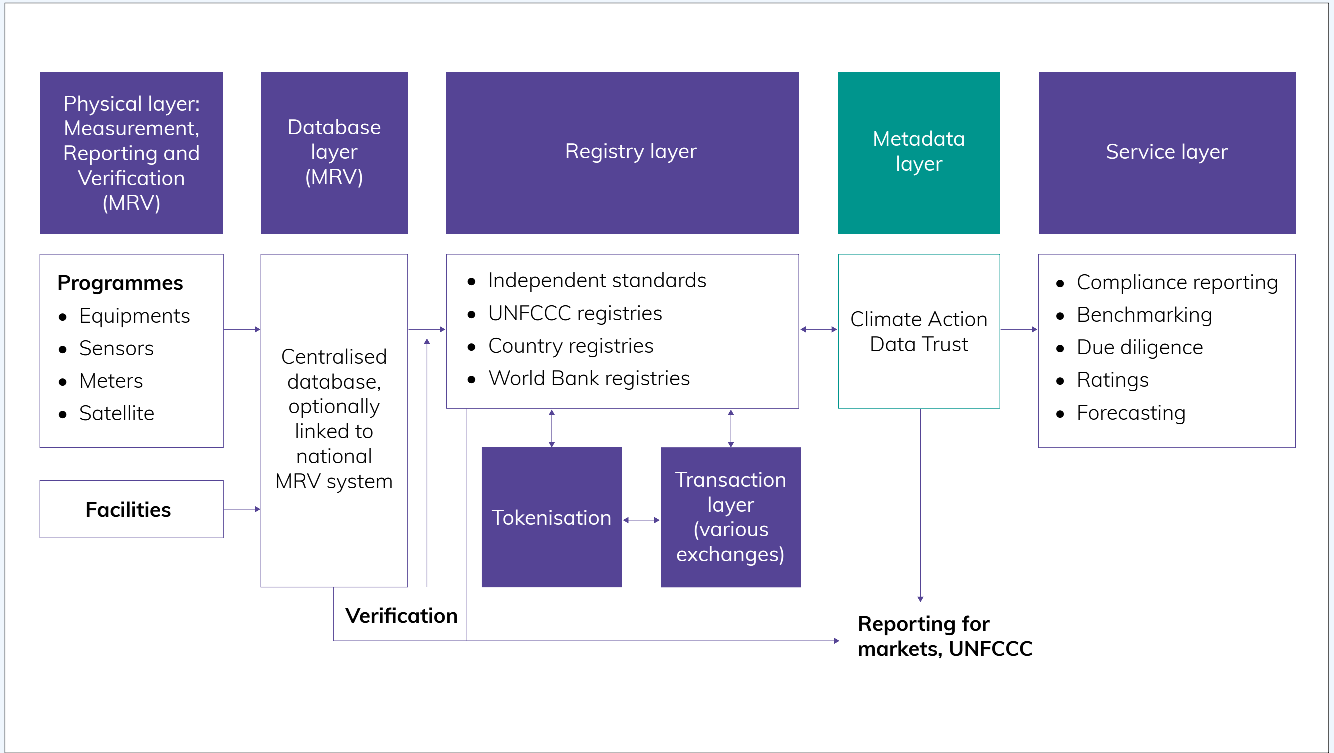
Climate Action Data (CAD) Trust

CAD Trust provides a data infrastructure for aggregating and harmonising local, national and institutional carbon registry data from around the world. This helps to mitigate double counting while building confidence in voluntary carbon markets data.

Blockchain addresses the issue of credibility by recording information on an immutable ledger. Through decentralisation, users can ensure that updates are legitimate, which mitigates the risk of double counting. As there is no requirement for a central server, participants can access the data for free with minimal hardware and bandwidth. Accountability and traceability are achieved at low cost. For users engaged with carbon registry data, this obviates the need for downloading multiple spreadsheets and reconciling disparate information.

CAD Trust was launched in December 2022 as a joint initiative by IETA, World Bank and the Government of Singapore. After three phased simulations in collaboration with national governments, standard-setting bodies, multilateral organisations and market participants, the system is expected to become fully operational in late 2023. Indeed, the Trust acts as a 'metadata layer' within the ecosystem of a global carbon market and forms an integral part of efforts to improve the transparency and integrity of carbon markets through the leveraging of digital technologies (Figure 9).

Figure 9: Role of CAD Trust in the carbon market ecosystem



Source: Adapted from Climate Warehouse (2023).

To ensure the cost effectiveness of implementation, the first two pilots involved storing data on a private permissioned Ethereum network (a well-established blockchain platform with a large developer community and limitations in terms of scalability and transaction processing times). Heavily regulated stakeholders such as electricity grid operators were allowed to engage in these phases.[xi, 66] A third simulation hosts data on the public permissionless Chia network (a newer blockchain network that uses a unique consensus algorithm which is designed to be more energy-efficient).

Reflecting the learning from all three programmes, the current CAD Trust is open source, with publicly available code on GitHub (a hosting platform for open-source code that allows for collaboration among developers). Data on climate action projects, outcomes and transactions sit within registries and are self-governed. What is stored on blockchain are the 'proofs of the data', enabling access using URLs. Moreover, only registries can edit their own data, allowing countries to define how they interact with the CAD Trust.[67]

xi Since electricity grids are heavily regulated, working with grid operators was essential to ensure that the pilot programmes were designed in compliance with relevant regulations and standards.

Table 3: Benefits and limitations of CAD Trust

Challenges in international carbon market	CAD Trust features	Benefits	Limitations
Variations in availability and level of detail of data	CAD Trust provides a common data taxonomy based on iterated simulations and engagement with stakeholders.	**Data standardisation:** Harmonised data fields afford interoperability of data held across different carbon registries across jurisdictions.	There remain challenges regarding the trade-off between flexibility (a necessary principle considering the bottom-up nature of the Paris Agreement) and standardisation of data taxonomy and entries.
Varying capacity across jurisdictions	CAD Trust standardises reporting and can be updated using various means, including application programming interface (API)[xii] and Excel.	**Reduced burden for reporting and reconciliation:** Having a user-friendly platform that can be integrated with existing procedures can help reduce reporting and administrative burden. **Further digital integration:** The immutable nature of the data also addresses the challenges associated with digital measurement, reporting and verification of climate outcomes in the future.	The solution requires stakeholders' buy-in to reach a critical mass. The survey after the third simulation suggests that a minority of stakeholders (15%) are still uncertain whether they would integrate their registries.

xii A function that makes different sets of data and applications programmatically accessible.

Challenges in international carbon market	CAD Trust features	Benefits	Limitations
Mistrust in carbon projects data due to the risks of double counting and lack of transparency	CAD Trust aggregates information on the key data and lifecycle of projects and makes these data publicly available.	**Data integrity:** Transparency and immutability of data further provide a means to identify conflicts of information and potential double counting. **Inclusivity:** The public nature of the data allows stakeholders outside of the carbon market to provide assurance and auditing functions using transparent data.	(Although it is not specific to CAD Trust), blockchain does not eliminate the risk of 'garbage in, garbage out'.

Sources: Shiraishi et al[67] and CAD Trust.[68]

Although blockchain is central to enabling transparency and immutability in carbon markets data, the CAD Trust is built upon a range of tools. Since blockchain is unsuitable for storing large amounts of data, the initiative connects with other platforms such as cloud data storage and relational databases. Moreover, CAD recognises the varying technical capacity across jurisdictions and was built with user accessibility in mind. For instance, data registries can use APIs as well as Excel spreadsheets and manual entries to upload data onto the platform.[67]

Importantly, the CAD Trust architecture is as much about organisational infrastructure as technology. For example, its newly established Council consisting of public and private sectors stakeholders provides governance and allows for consensus building. The project has adopted a design approach throughout conceptualisation and testing, with a focus on solving real-world problems through engagement with a wide base of stakeholders.[67] Meanwhile, a common infrastructure and data model that specifies the information to be captured addresses the fragmentation in carbon markets by facilitating cross-sector cooperation through simplified data sharing.

Key takeaways:

- CAD Trust provides a data infrastructure for aggregating and harmonising carbon registry data from around the world, helping to mitigate double counting and build confidence in voluntary carbon markets data.
- Blockchain technology enables the platform to address issues of credibility and accountability by recording information in an immutable ledger, achieving traceability at low cost.
- CAD Trust is built with user accessibility in mind, allowing data registries to use APIs, Excel spreadsheets and manual entries to upload data onto the platform. The project has adopted a design approach and engaged with an array of stakeholders, facilitating cross-sector cooperation through simplified data sharing.

Decision framework and checklist

One of the main barriers to wider blockchain adoption is the lack of sufficient knowledge about the technology. This can hinder discussions on how to use the technology to improve public policy outcomes in more collaborative ways. The decision to implement blockchain-based solutions should be based on a needs-driven approach.[39]

To aid this decision-making process, a decision framework has been proposed that prompts practitioners to consider key objectives across three phases of collaboration.[xiii] The framework, presented in Figure 10, synthesises the existing evidence on what works with the results from our survey. By working through this simplified logic diagram, decision makers can reflect on:

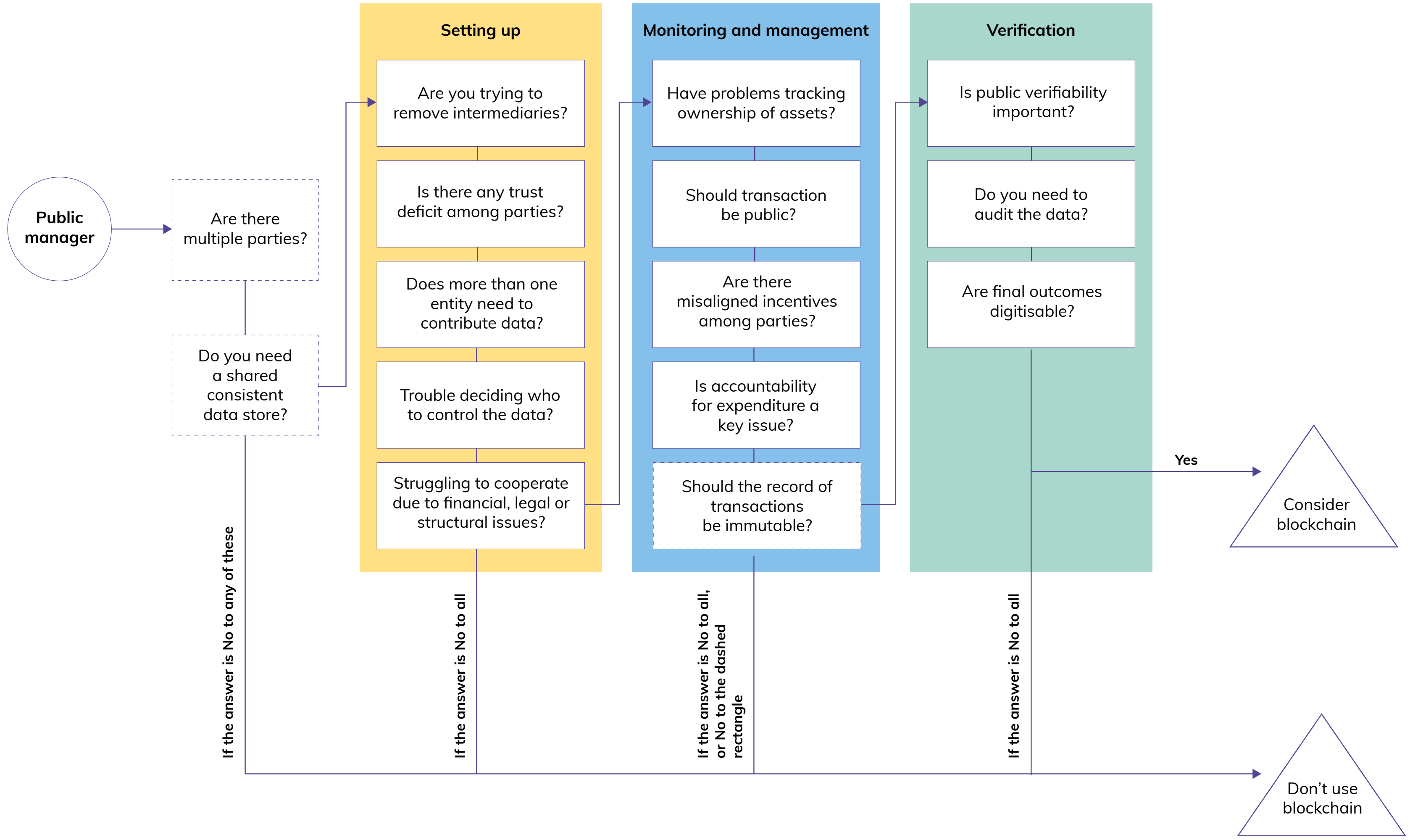
- the trust deficit among potential partners
- data contribution and ownership control
- the necessity of immutable records
- the risk of misaligned incentives
- how the outcomes of the collaboration will be assessed.

The decision framework is not exhaustive but aims to provide a tool for practitioners to be systematic in their evaluation of blockchain as an appropriate solution.

The focus should be on identifying when the technology may be necessary rather than simply viable. By considering key objectives and design features, stakeholders will be able to determine whether blockchain is adding value (in areas such as the 4 Es) and is vital for a specific collaborative project. The framework aims to address the lack of knowledge about blockchain technology and provide a guide for practitioners to make informed decisions about the adoption of the technology.

xiii The framework also builds on existing work and decision trees developed in prior work, including NISTIR 8202: Blockchain technology overview (Yaga et al, 2018) and Blockchain Beyond the Hype: A Practical Framework for Business Leaders (WEF, 2018).

Figure 10: Decision tree for adopting blockchain in partnerships



Conclusions

Drawing on expert interviews and new survey data, this study provides fresh evidence on the perceived and real benefits of using blockchain to facilitate collaboration. A decision framework helps to guide practitioners on the suitability of blockchain by working through key issues in the design and the monitoring and evaluation stages of a project. The report focuses on the public sector, where application of the technology can be used to collaborate with other organisations within and across the sector to achieve better outcomes.

Blockchain has emerged as a promising solution for collaboration and partnerships, offering a secure and transparent way for multiple parties to interact and transact without intermediaries. Key features such as immutability, decentralisation and programmability allow for the creation of decentralised networks that can be used to support relationships and trust, facilitate coordination and enhance transparency and accountability. Despite these potential benefits, there are inherent risks and limitations as well.

One of the key challenges is immutability at the expense of flexibility. While immutability ensures the integrity of transactions, it means that once a transaction is recorded on the blockchain, it cannot be edited or deleted. This lack of flexibility can be a disadvantage in situations where amendments need to be made to a transaction, such as in the case of errors or disputes. Overcoming such constraints will be particularly useful in areas such as procurement and commercial contracting.

Another challenge is the trust and blockchain paradox. While blockchain is often touted to eliminate the need for trust between parties, the technology inherently relies on trust in the underlying platform and participants within a network.

Last is the issue of decentralisation and power dynamics. Decentralisation is a key feature of blockchain technology that allows for the creation of peer-to-peer networks without a central authority. However, this can create power dynamics within a network, where certain participants may have more influence or control over the network than others.

In future, it appears that blockchain will play an increasingly important role in how public services are delivered. The technology is rapidly evolving to meet the needs of a globalising society, and with this change comes uncertainty. Whether these dynamics prove disruptive in a way that “takes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing established competitors” is too soon to say.[69]

For the time being, blockchain can play a complementary role alongside other technologies and processes with more established track records. Collaboration between the private and public sectors can help to accelerate the understanding, and potential application, of how digital ledgers can enable innovative ways of managing contracts and relationships. Building further evidence through investigating existing or past initiatives using comparative analysis, standardised case studies, experimental and quasi-experimental evaluations, and economic assessment methods is much needed to better understand the real-world effect of implementation.

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