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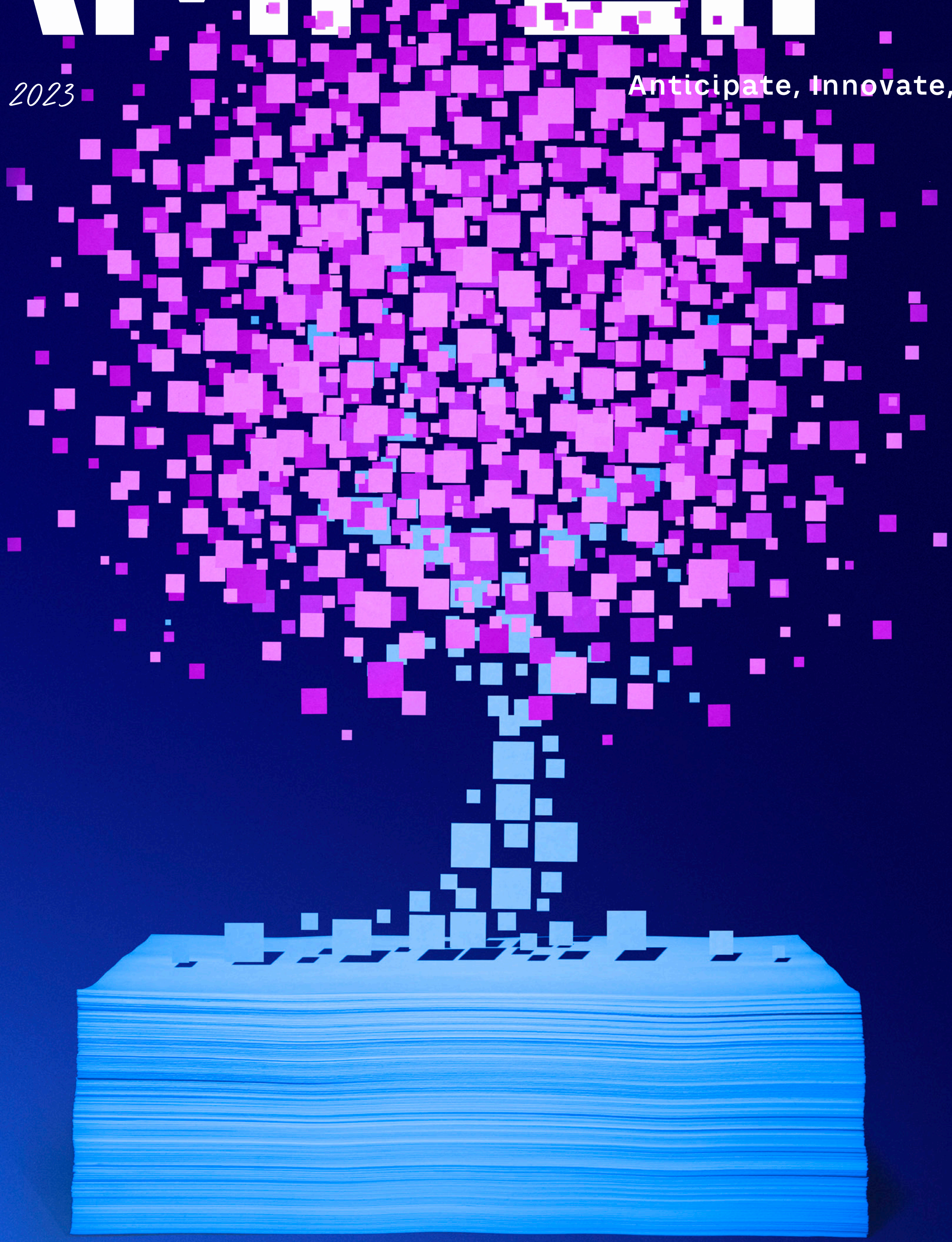
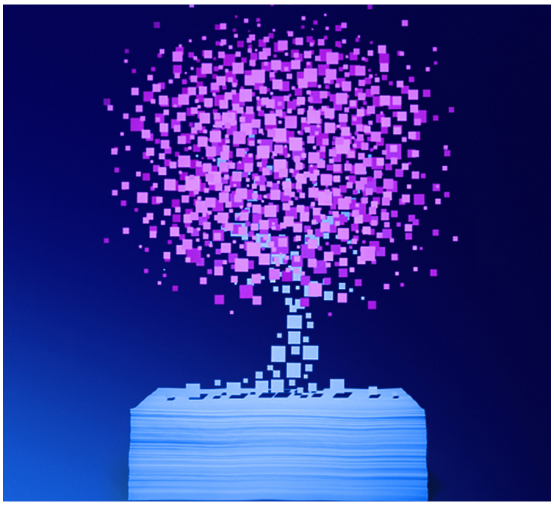
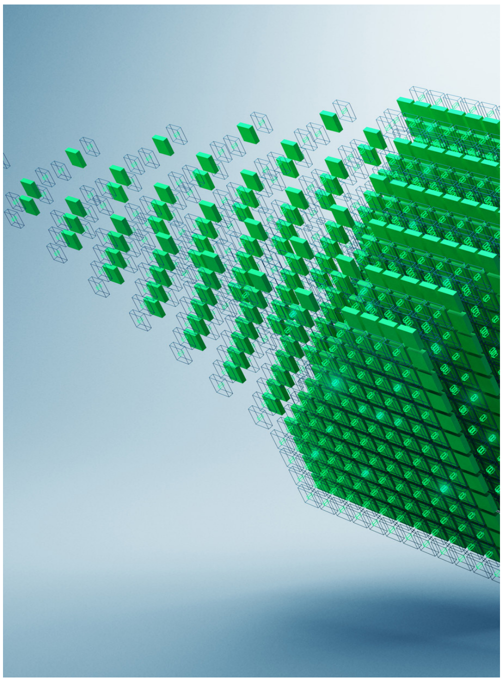
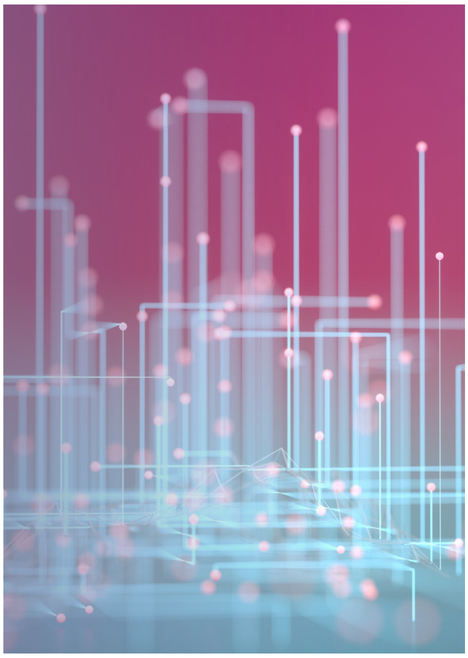


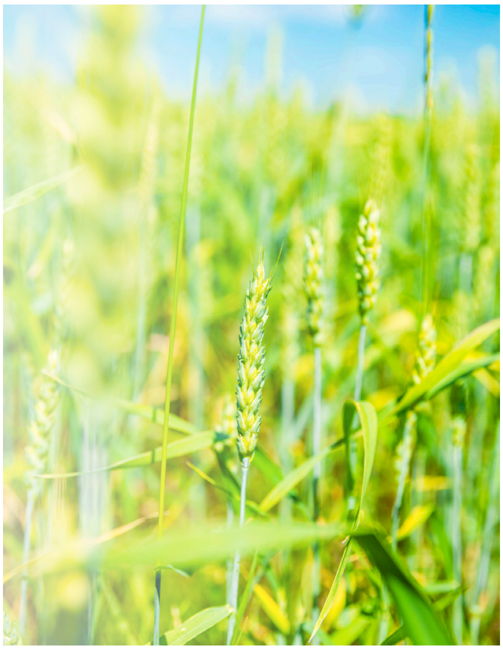
Blockchain Technologies & Environmental Sustainability

CONTENT









BLOCKCHAIN TECHNOLOGIES & ENVIRONMENTAL SUSTAINABILITY

BY HORST TREIBLMAIER, GUEST EDITOR

As humanity grapples with the urgent need to address environmental, economic, and social challenges, the global discourse on sustainability has taken center stage. In this context, blockchain technology has been suggested as a promising ally in the pursuit of a more sustainable future. At closer inspection, the relationship between blockchain and sustainability is complex and multifaceted, encompassing a wide range of opportunities and applications with the potential to reshape industries, value chains, and the way we impact the environment.

The first online deployment of blockchain was introduced by the pseudonymous Satoshi Nakamoto as one of the building blocks of the cryptocurrency bitcoin.[1] Even though the true identity of the inventor was never revealed, blockchain began to attract substantial attention in the industry and academia, and numerous ideas were generated on how to use it beneficially.[2] Due to the decentralized nature of blockchain and its emergent properties, it has already begun to transform value networks and business relationships. Many new applications go beyond cryptocurrencies and increasingly involve end users and consumers.[3]

Given the need to address the aforementioned sustainability challenges, blockchain has become the technological foundation for innovative solutions that help reduce negative environmental impact, foster economic fairness, and promote social justice. Academic research has identified several ways blockchain can contribute to the circular economy, including decentralization, transparency, trust, traceability, information sharing, low transaction costs, and the opportunity to enhance business collaboration.[4]

A systematic investigation of previous studies confirmed the potential of blockchain to positively contribute to several of the United Nations Sustainable Development Goals (UN SDG), including affordable and clean energy, industry innovation and infrastructure, sustainable cities and consumption, climate action and forests, and desertification and biodiversity.[5] However, on closer inspection, numerous ongoing initiatives specifically defined as "blockchain for good" projects seem to favor the status quo rather than transformative change and face sustainability dilemmas.[6]

Further research is needed to increase our understanding of the technology and identify use cases in which specific blockchain characteristics can provide value and foster sustainability, ideally without significant trade-offs. In other words, we need inspirational examples that give us a glimpse into the future and point business leaders and technology developers toward applications that can serve as beacons for organizations that need to overcome similar challenges.

In this issue of *Amplify*, we delve into the intricate connections between blockchain technologies and sustainability, highlighting how transparency, traceability, and decentralization can empower individuals, organizations, and governments to address pressing sustainability issues, from energy grids and sustainable forestry to agri-food ecosystems and regenerative finance (ReFi). As we explore this dynamic development, it becomes evident that blockchain is not merely a technological innovation: it can serve as a catalyst for transformative change that aligns with the global imperative to create a more sustainable and equitable world.

IN THIS ISSUE

This issue clarifies the complex relationship between blockchain and sustainability and provides inspiring examples of how the technology can be successfully applied to yield environmental benefits.

In our first article, I elaborate on the complex concepts of blockchain and sustainability, both of which are comprehensive and frequently misunderstood. My piece illustrates how the technology offers a multitude of capabilities (e.g., immutability of data, shared access, programmability, security) that can yield numerous beneficial outcomes for sustainability efforts.

Next, Ali Arabnya and Amin Khodaei explore blockchain's potential to create the sustainable energy grid of the future. One of the defining features of the technology is decentralization, which perfectly matches with the idea of distributing the production, trading, and consumption of energy. This transition is going to be complex, and the authors do an excellent job of outlining what needs to be done and which challenges need to be overcome to produce more robust and efficient energy systems.

The third article presents an interview with Michael Marus, conducted by Cutter Expert Curt Hall and me. Marus is CIO and director of IT at the Forest Stewardship Council, an organization governed by a global network of more than 1,000 individuals and member organizations with the mission to protect forests worldwide. It has been testing and applying blockchain since 2021 to enable sustainability with forest-based materials and has found that blockchain's traceability helps it achieve integrity and credibility for its certification system. Marus provides exciting details about the organization's practical experiences and offers his outlook on how blockchain might provide further value in the future.

> **BLOCKCHAIN TECHNOLOGY HAS BEEN SUGGESTED AS A PROMISING ALLY IN THE PURSUIT OF A MORE SUSTAINABLE FUTURE**

Next, Malni Kumarathunga and Athula Ginige address the important topic of sustainable agri-food ecosystems, an issue that affects all of us. The amount of global food waste is alarming and, not surprisingly, has a huge detrimental impact on natural resources. Blockchain can enhance trust along the supply chain and improve the situation, especially for smallholder farmers. The authors' suggested model simultaneously reduces greenhouse gas emissions, allows for better resource use, and improves the livelihood of farmers.

Finally, Cutter Expert Simon J.D. Schillebeeckx and Marco Schletz dive deep into the field of ReFi, a concept that enhances financial practices through decentralization and focuses on environmental and societal systems. The authors highlight several key problems of the space and point out that genuinely disruptive ReFi models are still in their infancy. The good news is that ReFi's potentials are manifold and exciting. In the not-too-distant future, we might see financial applications backed by blockchain that can enhance data credibility, exchangeability, and transparency to redefine how corporations create and apportion environmental value.

This insightful issue of *Amplify* not only exemplifies how blockchain technology can help create solutions that benefit the environment, it should also inspire business leaders to further investigate the topic and seek out solutions not yet considered.

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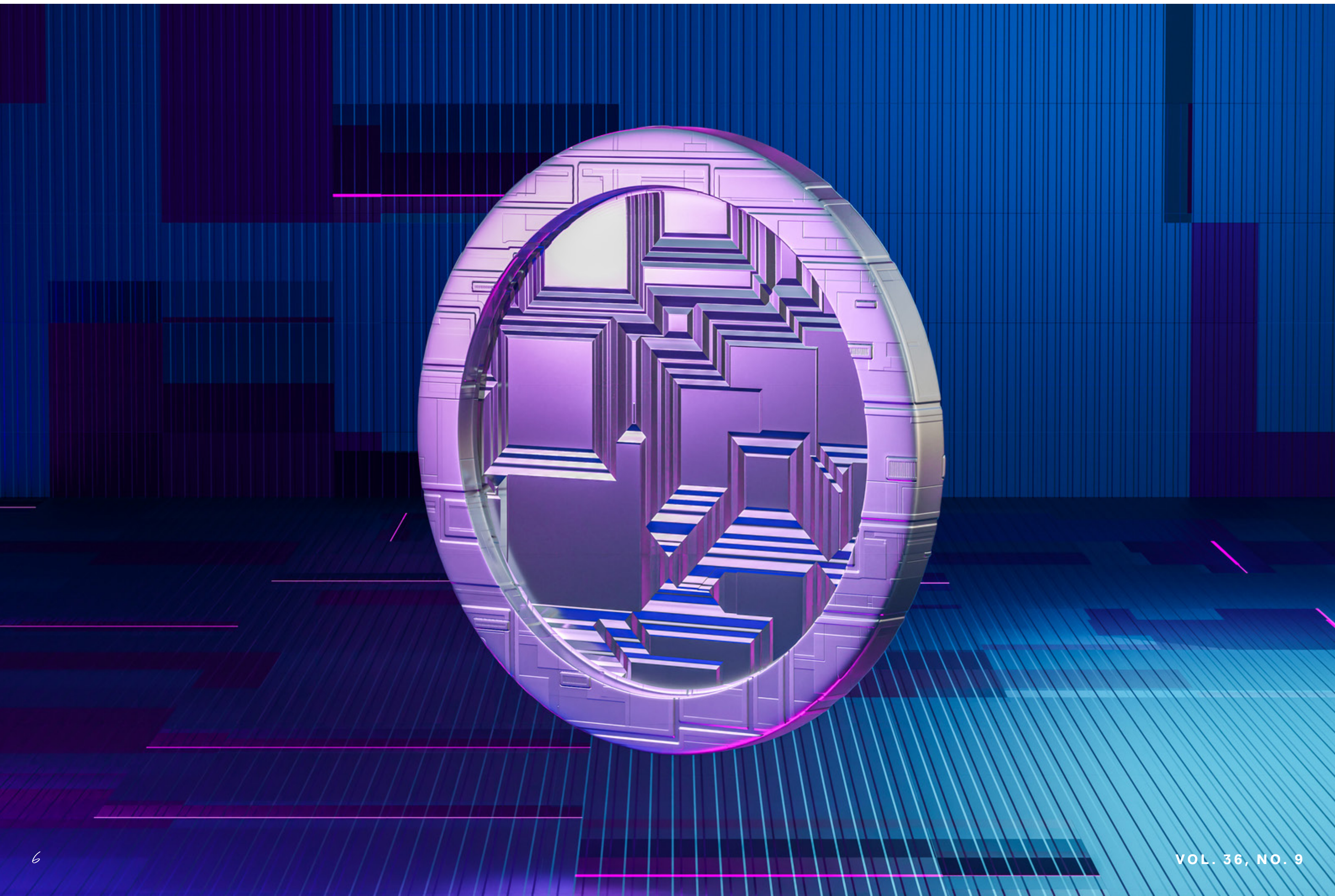

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SUSTAINABILITY IMPACT OF BLOCKCHAIN

HIGH HOPES & GREAT FEARS

Author

Horst Treiblmaier

Blockchain, a complex technology, and sustainability, an abstract concept, have two things in common: (1) they are fairly comprehensive and (2) vaguely defined. To understand how the former can impact the latter, core terms and existing trade-offs must be properly explained, and all positive or negative blockchain sustainability implications must be carefully evaluated. The good news is that inspiring examples exist to demonstrate how blockchain can foster positive aspects of sustainability.

Admittedly, the situation is somewhat confusing. If one goes by mainstream media, the idea that blockchains can foster sustainability is an oxymoron. A *Forbes* article from earlier this year is titled "Why Blockchain, NFTs, and Web3 have a Sustainability Problem,"[1] implying that blockchain itself and the applications built on it pose serious problems for the environment.

Bitcoin, the foremost blockchain application, gets most of the attention. As of September 2023, the cryptocurrency uses more energy than countries like Belgium or the Phillippines.[2] Several years ago, the World Economic Forum went so far as predicting that in the year 2020, Bitcoin would consume more energy than the whole earth.[3] Quite foreseeably, this didn't happen, but the current media discourse surrounding Bitcoin consistently focuses on its energy consumption, often augmented with stories about money laundering and darknets.

However, from a sustainability perspective, there is more to Bitcoin's energy consumption than meets the eye, and the complexity of the topic increases dramatically when the focus expands to blockchain in general.[4] Thus, any informed discussion of how and why blockchain technology can be relevant for sustainability must start with a careful investigation of what sustainability is and how blockchain works.

> **THERE IS MORE TO BITCOIN'S ENERGY CONSUMPTION THAN MEETS THE EYE**

SUSTAINABILITY: WEAK OR STRONG?

In 1987, the Brundtland Commission (formerly the World Commission on Environment and Development), a suborganization of the United Nations (UN), stated that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[5] In light of dwindling natural resources and the ongoing extinction of species, it is safe to say that humankind is not exactly on track.

A broad sustainability perspective includes more than the environment and natural resources. According to the concept of the "triple bottom line," economic and societal issues should also be considered. This viewpoint is often referred to as the "three Ps": profit, people, and the planet.

The concepts of weak and strong sustainability can be differentiated based on the relative importance of the three Ps (see Figure 1). Weak sustainability assumes the general substitutability of natural and manufactured capital such that a total capital stock is maintained, and the depletion of natural resources can be compensated for by human-made capital. Strong sustainability puts the environment first and argues that natural capital cannot be replaced. Advocates of this view argue for conservation measures, even if that means limited economic growth.[6]

THE CONCEPTS OF WEAK & STRONG SUSTAINABILITY CAN BE DIFFERENTIATED BASED ON THE RELATIVE IMPORTANCE OF THE THREE Ps

A personal side note: from the viewpoint of thermodynamics, the strong perspective is clearly the correct one, since resources (and species) that are depleted or extinct are gone forever. Given that the total entropy (as a measure of disorder) in a closed system constantly increases, all kinds of economic activities lead to environmental degradation. These ideas were outlined in detail by ecological economist Nicholas Georgescu-Roegen back in the 1970s, so no one can say we were not warned.[7]

Given the lack of specificity of the general sustainability definition, in the year 2000, the UN created several actionable tasks within a comprehensive framework called the Millennium Development Goals. It proposed eight international development targets for the year 2015, with a focus on addressing the living conditions of people in developing countries. In 2015, these goals were superseded by the Sustainable Development Goals (SDGs) that include 17 objectives, which, taken together, should help achieve a more sustainable, prosperous, and equitable world by 2030.[8] These goals are comprehensive and address a wide range of environmental, social, and economic challenges, some of which are arguably contradictory.

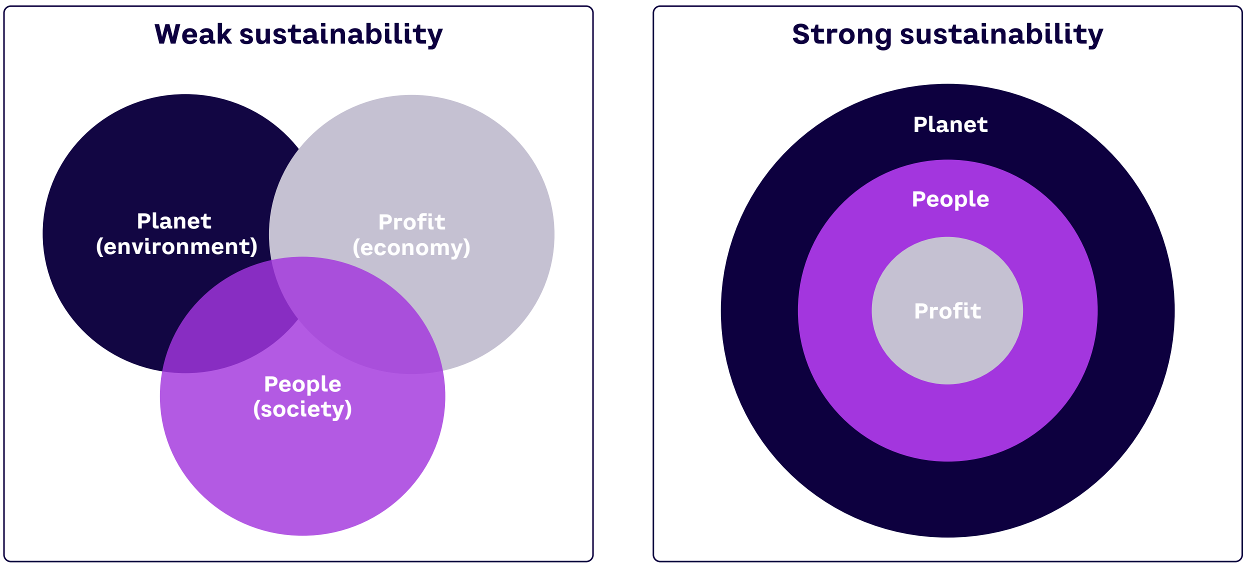


Figure 1. Perspectives on sustainability

BLOCKCHAIN: NOT A STATIC MONOLITH

The aforementioned *Forbes* article nicely illustrates the problem of blockchain's media coverage. It's "the blockchain" that consumes energy, destroys the environment, or (less frequently) helps build innovative and useful solutions.

The truth is that "the blockchain" doesn't exist. Instead, a wide selection of building blocks can be combined in various ways such that protocols based on distributed ledgers emerge that enable a wide range of hitherto impossible applications.

The fundament of the blockchain technology stack is the infrastructure layer in which, among other things, the rules of a decentralized network are determined, as well as the way data is stored and new coins are mined. Numerous implementation options are available for all these components. Similarly, a multitude of design choices exists for the building blocks of the subsequent layers: network and protocol layer, service layer, and application layer (see Figure 2).

This leads to a modular system in which components can be customized depending on the goals and desired features of a certain application. Importantly, no perfect solution exists, and all the different protocols have their own trade-offs between decentralization, security, and scalability. This is aptly named the "blockchain trilemma."

Furthermore, the technologies underlying blockchain are under constant development, which renders the idea of a static technology impractical. For the sake of simplicity, in the remainder of this article I use "blockchain" as an umbrella term, but readers should be aware that the respective implementations can substantially differ.

The most interesting and controversial blockchain building block in the context of sustainability is the proof-of-work (PoW) consensus mechanism. Originally designed as an ingenious method to combat junk mail, it was cleverly applied by Satoshi Nakamoto in the Bitcoin protocol to create a network in which consensus can be reached among participants who do not need to know or trust each other.[9]

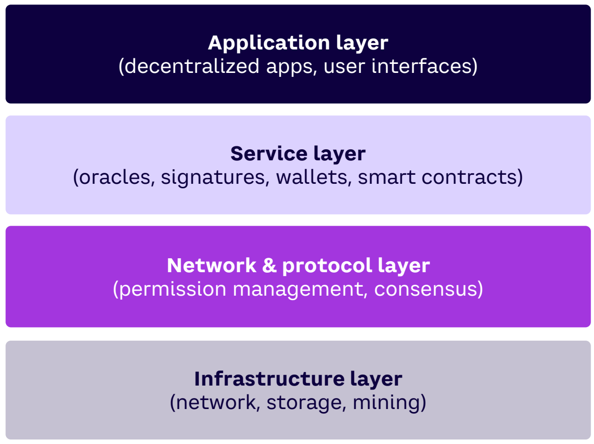


Figure 2. The blockchain technology stack

Such a network even works in the presence of malicious participants, as long as the majority follows the rules. To achieve this, energy is used by so-called Bitcoin miners who compete against each other in the race to create the next block of transactions on the chain, which goes along with an attractive reward that is paid out in newly created bitcoin.[10]

As Bitcoin's popularity soared, incentives to spend more and more energy to compete in the race for new coins increased. The desired side effect is that the overall security of the network increases, due to the sum total of energy that goes into it. This led some to conclude that it is the PoW consensus that is causing environmental havoc, but the decisive factor is the popularity of a specific blockchain.

For example, the second most popular PoW cryptocurrency, Dogecoin, only uses a fraction of the energy that goes into Bitcoin. It is therefore PoW in combination with Bitcoin's high appreciation that induces miners to invest in highly specialized equipment and use substantial amounts of energy to search for new blocks.

Additionally, PoW is just one option to reach consensus in a decentralized network. Alternative approaches such as proof of stake (PoS) rely on selecting validators in proportion to the amount of cryptocurrency they hold (i.e., lock up). Naturally, this approach needs much less energy, and a transition from PoW to PoS is possible, as shown by the Ethereum blockchain in September 2022. According to the Crypto Carbon Ratings Institute (CCRI), this transition reduced energy consumption by 99.988% and its carbon footprint by 99.992%.[11]

However, a change in the consensus mechanism has substantial implications on blockchain governance, which makes PoW and PoS hard to compare.[12] In light of the overall complexity and the numerous trade-offs, how can blockchain be used to create solutions that help to address at least one of the suggested sustainability goals? I argue that a multitude of options exists by simply combining the advantageous properties of blockchain with their respective sustainability goals. The most reasonable way is to look beyond the technical details of a specific implementation and focus on the emergent capabilities instead.

Figure 3 shows examples of such capabilities, including the immutability of stored data, shared access to data in real time, programmability with the help of short self-executing programs called "smart contracts," and increased security through encryption and clearly specified data-access roles.

These capabilities must be scrutinized to determine how they can enable and drive the respective sustainability goals, some of which are shown on the right-hand side of Figure 3. For example, the arrows illustrate how the combination of data immutability and shared data access can facilitate positive environmental, economic, and social impact via the traceability of goods (I will elaborate on this in the following section).

For illustration purposes, I have selected six potential blockchain applications with a positive impact on one (or more) sustainability goal. Although numerous projects in all these areas have already launched, I do not refer to any specific initiatives due to the fast-paced nature of industrial developments and the high likelihood that new and even more innovative projects will be launched soon. Instead, I briefly outline the underlying logic of how blockchain capabilities can have a positive sustainability impact.

SUPPLY CHAIN TRANSPARENCY

The immutability of transactions is a defining feature of blockchain. Access to this information is available to everyone in public blockchains (or at least to a clearly defined group of individuals or organizations in private or consortium blockchains). All authorized nodes can access the needed information in real time, and they can trust that this data has not been modified.

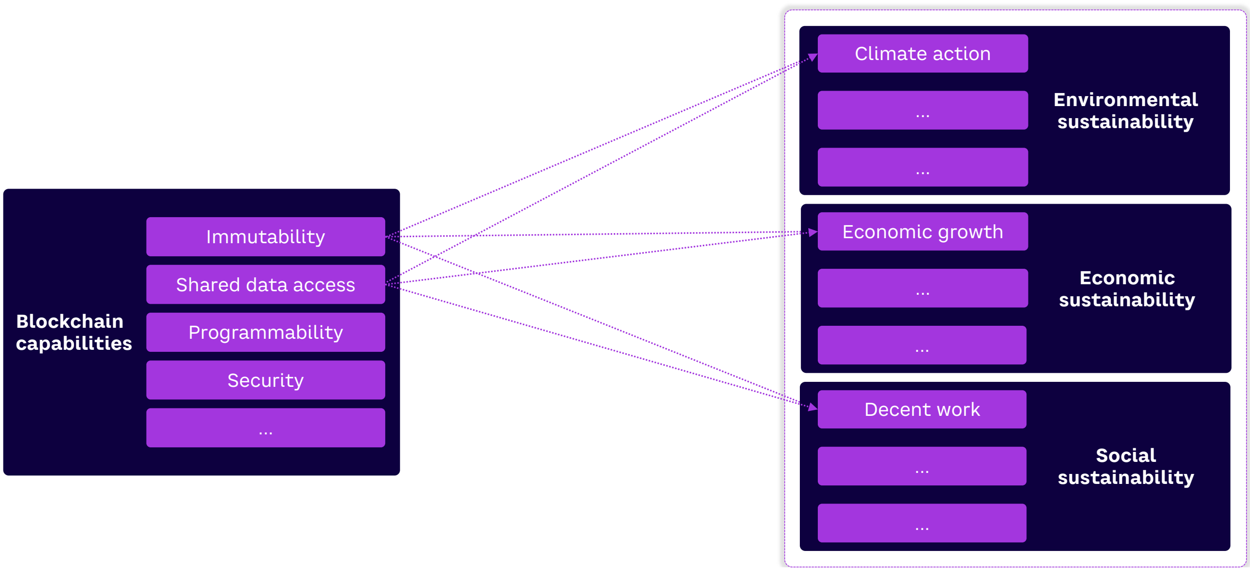


Figure 3. Blockchain as a driver and enabler of sustainability

The combination of these features has caught the attention of supply chain professionals who strive to develop solutions that improve the traceability of goods within complex value networks. Envisioned efficiency improvements include a reduction in carbon emissions (SDG 13: Climate Action), a more efficient use of resources (SDG 8: Economic Growth), and more transparent working conditions (SDG 8: Decent Work). Accordingly, the application of blockchain in supply chain management can simultaneously contribute to several sustainability goals.

WASTE MANAGEMENT

In a circular economy, waste should be avoided and materials recycled. Similar to the previous example, blockchain can improve waste management systems by enabling the tracking and tracing of waste streams, incentivizing recycling through the issuance of tokens, and reducing waste fraud through increased transparency. Furthermore, it can be used to record the provenance of materials, which can be tracked back to their source to ensure the quality and authenticity of recycled products.

FRAUD REDUCTION

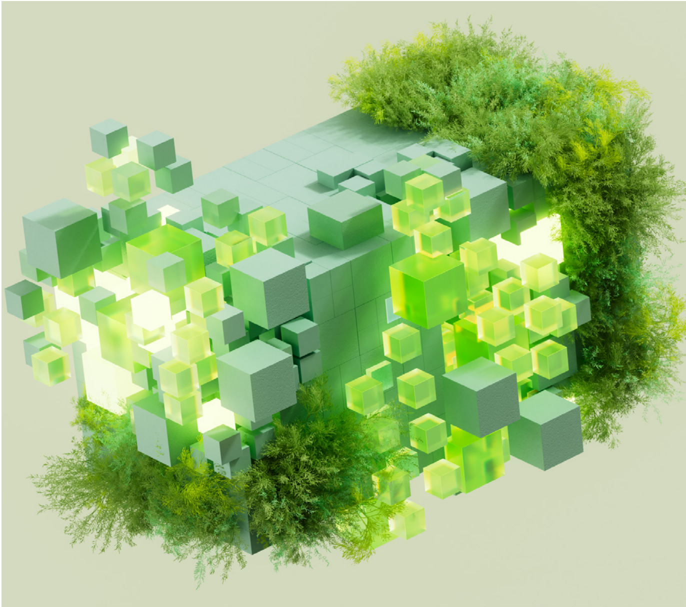
Blockchain's security and immutability features make it an ideal technology for preventing fraud. For instance, in the energy industry, blockchain can be used to verify the source and consumption of renewable energy, reducing the risk of false claims and ensuring that clean energy initiatives are genuinely sustainable. It can simplify the auditing process for all kinds of industries by providing auditors with an immutable and transparent transaction record, reducing the likelihood of fraud going undetected.

ENFORCEMENT OF SUSTAINABILITY AGREEMENTS

Smart contracts are computer programs that are automatically and deterministically executed when predetermined conditions are met. Among many things, they can be used to automate and enforce sustainability agreements. For example, a smart contract can ensure that a manufacturer meets prespecified sustainability criteria before receiving payment or that carbon-offset credits are automatically issued when specific emission-reduction goals are achieved.

CARBON EMISSIONS

Exact data on carbon emissions is crucial for organizations striving to reduce their environmental footprint and for governments implementing carbon cap-and-trade systems, in which emitters hold allowances for a certain amount of greenhouse gases. Blockchain can store emissions data collected from Internet of Things devices. Information about carbon output can also be gathered all along the supply chain, helping consumers and companies make better-informed decisions based on the overall environmental impact of their products. Smart contracts can be used to automate carbon-offset and emission-reduction agreements, and decentralized markets can be established in which individuals and organizations trade carbon credits without the need for intermediaries.



DONATIONS & IMPACT INVESTING

The transparency and traceability of blockchain transactions are ideal for managing donations and impact investments. Donors can ensure their contributions are used for the agreed-upon sustainability projects, and investors can track the social and environmental impact of their investments in real time. The peer-to-peer nature of the network allows for innovative forms of micropayments, which might especially benefit projects that require ongoing support and/or direct giving without the need to pay for intermediaries.

CONCLUSION

Sustainability is a complex, multifaceted topic, as is blockchain technology. Although concerns regarding the potential negative impact of Bitcoin need to be taken seriously and assessed objectively, blockchain technology has proven its potential to address pressing sustainability problems. However, to fairly assess its contribution, it is crucial to identify how its unique features can help create solutions that would have not been possible otherwise.

This article shows the connection between blockchain and sustainability and provides several examples of how blockchain-based applications can help preserve the environment, ensure economic stability, and increase social fairness.

Several recently abandoned blockchain projects indicate we still have a long way to go. The issue is not the technology — a new way of thinking is required that matches the capabilities of blockchain with environmental, economic, and social needs. Thus, ecologists, technology developers, and business leaders need to join forces and create solutions that can help to solve humankind's most urgent problems.

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THE SUSTAINABLE ENERGY GRID

BLOCKCHAIN'S ROLE IN ADDRESSING TRANSITION PAIN POINTS

Authors

Ali Arabnya and Amin Khodaei

Decarbonization, decentralization, digitalization, and democratization are shaping the future of energy systems. Blockchain is a powerful technology that can help us transition to a more sustainable, resilient, efficient, and equitable energy future. However, this transition involves a number of pain points that must be considered by senior energy and utilities executives.

Grid decentralization is the result of: (1) the current focus on resilience and (2) the increasing number of smart devices, microgrids, electric vehicles (EVs), and distributed energy resources (DERs) being integrated into the power grid. The Institute for Electric Innovation (IEI) reports that more than 114 million smart meters were deployed in the US as of 2021 and expects that number to reach 135 million by the end of 2025.[1] The International Energy Agency (IEA) forecasts a global EV deployment of 40 to 70 million by 2025, reaching between 120 and 160 million by 2030.[2]

These trends indicate the importance of investing in grid decentralization to facilitate scalable operational capabilities. Blockchain technology has the potential to facilitate this process in energy systems. However, there are at least three pain points that senior executives in utility companies will need to address to ensure a smooth transition to a decentralized grid:

1. Transactive energy infrastructure
2. Operational capabilities
3. Decentralized decision-making processes

TRANSACTIVE ENERGY INFRASTRUCTURE

Blockchain technology can be used to build the transactive energy infrastructure needed for grid decentralization.[3] Figure 1 shows a decentralized grid system architecture.[4] Operational information and processes are carried out by an energy aggregator, and market settlements are carried out through a blockchain platform. Blockchain can facilitate a transaction infrastructure for peer-to-peer (P2P) energy trading across the grid, but a robust collaboration plan involving all aggregators will be needed.

With this type of architecture, no intermediary is required to provide security support or keep a transaction ledger (in conventional centralized grids, these tasks are performed by the system operator). With blockchain's distributed digital ledger, a broad range of data (from financial transactions to power system signals) are stored in a package called a "block." These blocks are identified by a cryptographic characteristic called a "hash" and are connected in chronological order. The previous block hash is included along with the current hash, literally linking the blocks and creating a chain (hence, "blockchain").

> **TRENDS INDICATE THE IMPORTANCE OF INVESTING IN GRID DECENTRALIZATION TO FACILITATE SCALABLE OPERATIONAL CAPABILITIES**

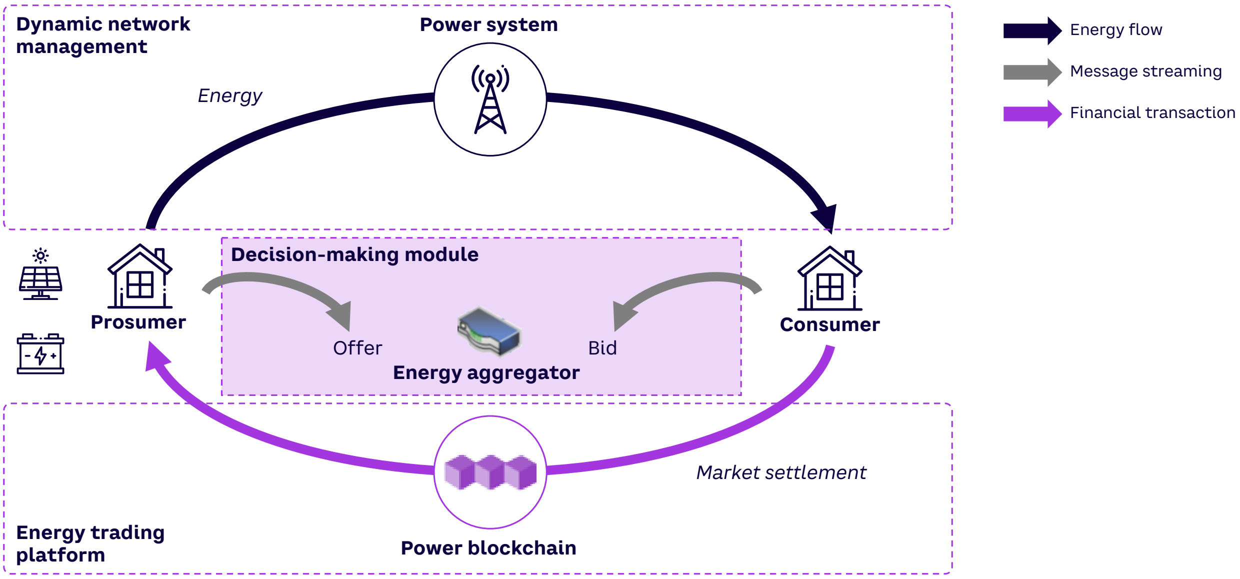


Figure 1. A system architecture for decentralized grids (adapted from Choobineh et al., December 2022)

A process called "consensus mechanism" prevents falsified data from entering the chain. Consensus mechanism guarantees the correctness of the latest block added to the chain to all nodes in the chain. That action is called "mining," and the nodes that carry out this task are called "miners." The most common consensus mechanisms are proof of work (PoW), proof of stake (PoS), practical byzantine fault tolerance, proof of authority (PoA), and proof of elapsed time (PoET).

In "Conceptual Design of a Consensus Mechanism for Renewable Energy Markets on Blockchain," we proposed a proof of concept (PoC) for a novel consensus algorithm, namely proof of reserve (PoR) designed for P2P renewable energy transaction on blockchain platforms.[5] PoR is a combination of PoS and PoW algorithms. It attempts to avoid the high computational power needed for PoW while allowing as many nodes as possible to participate in the mining process. It also maintains the voting procedure and higher scalability potential of PoS.

Large-scale implementation of blockchains to facilitate transactive energy infrastructure requires significant investment and new regulatory frameworks. The investment includes both the cost of blockchain platform deployment and the cost of required upgrades to smart meters, communication protocols, data-storage devices, and other power grid components.

Senior utilities executives should consider the decentralization process not only as grid-modernization project, but also as a capital project in which investment decisions should be justified via expected future cash flows and the required ROI during the project lifecycle.

OPERATIONAL CAPABILITIES

Blockchain can provide a secure, distributed system architecture to facilitate grid decentralization. However, limitations on the number of transactions, latency, and storage capacity remain serious hurdles for large-scale implementations of this technology. There is promising work underway to address this issue by increasing the block size, sharding, forking, and developing new blockchain architecture.

Another hurdle is the need for more efficient consensus mechanisms. Current consensus mechanisms suffer from high energy consumption and the risk of monopoly formation on the blockchain. PoW in aggregate consumes as much electric power as the country of Denmark.[6]

Consensus mechanisms like PoS were introduced to overcome this issue, but they put blockchains at risk of being monopolized by bad actors, weakening the decentralization objectives of the system. The creation of consensus mechanisms that offer more energy savings, higher levels of decentralization, and improved scalability and security is a prerequisite to creating a large-scale, fully decentralized grid.

The current state of blockchain interoperability (defined as the ability of blockchain platforms to exchange information with each other) also poses a challenge to efficient operations of such decentralized energy systems.[7] It is expected that other blockchain applications (e.g., in banking) required to interact with energy blockchains will emerge in the future. To enable that interaction, more capabilities for cross-chain interoperability should be developed to facilitate the future interoperability requirements between different blockchain platforms.

Senior utilities executives should consider the existing technical limitations of blockchain technology when reviewing the functional requirements of their grid-decentralization strategy.

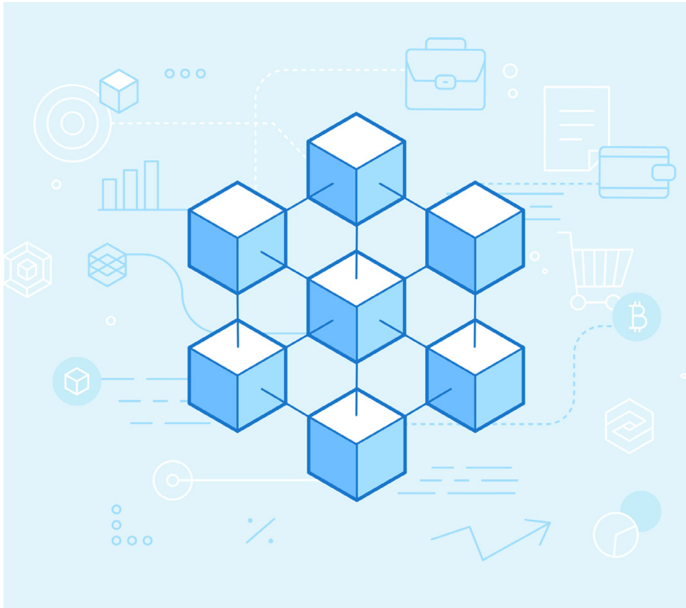
DECENTRALIZED DECISION-MAKING PROCESSES

In a decentralized power grid enabled by blockchain, the decision-making process is distributed among network participants (or decision agents in this context). Each participant has a certain level of authority in a distributed framework that replaces the centralized decision-making process used in conventional systems with a cooperative decision-making process.

Game theoretic decision models and cooperative decision models, such as decentralized, partially observable Markov decision processes, replace decision theoretic models that are primarily focused on unilateral or one-player decisions. Despite this decision distribution, there still is a need for a single entity to oversee various operational configurations, such as power dispatch, frequency control, and voltage control. This can pose a challenge for governance of the decentralized system. Decision processes are, to a large extent, distributed across the grid, but some grid operations are still centralized in nature.[8]

Even if these central operations aspects are automated through autonomous software agents, there still is a need for a single entity to maintain the stability of the system and provide the required network maintenance and support services.

Senior utilities executives should pay special attention to the design of system governance structure and policies before transitioning to a completely decentralized grid.



THE ROLE OF UTILITIES IN TRANSITIONING TO THE GRID OF THE FUTURE

Electric power distribution networks will become more decentralized and autonomous in the foreseeable future, but this will likely be partial rather than full scale. Existing decentralization technologies, including blockchain, are still primarily focused on facilitating the settlement processes and keeping a distributed ledger of P2P transactions. Important parts of system operations (e.g., power flow planning, voltage stability, frequency control, transient stability, and other dynamic network management activities) should still be performed by third-party intermediaries, such as utilities and distribution system operators.

A hybrid decentralization architecture is a more plausible scenario for distribution network system design, as shown in Figure 2. The purple arrows represent the information flow for the tasks performed by the utility; the gray arrows depict the information flow for decentralized tasks. The solid gray arrows represent financial transactions on the blockchain, and the dashed gray arrows show the message-streaming activities. In this example, blockchain nodes 1, 3, 4, and 6 are authorized by the utility to engage in P2P transactions. Users submit bids and offers through this channel to the aggregator, and the aggregator notifies them about transaction decisions based on the underlying market rules.

Some utilities may be able to monetize their platform by offering infrastructure as a service (IaaS) to consumers and prosumers, providing system maintenance and other support activities. For instance, the power dispatch from prosumers to consumers can be facilitated on their blockchain through game theoretic models programmed into smart contracts in which both prosumers and consumers are considered as passive loads in their power-flow studies. As part of their business model, utilities can perform power-flow studies to determine the output of the utility-owned generators, power purchases, voltage levels, and reactive power decisions in return for the per-transaction commissions they receive.

Utilities can also play a crucial role in maintaining system stability. For example, they can be in charge of P2P transaction modifications required due to system-frequency or voltage-level deviations and compensate the prosumers and consumers involved in those unfulfilled transactions.

A private blockchain (an invitation-only platform governed by a single entity) can be a reliable solution for decentralization of power-distribution networks. In this scenario, the administrator manages user access in the system using a private key. Utilities act as a system administrator, sending invitations or granting permission to consumers and prosumers to join the transactive energy platform.

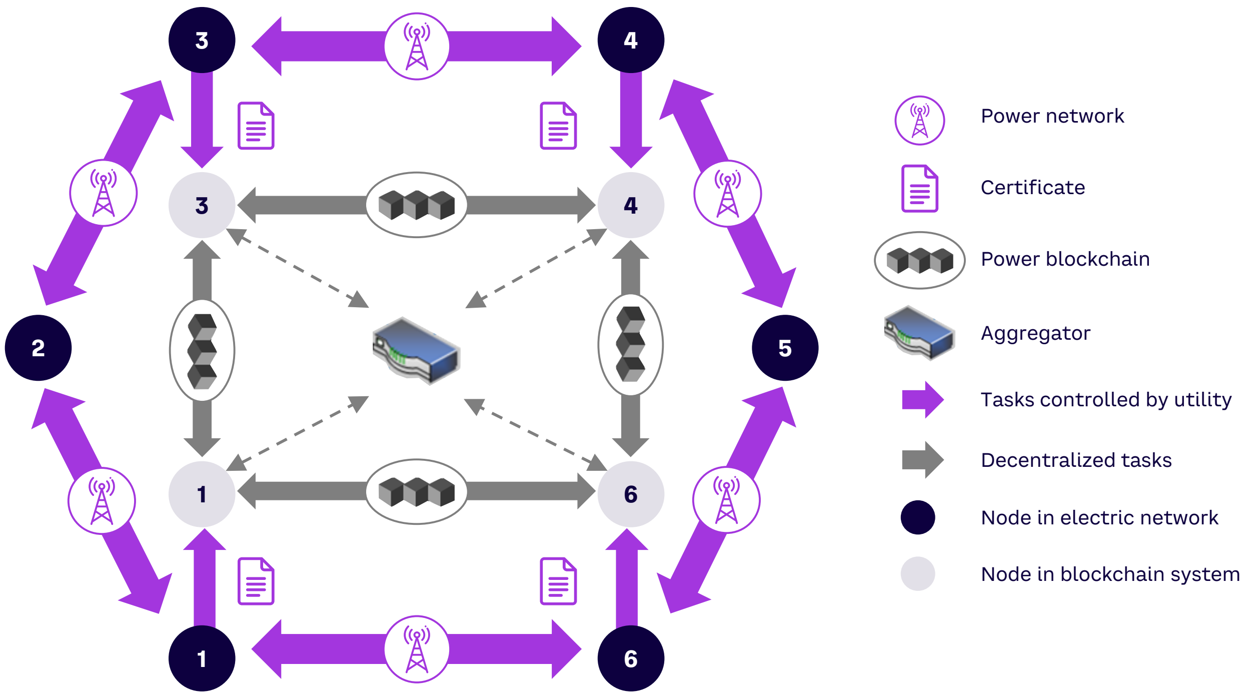


Figure 2. System design for a decentralized grid

Utilities can also certify authorized users to monitor fraudulent activities on the platform and keep out bad actors. That may include eliminating such users from participating in the consensus mechanism, denying access to the platform, and other disciplinary measures based on the gravity of the noncompliance. In addition, utilities can determine the blockchain's operational policies and governance structure. That may include decisions on block size and structure, consensus mechanism, smart contract configurations, incentive design, and transaction structure.

In our view, as the underlying concepts, system design, technologies, and business models related to the decentralized grid evolve, new functions will emerge for utilities to fulfill, and some current functions can be outsourced to autonomous systems and new players. What should not change, however, is the central role of utilities in the decentralized grid.

BLOCKCHAINS & INTEROPERABLE MICROGRIDS

Modern energy systems are increasingly integrating independent, local, decentralized power systems known as "microgrids." Microgrids offer better operational efficiency and higher resilience than conventional power systems. Further benefits can be obtained through a cooperative microgrid ecosystem comprising clusters of multiple microgrids.

In these collaborative ecosystems, each microgrid can supply loads from the excess generation capacity of other microgrids and sell its power surplus to other microgrids. Achieving this requires a system architecture that facilitates cooperation among microgrids by providing appropriate cross-market rules and transaction infrastructure.[9]

Blockchain has the potential to decentralize systems in various applications, including power-distribution networks, providing a secure platform for optimal network operations. In addition, blockchain can facilitate information sharing and transactions among blockchain platforms without the need for intermediaries. These capabilities can be leveraged for implementation of decentralized distribution networks with multiple interoperable microgrids (IMs).

With this type of architecture, users can view the power surplus and electricity rates in other microgrids, send bids, receive offers, and complete energy transactions on the blockchain using designated market rules. This provides a transparent infrastructure for monitoring the carbon footprint and share of renewables in the energy composition of each microgrid; it can even be used to establish market mechanisms for carbon pricing.

IMs can enable better ancillary service provisions and improved dynamic management of the network by providing better access to other microgrid resources. IMs also bring resilience to the network by adding redundancy to the system topology due to their decentralized architecture. This has the potential to reduce operational costs and increase the reliability and efficiency of power-distribution networks.

> **BLOCKCHAIN HAS THE POTENTIAL TO DECENTRALIZE SYSTEMS IN VARIOUS APPLICATIONS**

However, IMs can also create challenges for decentralized distribution networks. First, the interoperability of the transaction infrastructure must be accompanied by well-designed, cross-market rules to facilitate marketplace interoperability. Second, effective governance structure and standard protocols must be developed to ensure the compatibility of various consensus mechanisms across platforms. Third, there are several technical challenges, including ensuring transaction atomicity, improving transaction speed, securing data transmission, ensuring universality of cross-chain protocols, and implementing user- and developer-friendliness of the blockchain.

We are encouraged by recent technological developments in the interoperability of blockchains and the decentralization of distribution networks.[10] In our view, interoperable microgrids enabled by blockchain can offer more choices to consumers, improve market efficiency by eliminating middlemen, increase resilience by decentralizing the network topology, and enable new marketplaces, such as carbon markets.

IMs should be part of the grand strategy of the utilities for decarbonization, decentralization, and digitalization of the smart grid.

CONCLUSION

Blockchain is a powerful enabling technology for decarbonization, decentralization, digitalization, and democratization of our future energy systems. Although blockchain has potential in a wide spectrum of applications in the energy and utilities industry, several challenges and limitations must be addressed before its full implementation into grid operations.

Senior energy and utility executives should acknowledge these limitations as they develop business strategies while watching for technological developments that can facilitate successful adoption of this technology. As the industry undergoes a gradual but fundamental restructuring into a more competitive market, advancement in blockchain technology can be a game changer for utilities competing in increasingly decentralized, highly fragmented energy markets.

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FOREST STEWARDSHIP COUNCIL'S BLOCKCHAIN

VERIFYING MATERIAL TRADE COMPLIANCE ACROSS SUPPLY CHAINS

Authors

Michael Marus, Curt Hall, and Horst Treiblmaier

The supply chain is an ideal domain for applying blockchain technology. There's a critical need to build trust and facilitate consensus among multiple stakeholders, from manufacturers and suppliers to shipping firms, government agencies, customers, and third-party service providers. There's also a critical requirement to provide a secure record of transaction history that can be shared among all supply chain network participants.

Blockchain can enhance the supply chain by serving as an immutable ledger for recording transactions between members of a supply chain ecosystem and by facilitating visibility (for all permissioned members) into the exchange of information throughout overall supply chain operations.

Dr. Horst Treiblmaier, professor and head of the School of International Management at Modul University, Vienna, Austria, and Cutter Expert Curt Hall recently spoke with Michael Marus, CIO of the Forest Stewardship Council (FSC). The purpose was to learn more about FSC's experience with developing a blockchain-based supply chain application designed to facilitate its mission of ensuring the sustainability of forest-based materials and enabling better forest management. This article is based on their interview.

Horst Treiblmaier (HT): Before discussing how FSC is using blockchain, please provide us with some background about your organization and its mission.

Michael Marus (MM): FSC is an international nonprofit founded in 1993 to enable sustainability with forest-based materials and support forest management in becoming more responsible and sustainable in its practices. We are a standard-setting organization. Our standards are set up to ensure that forestry is practiced in an environmentally responsible and socially beneficial manner while being economically viable.

For us, responsible management means safeguarding biodiversity and benefiting the lives of local communities and workers. Our goal is to ensure safe conditions and create an environment where economic viability is possible for all of those who work in and rely on our precious forests. So our certification focuses on three pillars of sustainability: social, environmental, and economic.

Companies that meet our standards through certification are licensed to use our trademarks to claim and promote the FSC materials they trade across the chain of custody. More than 55,000 companies worldwide have joined us in promoting sustainable forest management. You'll find the FSC label on many forest-based products, from furniture and paper to honey, nuts, and milk cartons. The FSC label is widely recognized as assuring that the materials come from sustainably managed forests and have legal and sustainable origins.

> **RESPONSIBLE MANAGEMENT MEANS SAFEGUARDING BIODIVERSITY & BENEFITING THE LIVES OF LOCAL COMMUNITIES & WORKERS**

I joined FSC about six years ago. I saw that FSC needed to invest in technology to better achieve its mission through timely information and knowledge management. So what technology does that mean today? Blockchain.

HT: How is FSC applying blockchain, and how does it benefit your business model?

MM: Integrity is fundamental to FSC's system. That's why we went with blockchain. For example, we take seriously and investigate allegations of supply chain problems reported to us. I know from our investigations that our certification and our assurance system are very strong. But we understand that systematic checks of the use of our trademarks (I'm not just talking about the use of the label or the language; I'm talking about the day-to-day trades when companies claim that they are selling or purchasing FSC materials) are also important. We know that verifying trade claims helps reduce the risk of nonconforming materials entering FSC supply chains. One fundamental reason for our blockchain is to be able to more systematically check compliance with our rules.

At the same time, FSC-certified companies and license holders want to use FSC certification to support demonstrating compliance with the legal authorities — for example, when importing or exporting across borders. There are lots of regulations. The new EU deforestation-free regulation (dubbed EUDR) is a good example. But even in the US or Australia, where demonstrating the origin of the materials is fundamental, there are lots of legal requirements when trading across borders.

We believe blockchain can help because it can account for the certified materials (from us to the final product) along those supply chains and ensure the data is protected. It's really the spot-on technology to meet current needs, both for checking compliance with our rules and supporting certified companies that need to demonstrate legal compliance.

FSC introduced blockchain through a set of pilots. In 2021, we developed a beta version. We tested that platform in 2021 and 2022 in Ukraine (before the war began) and China. We tracked where the source materials were coming from in these countries.

The beta version provided some easy-to-use interfaces and ways to input transaction data from companies regarding their claims about the inputs they were receiving from their trading partners and what they were outputting as a trading partner. Those claims were verified, based on matching claims among trading partners and by an algorithm that we developed to relate certification data to claims in order to verify their veracity.

The beta platform encouraged companies to consider what kinds of analytics and reporting capabilities would be possible, beyond what we were delivering, assuming traceability of the materials being purchased and without revealing any business-sensitive information.

After completing those pilots, with tens of thousands of transactions taking place on those supply chains, we gathered and considered all the feedback and what we learned. We used that knowledge to define what would be most valuable for FSC and for companies trying to use FSC certification as a tool for demonstrating compliance.

Based on the feedback, we created a next-generation FSC blockchain platform that is designed to cater to the analytics and data-related needs of FSC and companies. That includes having a bird's eye view of which claims are being made across supply chains while providing tools to certified companies that will support them with documenting their compliance with, for example, cross-border trades. We are finishing development of the new blockchain in Q4 of this year.

With the conflict in Ukraine, it's been difficult to continue the beta platform. However, we gathered all the feedback and are still connecting with companies there to take what we have learned and apply it to make the new blockchain something that can go beyond China and Ukraine.

HT: Which features of blockchain technology did you find especially useful for your purposes?

MM: It's an interesting time for blockchain. I think privacy is among the main features that show promise for the purpose of establishing traceability and trusted, verified supply chains. Blockchain enables private, confidential transactions; the details of those transactions are only visible to those participating in the transaction. Blockchain's auditability is another important feature: we can examine the transaction blocks for private transactions, and only those companies involved would be able to see the details of that data.

I also think that performance, and the launching of cloud services infrastructure, means that blockchain can be constructed as a set of cloud services with the focus on throughput and latency, so that you can provide the necessary network and permissions management. This is an important feature that we look to benefit from by using blockchain. Leveraging cloud services with consensus mechanisms means that blockchain doesn't have to ruin the environment, as it often is seen as doing.

Data hashing (the process of converting data such as text, numbers, or files) into a fixed-length string of letters and numbers is another important feature. The cryptographic hash produces immutable records that not even a system administrator can change. These are the main features that help establish a solid, trusted supply chain–traceability platform.

HT: I started researching blockchain in 2016. In 2017, there was a lot of hype around the technology. Then there was a blockchain "winter," with some people saying you don't need a blockchain for anything. So it's great to have these real-life examples. You mentioned energy consumption and environmental destruction. But FSC is using a private consortium blockchain. I assume that you're not using a proof-of-work (PoW) mechanism, meaning that energy use is not much of an issue in your case. Is this correct?

> **PRIVACY IS AMONG THE MAIN FEATURES THAT SHOW PROMISE FOR THE PURPOSE OF ESTABLISHING TRACEABILITY & TRUSTED, VERIFIED SUPPLY CHAINS**

MM: Correct. It's a distributed ledger application. The protocols are permission-based because it is a consortium private blockchain. It includes parties that are already working with each other. We also have algorithms to help determine the veracity of the claims being made and, therefore, what's actually written to the blockchain. So there is no PoW mechanism like you might find in a public blockchain application.

HT: Did FSC develop its blockchain on its own? Or did you use an existing platform like Hyperledger Fabric?

MM: We're using cloud services that allow us to use Quorum, an Ethereum-based distributed ledger. We have partners that are helping us develop these cloud services in a way that that meets our needs. But you could also say that we're doing it on our own. However, before constructing our first version of blockchain and running our pilots, we examined many different potential options.

You characterized the period from 2016 through 2017 so beautifully: it was a period of lots of hype. Today, in terms of supply chains, you do find some general examples of blockchain in use — in agricultural food supply chains or diamonds, or precious metals, or similar items. But when it came to the options for wood supply chains, those that would meet our needs and be very much no-nonsense about what you can put on a blockchain, we didn't find a lot of great options at the time. That's why I believe that cloud services that can be constructed in a way that meets our needs are so important. They don't create a lot of hype or burden around what you can actually do and are a good fit for what we need to do.

BLOCKCHAIN NETWORKS ARE EMERGING BECAUSE OF NEW LEGALITY REQUIREMENTS

HT: Did you encounter any disadvantages from applying a blockchain solution?

MM: The biggest disadvantage I find with using blockchain is interoperability. The supply chain–related ecosystem of blockchains emerging right now hasn't yielded any kind of solid standardization and well-defined interoperability. And when I look at FSC-certified companies, many of them are handling more than just forest-based materials. Consequently, they're looking at sustainability for all the materials they're handling, and they don't want to be overtaxed by having to input or connect to multiple systems.

Blockchain networks are emerging because of new legality requirements. And with supply chains, this could lead to interoperability issues that just haven't been addressed yet. But we're aware of these disadvantages and the potential burden. Our next-generation blockchain platform is designed for interoperability, letting companies push and pull their transaction data through the use of standard protocols and data structures. These are the base capabilities we're making sure can be engineered to be interoperable.

HT: Let us talk about the future. You told us about your next steps and vision. But if you think ahead, say five or 10 years, what do you envision? What would be the ideal solution for you? And what can blockchain do to help you achieve your goals?

MM: I'm not one to look for perfection, so I want to be clear on how I see this. My view is that blockchain will be one essential tool for ensuring the integrity of our system. But it's part of a suite of tools. For example, we use wood-identification technologies; we also use geospatial analytics to help determine what's going on in our supply chains and certification, as well as how our rules are being followed or where to investigate.

But looking at a five-year horizon, I hope that blockchain will be of such value to FSC and the certified companies that, alongside certification, it is considered something powerful and valuable. Companies that meet our certification requirements can already say they've been checked on environmental sustainability, worker safety, the rights of Indigenous Peoples, and social issues, among others. They have been checked and meet those standards. But at the same time, as they trade day-to-day, they are part of some very complex supply chains. I think blockchain will become something that complements their participation in verified supply chains. I see blockchain in FSC as a value proposition for companies that want to immediately demonstrate what they're doing on a daily basis, based on the materials they're handling and how they're connected to companies that have met our standards.

HT: When it comes to wood identification, is it possible to take a sample and be able to tell where exactly the wood came from?

MM: That's a difficult question because there are various types of wood-identification technologies, and they are always improving. For example, with anatomy, you look at the wood under a microscope, and you can potentially determine its species and perhaps where it came from. If you know generally where it came from, you may be able to determine its likely origin.

With composite products like paper or plywood, there may be other methods you can use. Some of those require reference samples from us. For example, stable isotope testing could help you understand something about the origin of the product, especially if you have enough reference samples, because it's a comparative science. For instance, I could run a stable isotope test on this wooden table to establish a kind of fingerprint. If I don't have something to compare it against, I may not be able to determine very much. But it's definitely something that we use, especially when we have reference samples. We're also able to use wood anatomy to determine the species and the composition of certain products.

It's something that is part of our tool set, especially because the technology is constantly improving, along with the methods and results that help you determine geographic location.

Curt Hall (CH): You touched on some of the analytics of the FSC blockchain platform here and in your podcasts. Can you comment on the additional analytical capabilities that participants in the pilots indicated they would like to see in the next version of the platform?

MM: The pilot gave companies a very basic view of their transactions: so I've input these transactions, and these are the ones that have been verified by my trading partners and the FSC algorithm, and these are the ones that have not, etc.

We also provided mocked-up dashboards of what would be possible to encourage companies to consider the kind of functionality they would like to have going forward. In particular, we wanted them to consider the type of analytical capabilities they would like to see built into our next blockchain platform because the real value of blockchain for traceability is in the analytics.

I'll give some examples of what we learned during those pilots, beginning with trading partner analysis. This means knowing which trading partners you're using and the volumes that they're providing you as a company, the region where their materials come from, and whether their trading partners are connected to those that have been 100% verified.

This type of information can tell a company a lot. For example: I know about my trading partner and what they're claiming, and if they're verified with me as a company. But I could potentially look far beyond that, to be able to understand that everything has been verified for those materials I am currently handling. A company can get a good compliance report out of that: I know that the materials I'm handling have been accounted for and verified, not just with my direct trading partner, but also with all of those connected to my trading partner all the way back to the source.

This type of provenance analytics can support a focus on source countries and regions. We also have a product-classification system that can include detailed species information of materials. All this information is captured, which is another important feature of blockchain, and this is valuable when it comes to know-your-trading-partner compliance. You usually trust your trading partner, but, that said, you don't know who your trading partner is connected to and who they are connected to, and so on. Understanding whether or not your trading partner is 100% verified like your own company is fundamental now.

This holds great potential for documenting compliance. Also, during our pilots, companies asked this question: if we have all of our trade transactions in an immutable and verified ledger, can we not just share that with our auditor every year, so they have a clear registry of our inputs and outputs? The FSC chain of custody certification requires companies to maintain up-to-date records of their inputs and outputs of FSC materials. So this is the basis by which that becomes an immutable record of verified transactions.

CH: Those are great examples. In 2017, I conducted a large Cutter survey on blockchain that asked companies how they were using/planning to use the technology. We saw a lot of initial excitement around blockchain. Then it sort of plateaued. But I was always curious about what emerged during the pilots and what the end users found useful. You mentioned that you want your next blockchain to support more real-time or even forward-looking capabilities. Analytics, I assume, will play a big part in that vision?

MM: Our next-generation blockchain platform will cater to some of those very basic needs and will go quite deep. Already by connecting with your suppliers in a blockchain, we are able to also present the certification aspects of your suppliers to the companies directly that help them determine, for example, where you are getting certain types of materials that you're transforming to become a final product. But I think the real promise is that our next blockchain will be built in such a way that we will be able to develop future analytics capabilities.

For example, I imagine that once we start getting supply chains on board, there will be even more requests to have analytics that support greater supply chain efficiency, like metrics, to help companies understand the efficiency or the carbon footprint or the sustainability impact based on the data from the supply chains they're connected to. These capabilities could be possible if we have a good flow of data in a connected supply chain. Consequently, we're thinking beyond our next-generation blockchain and continuing progress on the analytics front because that could prove very valuable to companies.

CH: I'm fascinated that your pilots focused on Ukraine and China. This raises another question pertaining to legality — for example, with respect to sourcing. I imagine that, with the sanctions against Russia due to the war in Ukraine, you want to make sure you don't get anything from Russian companies.

MM: It's just not possible to continue certification in Russia until there are conditions that will allow providing assurance and integrity under FSC's rules. Unfortunately, there is a large area of forest in Russia that cannot be certified because of the war.

CH: You mentioned some usability concerns with the blockchain pilots. Usability is key with any application, especially those involving implementation of a new technology like blockchain. Can you comment on the types of new features companies indicated they would like?

MM: Most of the feedback was positive. Some companies indicated places we could improve or make changes. There are a couple of areas where we got very targeted, key feedback. One was on the performance of the technology platform. The usability was the least satisfactory for users because it was very basic. Users could only see a few things when inputting data into the blockchain, and they couldn't get a lot out of it.

For me, the way to make the platform more useful for participating companies involves applying more analytics. Companies want to know something more than what they can already see on paper. As far as accessing the platform or the responsiveness of the platform, users were satisfied. They could use a Web interface or even a mobile device, it worked really well, and it was responsive.

Another area of feedback pertained to data. As mentioned, companies already are required to maintain up-to-date accounting records of all of their inputs and outputs. You're essentially asking them to make that information compatible to put it into our blockchain, and that means having consistent formats, units of measure, and notation for volumes of materials. However, feedback on the data format was generally satisfactory.

One other area of feedback was on the time it took to verify a transaction. Companies saw they could enter thousands of transactions in bulk very easily, but seeing the transactions as verified depended on their trading partner entering the matching information, which could take days or weeks. Consequently, there was clear feedback on the importance of providing some kind of connectivity or feature so companies could understand whether their trading partner had been alerted that there were missing transactions — basically, to notify and instruct them to take action.

The last part of feedback involved the types of features and information companies would want to share with their auditors — that is, how can I share this information as I see fit? These kinds of sharing mechanisms will become part of our next platform.

The most important feedback was that companies must be able to output compliance-related information. Companies need to be able to capture this information, and the blockchain must "package" it so that when it comes to a table that could have come from five sources, the information can be aggregated and documented to support demonstrating compliance to, for instance, border control.

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BLOCKCHAIN FOR SUSTAINABLE AGRI-FOOD ECOSYSTEMS

Authors

Malni Kumarathunga and Athula Ginige

Food systems play a significant role in global greenhouse gas (GHG) emissions, with agricultural activities accounting for more than 80% of these emissions. Approximately 30%-40% of all food produced globally is wasted at various supply chain stages from production to consumption.[1] This squanders valuable resources (including water, land, energy, and labor) and is a lost opportunity to alleviate food insecurity. Addressing these challenges is critical for environmental sustainability and keeping pace with a projected global population of 9.7 billion by 2050.[2]

Traditional supply chains, characterized by rigid structures and slow response times, are ill-equipped to meet the evolving demands of consumers and the challenges posed by climate change. Inefficiencies in these supply chains contribute to significant food waste and unnecessary GHG emissions.

Food waste has severe economic, social, and environmental consequences. Economically, it represents a loss of investment and resources for producers, retailers, and consumers. Socially, it exacerbates food insecurity and hunger, particularly in regions with limited access to food. Environmentally, decomposing food generates methane, a potent GHG.

> **FOOD WASTE HAS SEVERE ECONOMIC, SOCIAL & ENVIRONMENTAL CONSEQUENCES**

SMALLHOLDER FARMERS: KEY ACTORS IN SUSTAINABLE AGRICULTURE

Smallholder farmers constitute about 70% of the global farming population and play a crucial role in global food production and security.[3] Despite their significant contributions, smallholder farmers face numerous challenges in traditional agri-food supply chains, including limited market access, financial constraints, and lack of resources and technology. Limited market access, combined with information asymmetry and lack of trust, leads to farmers selling their products to a few trusted buyers at lower prices. This hinders their ability to maximize profits, expand their businesses, and access fair pricing mechanisms.[4]

Smallholder farmers often lack market intelligence, such as real-time information on demand, pricing, and consumer preferences. This leads to oversupply as farmers struggle to align their production with market needs.[5] Consequently, a significant portion of the food produced by smallholders goes to waste, reducing environmental sustainability.

THE NEED FOR DYNAMIC & EFFICIENT SUPPLY CHAINS

We need dynamic, responsive systems to address waste-reduction challenges and increase efficiency in agri-food supply chains.[6] Dynamic supply chains embrace flexibility, agility, and responsiveness. They can sense, respond, and adapt to changes in demand, enabling more efficient resource allocation, reducing waste, and optimizing overall supply chain performance.[7]

A key aspect of dynamic supply chains is the ability to leverage real-time data and market intelligence to make informed decisions. With access to timely and accurate information on consumer preferences, market trends, and supply chain dynamics, stakeholders can optimize their operations, reduce oversupply and waste, and align their production with market demand (see Figure 1).[8]

In the dynamic supply chain in Figure 1, there is a market between suppliers T2 and T1. Similarly, there is a market between suppliers T1 and manufacturers. This trend continues until the product is transferred to the customers.

In agri-food supply chains, there are many similar markets, such as:

- A market between agri-input providers and farmers
- A market between farmers and buyers
- A market between buyers and retailers
- A market between buyers and transport providers
- A market between buyers and consumers

Traditionally, instead of having open competitive markets between players in the agri-food supply chain based on preestablished trust, rigid supply chains get formed. These work well if the supply, demand, transport, and storage needs remain the same. But when those needs change, rigid supply chains find it hard to adjust, resulting in the waste mentioned earlier.

These markets should be dynamic, efficient, and responsive. Additionally, trust plays a crucial role in enabling dynamic markets, since the farmers and buyers who respond to certain market demands can be unknown to each other and have no preestablished trust between them.

THE ROLE OF TRUST & SOCIAL CAPITAL IN AGRICULTURAL MARKETS

Trust is a crucial aspect of human lives. It is defined as the "willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party."[9] The trustor is the person who places him or herself in a vulnerable position under insecurity. The trustee is the person on whom the trust is placed and has the advantage of the trustor's vulnerability.[10]

Trust enables transactions/exchanges between parties, and it functions as the bedrock for fair transactions in agricultural markets by mitigating risks and information asymmetry. A survey among smallholder farmers in the Nuwara Eliya district in

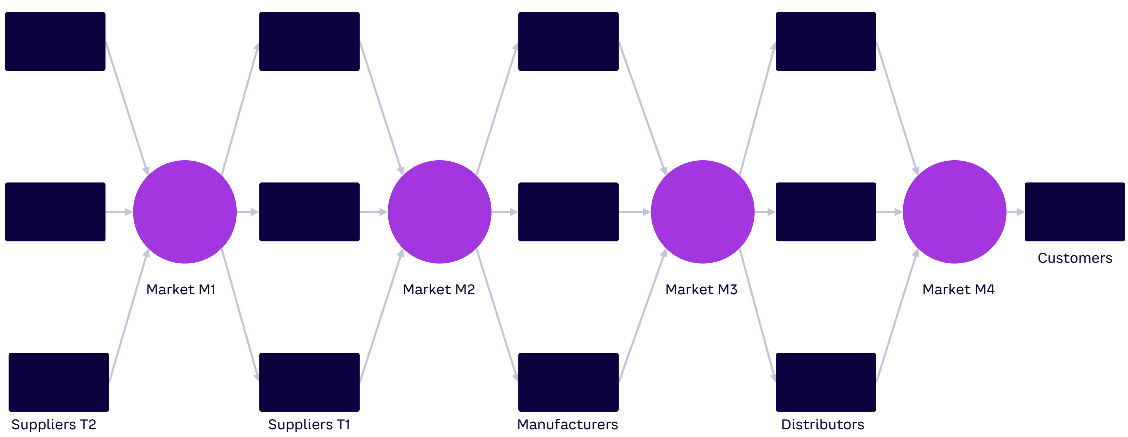

Figure 1. Structure of a dynamic supply chain

Sri Lanka revealed that farmers are in a small trust bubble with a small number of trusted buyers. These farmers often choose trusted buyers to sell their harvest, even if their rates are low. They sell their harvest to unknown buyers only if they receive payment on the spot, due to the risk of not getting paid. This situation limits their options to reach buyers who offer competitive prices.[11]

Digital markets have enabled farmers to reach many buyers by removing time and location constraints, but they have increased the need for trust. A smooth buyer-seller relationship depends on contractual trust and competence trust. Contractual trust implies that promises will be kept. Competence trust refers to self-confidence in the ability of the trading partner to complete the task.[12]

In today's digital world, most transactions happen in an e-commerce environment. Transaction trust in e-commerce depends on the trust placed in the counterparty (party trust) who engages in the transaction, trust in the control mechanism (control trust), potential gain, and the risks associated with the transaction.[13] The control mechanism defines the procedures and protocols that monitor and control the successful performance of a transaction.

Blockchain technology is an exemplary mechanism to implement contractual and competence trust, with smart contracts based on a tamper-proof history of transactions. A tamper-proof history can enable a network of community relationships that facilitates trust, motivating purposeful action, known as "social capital."[14]

HOW TRUST RELATIONSHIPS GENERATE SOCIAL CAPITAL

In the context of social relations, trust can be distinguished as particularized trust and generalized trust.[15] Particularized trust exists in a specific domain with a narrow circle of familiar individuals. A trustor relies on past and present interactions and broader networks to measure a trustee's motivations and trustworthiness. The broader network refers to the social environment in which both the trustor and trustee are embedded.[16]

Accumulated relationship experience can be used to find cues in the trustee's expected behavior.[17] Future interactions depend on how much the trustee values the relationship between the trustor and trustee and wants to maintain it.[18] If the trustee has a reputation for success in his or her field, he or she is more inclined to be trustworthy to maintain his reputation.[19] Note that using reputation systems for trust building has been shown to be a reasonable choice that can be justified.[20]

Generalized trust enables a wide array of activities at the societal level among a broader circle of unfamiliar individuals. As seen in Figure 2, a trustee's trust radius begins in a particular domain where the particularized trust exists and expands to highly generalized trust with intermediate steps.[21] However, the radius in each circle is indicative only, and there is no definite limit for each trust radius.

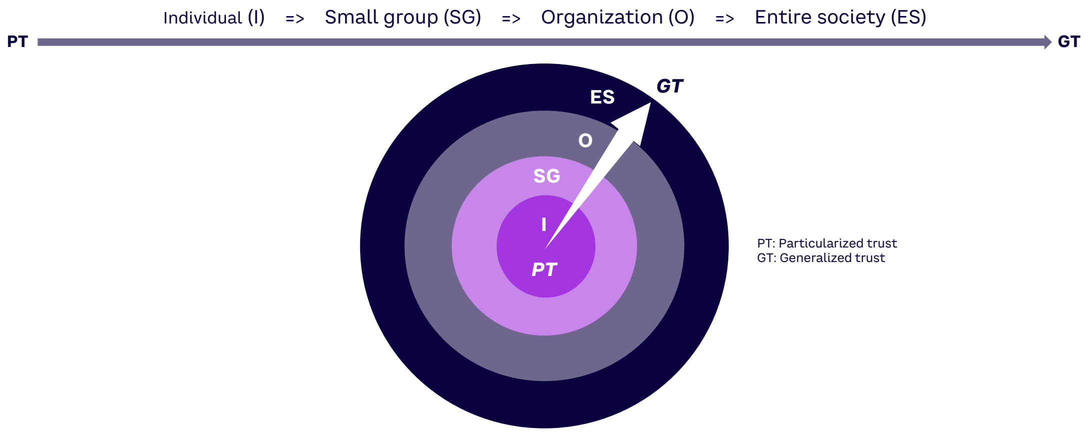

Figure 2. Trust radius from particularized trust to generalized trust

Although a smaller trust radius might indicate an individual success outcome, a larger radius might specify civic outcomes like community engagement. Communities are built on trust, most notably the generalized trust established on voluntary regulation of interpersonal relations between unknown individuals.[22] These individuals perform actions without knowing the reciprocal actions of others, believing that positive communal relationship development will reward their altruistic behavior.[23] The reward emerges as a specified social value to an individual, which is apparently the social capital.[24] The more that social capital is used, the more trust, association, and civic engagement are strengthened, engendering the collective well-being of the community.[25]

DIGITAL TRUST TRANSFORMATIVE MARKET MODEL

The Digital Trust Transformative Market (DTTM) model offers a robust solution to the challenges faced by traditional agri-food supply chains. By leveraging blockchain technology to foster trust among supply chain actors, DTTM enables the creation of dynamic, efficient, sustainable supply chains.

A supply chain in which various actors are connected through an efficient market mechanism can rapidly adjust to varying conditions. Among other factors, the ability to establish trust among previously unknown parties is a key requirement for an efficient market. DTTM consists of three market mechanisms with various levels of trust for its operation: spot markets, smart contracts markets, and smart futures contracts markets (see Figure 3).

Actors can start trading with a market mechanism that requires a low level of trust and, over time, transit into mechanisms that require a higher level of trust. The market models that require a higher level of trust provide higher economic benefits, such as support for automatic aggregation, enabling economies of scale.[26]

The spot market, which requires the least amount of trust, helps farmers trade their harvest after negotiating a price with buyers. Transactions are recorded in the blockchain, ensuring non-repudiation, reliability, and immutability, thus enabling trust in the market model. This tamper-proof data is used to generate ranks for the farmers, buyers, and farmers' communities, generating trust indicators for them.

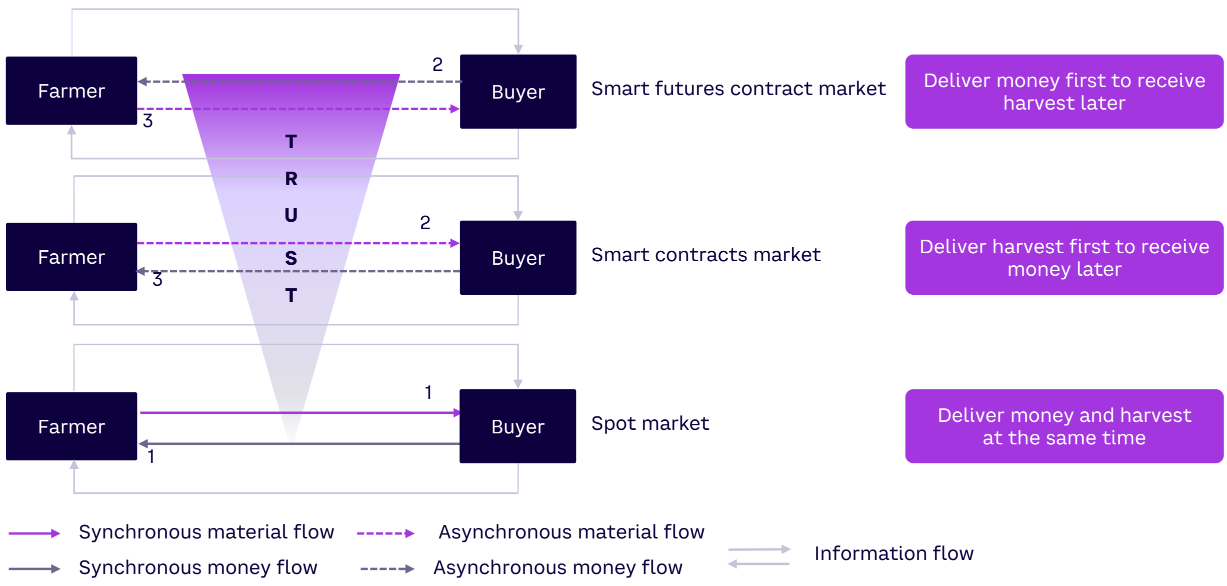

Figure 3. DTTM model

Over time, DDTM enables the smart contracts market, where farmers can sell their expected harvest in advance to buyers who offer competitive rates. These transactions are recorded in the blockchain to update the ranks, improving the trust relationships between them. The improved trust relationships enable engagement in the community, influencing stronger social networks, increased cooperation, and enhanced collective well-being, generating social capital.

This social capital enables the smart futures contract market, where the farmers can sell their expected harvest in advance and request an up-front payment using social capital as collateral. The farmers can use this payment to apply high-quality inputs and modern technology to produce high-quality harvests that attract higher prices. The process of trust and social capital development in the DTTM model is shown in Figure 4.

With enhanced trust levels, DTTM enables dynamic behavior in the market, since the buyers and sellers do not need preestablished trust to perform transactions. They can sense and respond according to the market requirements, since the risk of not getting paid or not receiving the products is minimized. This helps them allocate resources optimally, reducing waste and improving efficiency.

Additionally, DTTM optimizes transportation by enabling better coordination and planning. With real-time market intelligence and demand information, logistics can be optimized to minimize empty trips, reducing fuel consumption and lowering transportation-related GHG emissions.

DTTM IN ACTION: DIGITALIZING VILLAGE FRUIT & VEGETABLE MARKET

We have applied the DTTM model to create a digital version of village fruit and vegetable markets, creating significant benefits for market participants, establishing price stability, enabling better supply and demand balance, and reducing waste.

These markets are common in semi-urban areas and villages in most countries, and they played a crucial role in ensuring food security during the pandemic when long food supply chains got disrupted.

However, the limited number of buyers and sellers associated with physical markets leads to significant price fluctuations and over and undersupply situations, resulting in substantial waste and unsatisfactory outcomes for market participants.

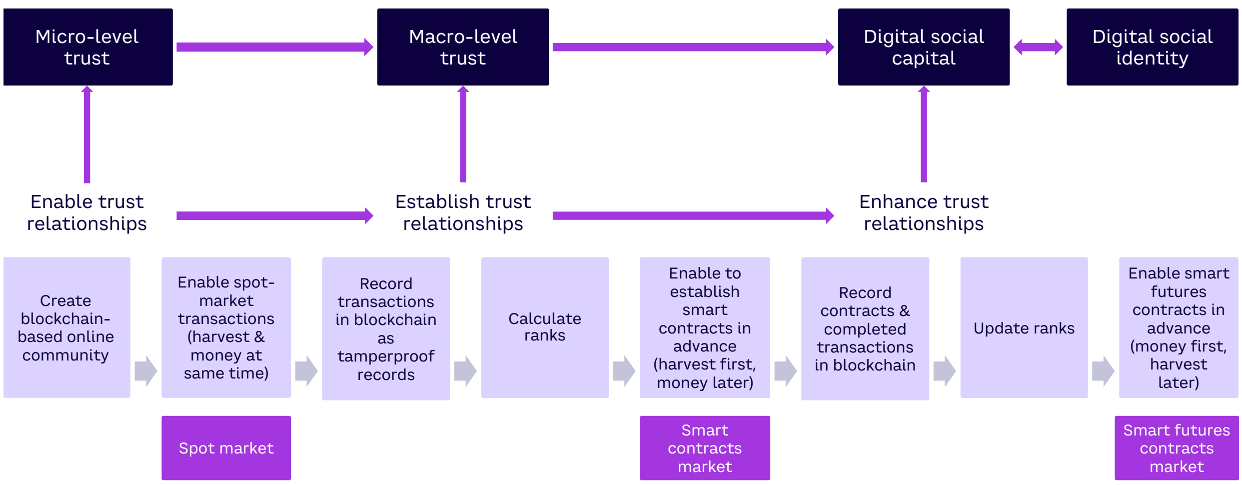

Figure 4. The process of trust and social capital development in DTTM

We studied the behavior of buyers and sellers in these markets, looking at price discovery, trust establishment and exchange mechanisms, and how these factors change over time. A new buyer who comes to the market will first walk around, checking prices (the price-discovery phase). Over time, the buyer will make connections with a few sellers and mostly buy from them, significantly reducing the time spent on buying items during subsequent visits. To establish these connections, the sellers have provided quality items at competitive prices (spot market and initial trust establishment phase in DTTM).

In time, the buyer can ask trusted sellers to provide a fixed quantity of items at regular intervals. If the buyer is purchasing in bulk, for example, for a restaurant or for resale in a shop elsewhere, he or she can establish contracts with many vendors. This reduces the buyer's transaction and transport costs and ensures timely supplies. If sellers know about future orders, they can better plan, reducing potential waste. The buyer and the sellers can use the contract market model now in DTTM to support these exchanges.

LOGISTICS WAS A CHALLENGE WE HAD TO SOLVE WHEN CREATING THE DIGITAL VERSION OF THE VILLAGE MARKET

If transacted quantities are high, many farmers can aggregate their produce to meet buyers' requirements. This community selling requires trust among the farmers, in addition to trust between buyers and sellers. Trust among farmers is very important; they collectively need to take responsibility for the quality to maintain a healthy trust relationship between the community of farmers and the buyers. When high trust levels are achieved, farmers can ask for advance payments, transforming the market mechanism to a futures market. We have observed that at this level of trust and income stability, farmers can get loans to buy items like tractors, harvesters, and solar-powered water pumps at competitive interest rates from banks focusing on agriculture and rural development.

Logistics was a challenge we had to solve when creating the digital version of the village market. With buyers and sellers at two locations, we had to replace the simple face-to-face exchanges of a physical market with a more complex exchange mechanism that includes logistics. By aggregating order details, we were able to create a very efficient way to transport purchases from supplier to buyer by using trucks that come empty after taking various goods from cities to villages (in logistics, this is known as "backhauling").

We partnered with a farmer-focused development finance bank in Sri Lanka to establish collection centers in villages and managed the finances necessary for the DTTM model using their banking network and ATMs. We used WIDYA (an agri-tech start-up in Australia) to implement the technology and a major logistics provider in Sri Lanka to provide backhauling and last-mile delivery to consumers.

Consumers can search for a product and see farmers that are offering that product as well as the various prices (see Figures 5 and 6). Based on the information provided about the product and the farmer, the consumer can decide which farmer's product to buy and place an order (see Figure 7). The farmer can decide the selling price and the price set by other farmers for the same product. A farmer being able to set the price and sell directly to the consumer without an intermediary is a key feature that mimics physical village markets. This approach puts the responsibility of maintaining the quality on farmers if they want high rankings and repeated sales.

Once the order is placed, the system holds the payment and asks the farmers to deliver the product to the village collection center. During this process, the farmers receive 50% of the agreed-upon price. The aggregated orders are sent to the distribution centers in the cities. At the distribution centers, the items going to the same locations are grouped and handed over to a last-mile delivery service.

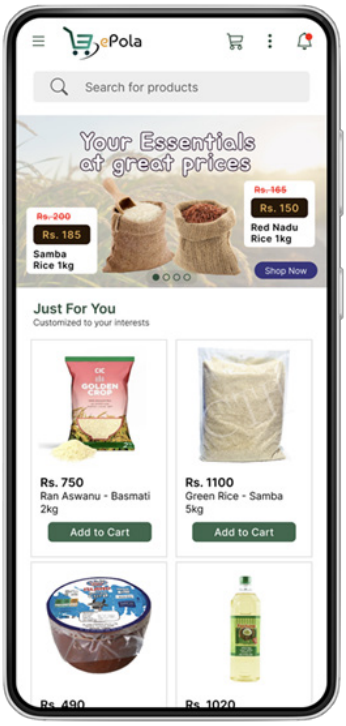

Figure 5. Mobile user interface for consumers to select products

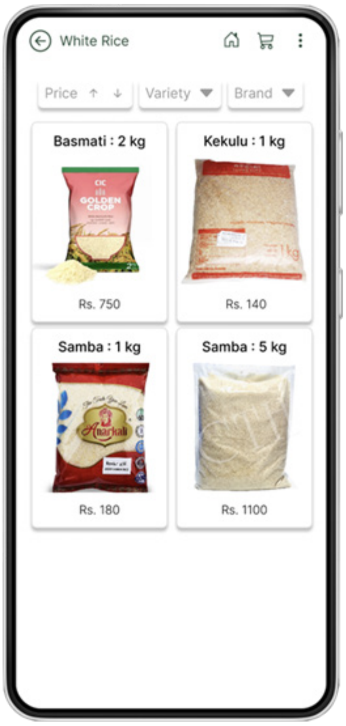

Figure 6. Mobile user interface for consumers to select products

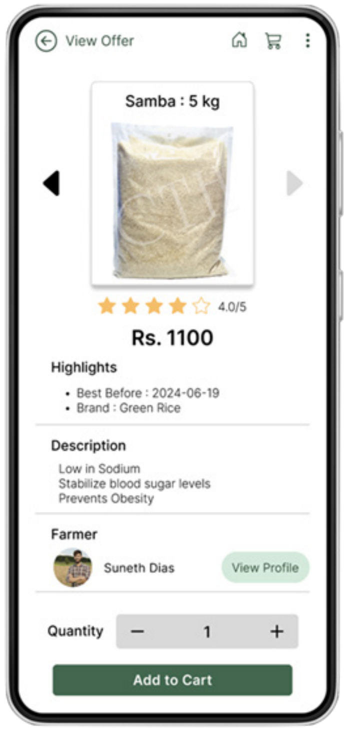

Figure 7. Mobile user interface when a consumer selects a product

Once the item is delivered to the customer, the farmer receives the balance of the price, less service fees and delivery costs. Due to the economies of scale achieved through efficient aggregation and coordination, the service and delivery costs are very low compared to traditional supply chains that have intermediaries.

Successful completion of orders, ratings, and reviews helps farmers establish trust among themselves as well as with consumers.

CONCLUSION

The DTTM model offers a transformative solution to the challenges faced by traditional agri-food supply chains. By leveraging blockchain technology and fostering trust among supply chain actors, the model has the potential to enable dynamic, efficient, sustainable supply chains.

Through spot markets, smart contracts markets, and smart futures contracts markets, DTTM facilitates transactions, enhances market intelligence, and enables better matching of supply and demand. By addressing the lack of trust among farmers and buyers, DTTM expands the market activities of smallholder farmers, reduces waste, and promotes socioeconomic sustainability.

The successful implementation of the DTTM model in our example demonstrated its ability to reduce waste, optimize logistics, and achieve sustainable outcomes. By embracing this model, the agri-food industry can create a more sustainable future, ensuring efficient resource use, reduced GHG emissions, and improved livelihoods for smallholder farmers.

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FROM HYPE TO REALITY

A CRITICAL ANALYSIS OF BLOCKCHAIN-BASED REGENERATIVE FINANCE

Authors

Simon J.D. Schillebeeckx and Marco Schletz

In an era marked by unprecedented global environmental challenges, our common resources (including the atmosphere, the oceans, soils, and the rainforest) are in peril. Despite concerted international efforts and agreements around climate (*COP27*) and biodiversity (*COP15*), the Intergovernmental Panel on Climate Change's latest assessment confirms global temperatures are on track to rise well above the 1.5°C target set in the Paris Agreement, with catastrophic implications for ecosystems and human communities.[1]

COP15 highlighted the loss of biodiversity at an unprecedented rate, making it clear we are in the throes of a sixth mass extinction event, with more than 1 million plant and animal species threatened with irrevocable extinction.[2] These converging crises call for urgent, innovative solutions and the need to adopt novel approaches to stave off further degradation and restore our ecosystems.

Two types of actions should be taken in parallel and at an unprecedented scale to achieve sustainability. First, we need to reduce the adverse environmental effects of industrial activity by accelerating the green transition and adopting reduce/reuse/recycle waste management for industries responsible for the making, moving, and mining of physical products (e.g., manufacturing, mining, cement and steel production, transportation, apparel, and energy).[3,4] Second, we need to increase our investment in nature to strengthen the earth's carrying capacity and restore damaged ecosystems.

The former objective has long been part of political and business debates and is anchored in the narrative of carbon-footprint measurement and reduction. The latter is rapidly rising to the top of corporate and governmental agendas under impetus from the 30x30 Initiative and is rooted in the more recent "handprint" approach.[5]

This article focuses on the handprint approach (i.e., regenerative sustainability), juxtaposing it with the more familiar footprint approach reminiscent of legacy sustainability. Our goal is to provide insight into how Web3 technologies can help address the tragedy of the commons.[6] Elinor Ostrom's seminal research found that non-excludable, open access, and unregulated common-pool resources do not invariably suffer exploitation in localized settings, yet solutions for averting the degradation of such resources on a global scale remain conspicuously absent.[7]

> **THESE CONVERGING CRISES CALL FOR URGENT, INNOVATIVE SOLUTIONS & THE NEED TO ADOPT NOVEL APPROACHES**

The governance systems we have employed over the last decades to stave off environmental collapse have not succeeded, to put it mildly. Legacy sustainability approaches, for all their complexity, data collection, and reporting requirements, and increased governmental regulation pertaining to environmental, social, and governance (ESG) have so far failed to incent sufficient environmental actions.

Government systems have not stimulated the collective action needed to achieve the goals of the various transnational nature-protection agreements and have failed to enforce regulations. A lack of strong incentives to tackle these problems head-on has led to businesses failing to collect needed data and develop innovative business models for shared value creation.[8]

CORE COMPONENTS OF REGENERATIVE FINANCE

Regenerative finance (ReFi) has the potential to address governance failures and underpin new sources of business value creation and capture. ReFi is an alternative to traditional financial systems for sustainability that can be defined as a "decentralized movement leveraging blockchain technology and Web3 applications for the coordinated financing, governance, and regeneration of common pool resources."[9]

ReFi uses the principles of circularity, decentralization, and transparency to incent sustainable practices for rejuvenating natural resources. These three principles underpin both the ReFi movement and the more generic regenerative sustainability paradigm:

1. **The principle of circularity replaces the traditional linear economic model of take/make/dispose with a cyclical framework focused on regeneration and restoration.** In this paradigm, resources are not mere consumables but assets to be reused, refurbished, or recycled, thereby extending their lifecycle and reducing environmental impact. This goes beyond simple recycling to include considerations in product design, manufacturing, and business models, aiming to decouple economic growth from environmental degradation. Circularity offers a sustainable, restorative approach that embeds ecological resilience into economic transactions, reshaping how we view production and consumption.
2. **The principle of decentralization counters the notion of centralized authority by advocating for a more democratic and distributed approach to governance, in which power is more equitably dispersed among stakeholders.** For environmental and social impact, credibility often hinges on either reputation (as evidenced by trust in established nongovernmental organizations [NGOs]) or authority (as in the case of third-party-verified carbon credits). However, these traditional credibility markers face scaling limitations across diverse impact types, since each impact type may necessitate unique verification processes, standards, or domain-specific expertise that cannot be universally applied. As a result, reputation and authority become bottlenecks, an inefficiency we cannot afford given the immediacy and magnitude of our global challenges. In contrast, a decentralized governance model that harnesses the wisdom of crowds, fosters competitive innovation, and ensures visibility presents a more versatile and scalable solution.

3. **The principle of transparency is central to decentralized governance, providing clear insight into system processes, decisions, and outcomes.** Transparency is not a theoretical construct; it is instrumental in actualizing equitable power dynamics and facilitating informed participation among stakeholders. By ensuring that information is accessible to all participants, regardless of their position within the system's hierarchy, transparency diminishes the information asymmetry that often accrues to the advantage of centralized authorities. Transparency fosters accountability through more effective audits and evaluations while engendering a culture of trust essential for collaborative decision-making. As such, it acts both as a safeguard against power abuses and an enabler of informed, democratic governance.

These three principles are supported by digital measurement, reporting, and verification (D-MRV) and blockchain applications. D-MRV approaches range from space-based intelligence to the use of local, sensor-derived source data and expansive big data techniques.[10,11] Space-based approaches can help us understand the current state of the earth by using remote sensing technologies and various earth-surveying techniques to collect data on biological, physical, and chemical processes.

Since conventional approaches entail meticulous manual expert review, there's a growing trend toward using machine learning (ML) to elevate this process. Through ML, data from diverse sources can be triangulated, ensuring data consistency and revealing any tampering.[12]

BLOCKCHAIN'S ROLE

Blockchain technology has the potential to substantially elevate the credibility, exchangeability, and transparency of environmental data and action. Its architecture includes an immutable ledger, facilitating an auditable trail of data points and lending an additional layer of credibility. Blockchain supersedes traditional centralized data repositories by offering a decentralized approach to data governance, thereby democratizing data access, portability, and exchangeability.

Such democratization has the potential to shift transparency into tangible accountability for environmental outcomes.[13] The principle of accountability is intrinsically bound to data transparency, availability, accuracy, and reliability, as it empowers stakeholders to independently access and scrutinize reported information. This fosters a climate conducive to peer review and public oversight, ensuring the fidelity of a party's declared actions and progress.

By enhancing information sharing and implementing a comprehensive, transparently codified system of rules, ReFi enables the tokenization of nature as digital assets. This means translating the inherent value of resources into digital representations, like community currencies, regenerative non-fungible token collections, and social tokens.

> **BLOCKCHAIN HAS THE POTENTIAL TO SUBSTANTIALLY ELEVATE THE CREDIBILITY, EXCHANGEABILITY & TRANSPARENCY OF ENVIRONMENTAL DATA & ACTION**

Tokenization is a mechanism to associate a quantifiable value and transferable ownership to positive impact claims. This paves the way for businesses to capture and represent value derived from the generation of public goods, offering the potential to "solve" the tragedy of the commons.[14]

For example, ReFi components could enable systems in which governance is not monopolized but inclusive. ReFi could also facilitate integration between environmental and social impact metrics and financial models, bridging the gap between economic outcomes and tangible sustainable efforts.

Incorporation of smart contracts in blockchain platforms ensures that transactions are not only automated (enhancing efficiency) but characterized by an unprecedented level of reliability and reduced counterparty risk.

INVESTMENT PRIORITIES IN DIGITALIZING SUSTAINABILITY

ReFi and the application of digital technologies to achieve sustainability are globally increasing trends.[15] Figure 1 provides an anecdotal (and somewhat subjective) distribution of attention and investment of businesses to the quadrants of sustainability and digitalization. The percentages are only indicative; they are estimates based on our extensive expertise in the digital sustainability space, the reading of many sustainability reports of publicly listed companies, and more than 70 conversations with venture capitalists interested in areas such as climate tech, fintech, nature tech, and sustainability as a field of investment.

To distinguish the four quadrants, we use a simple rule to identify a company's dominant sustainability design.[16] When the majority of a company's sustainability activities or interests can be interpreted as reducing negative impact, we categorize it as "legacy & TradFi." When the business has a clear set of activities that focuses on the creation of positive impact, it is classified as "regenerative & ReFi." To make our digital classification, we focus on the types of digital tools used by the company. Companies that explicitly mentioned activities or experimentation with novel digital technologies were categorized as "novel," and the rest were categorized as "legacy."

The top-left quadrant is the domain where most legacy sustainability investment and attention is situated, representing the established incumbents in the voluntary carbon market and ESG space, as well as the companies servicing them using legacy digital technology.

The dominant investment focus is on reducing or avoiding negative environmental externalities, improving data tracking using Web2 approaches, and collecting data for sustainability reporting. Data collection often takes place in a manual and self-reporting way, as with the Carbon Disclosure Project. Similarly, most carbon-offset projects are verified through manual expert sampling following bureaucratic methodologies and registered on a centralized registry (e.g., Verra or Gold Standard).

Energy-efficiency and energy management systems are used by thousands of companies to better track energy consumption (and thus carbon emissions). ESG reporting tools like brightest.io are using Web2 tools to digitalize existing sustainability standards and facilitate data collection and decision-making. ESG ratings like MSCI, Sustainalytics, EcoVadis, and B Corp rely extensive self-reporting and human sense-making to evaluate the ESG credentials of companies and award them some form of recognition.

Traditional green bonds are issued by companies with a commitment to achieving specific environmental objectives, often related to carbon reduction. These bonds may come with built-in enforcement mechanisms, such as the obligatory purchase of carbon credits if targets are not met, or they may simply offer a more cost-effective way to finance sustainability investments.

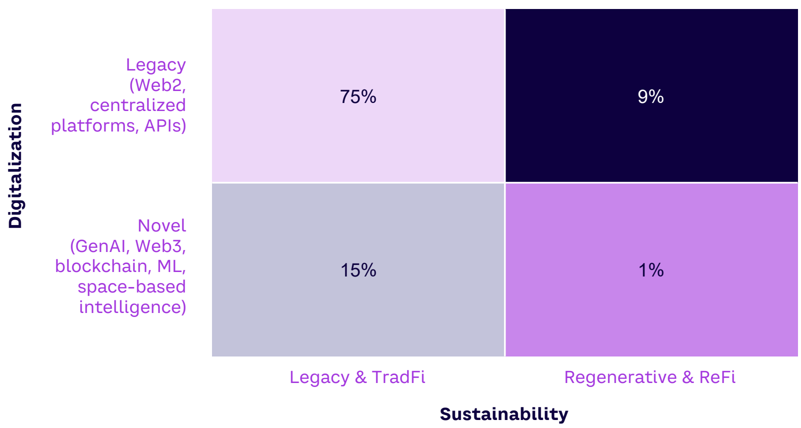

Figure 1. Distribution of companies according to sustainability and digitalization

The second most common quadrant is the bottom-left, where legacy sustainability approaches are combined with disruptive technologies from the Web3 space to improve data credibility, exchangeability, and transparency. Companies in this space tend to deploy blockchain and other Web3 technologies to make an existing practice more efficient, credible, or transparent.

In a simple form, this could be the tokenization of data or assets from a centralized registry (e.g., Verra) that are converted into blockchain-based tokens (e.g., through Toucan Protocol, Hedera Hashgraph, or TYMLEZ) for tracking and trading.

Singapore's SP Group is one of the first mainstream energy companies to combine blockchain and Internet of Things (IoT) sensors to track energy consumption in real time to add credibility to the market for renewable energy certificates. Orobo seeks to innovate ESG reporting by focusing on the complexities of data collection in manufacturing supply chains, adding intelligence to regulatory frameworks from the EU using blockchain and artificial intelligence (AI). OpenESG aims to advance ESG ratings by creating an open, AI-powered rating system to provide more independent assessments of companies' ESG performance. New standards like OxCarbon, and companies like Pachama and Kumi Analytics, are leading the way to make D-MRV essential to credible carbon offsets. Finally, various companies have used blockchain platforms like so|bond and GFT to issue tokenized green bonds with performance tracking happening on-chain. These approaches all seek to provide better-quality, more accessible, more transparent data to inform financial decisions within a TradFi approach.

The third most popular quadrant, top-right, contains approaches where regenerative sustainability and ReFi are reliant on Web2 technologies but are geared toward developing new business models in which new sources of value capture are tied to achieving regenerative sustainability.

Donation platforms like B1G1 help companies donate to trusted NGOs and benefit from tax deductions. Voluntary regeneration standards like 1% for the Planet, launched by regenerative pioneer Patagonia, help companies spend 1% of revenue on nature positive contributions. Beyond fostering a sense of moral responsibility, companies with the 1% for the Planet logo may benefit from more loyal employees and customers.

Rather than buying carbon offsets, AstraZeneca has embraced carbon onsetting by committing to planting 200 million trees across six continents by 2030 to support the World Economic Forum's Trillion Tree Campaign.

Alipay's Ant Forest is a gamified loyalty program that rewards users with energy points that can be converted to digital (and then real) trees. It is by far the most impactful corporate reforestation program in the world.

These centralized ReFi approaches pave the way for companies to capture value from restoring earth's natural resources. Ant Forest has proven to be the most impactful loyalty program imaginable, ensuring that users use the app daily, often as one of the first things they do after waking up, to avoid friends stealing their energy points.

The fourth quadrant is the least populous but arguably the most ambitious and most aligned with the ReFi principles highlighted above. Within this quadrant, digital enterprises harness disruptive technologies to facilitate a more nuanced understanding and valuation of natural ecosystems. This enhanced comprehension is not an end in itself but serves as a cornerstone for value creation through the generation of positive-impact assets.

For example, Upright Platform, a German start-up, uses AI to analyze thousands of sustainability reports from the world's largest companies to evaluate their global impacts using 19 different metrics (by giving a dollar value). Its metrics and assessments are publicly accessible.

EcoMatcher has evolved from a pure tree-planting organization into a disruptive digital company that uses AI-powered chatbots to let customers chat with trees and blockchain to track and tokenize each tree planted. Similarly, Plastic Bank has developed a blockchain platform to better track all the plastic its communities remove from the ocean and what happens with the plastic afterward, providing ocean-to-product traceability.

Finally, Handprint is a digital infrastructure that merges Web2 and Web3 to help companies capture value by creating a global positive impact across all 17 of the United Nations Sustainable Development Goals (UN SDGs). Handprint orchestrates space-based intelligence for impact visualization (with OpenForests), carbon estimation (with Kumi Analytics), biodiversity estimation (with Gentian), blockchain-based transparency (with multiple partners), and Web3-based funding for ecosystem restoration, all the while transferring impact ownership to its clients and allowing portability in the spirit of openness.

CONCLUSION

ReFi posits a revolutionary framework for the governance of global common-pool resources. However, this assertion is mitigated by myriad challenges, both technological and conceptual, particularly the feasibility of decentralized governance structures. These impediments persistently act as barriers to widespread adoption, inhibiting progress toward planetary health.

For instance, can decentralized governance structures be implemented in a way that meets both the efficacy and legitimacy criteria? Is improving the credibility, exchangeability, and transparency of nature and climate data and information sufficient to herald a change in deeply entrenched business models in which environmental externalities remain unpriced?

Advocates praise the transformative potential of emerging digital technologies with respect to decentralization, data credibility, and transparency, but it is prudent to question whether such innovations can truly disrupt existing paradigms absent a more comprehensive reconceptualization of corporate value creation and capture. The problems plaguing our current transactional systems (e.g., bureaucratic lags, opacity, and inefficiencies) are unlikely to magically dissipate with the adoption of novel digital technologies.

These problems could metamorphose into new forms of challenges, obscured beneath intricate layers of cryptographic algorithms, ML complexities, and the cybersecurity vulnerabilities inherent in IoT sensors and decentralized ledgers. This is often evident when disruptive ReFi organizations try to collaborate with financial incumbents — they face conflicts in underlying business principles that make collaboration almost impossible.[17]

Moreover, blockchain technology's purported ability to catalyze innovative, participatory forms of governance embodies a paradox. The principle of decentralized, collaborative decision-making holds democratic appeal, but it simultaneously exposes the system to risks, such as fragmentation, diminished accountability, and potential subversion by technologically sophisticated actors.

Nevertheless, the exigencies of our planetary condition demand that both corporate and governmental entities radically reimagine their operational paradigms to reverse the trajectory of environmentally extractive practices. The conventional approach to sustainability, preoccupied as it is with minimizing detrimental impacts (footprints), is manifestly inadequate.

A more urgent, forward-looking paradigm is called for — one that shifts the discourse from culpability and remediation to opportunity and value creation (handprints). Imperfect as it may be, ReFi is perhaps the most viable conceptual innovation at our disposal for mitigating ongoing environmental degradation.

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