Moving from Shareholder to Stakeholder Value

An Investigation into Blockchain and its Ability to Govern Common Pool Resources and Incentivize Collaborative Behavior

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Abstract:

The transgression of Earth's nine planetary boundaries is a phenomena that will have consequences shared by us all. Contemporary political and economic paradigms vow for the substitution of Earth's limited natural capital with growing human capital for our self-aggrandizing interests. Based on the lack of collective action towards sustainability, international bodies such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations (UN) are urging countries to act. Just recently, the UN released the Sustainable Development Goals (SDGs), 17 cross-sectoral goals to aid countries in the process of achieving a sustainable state, to serve as a blueprint for future progress. Achieving these goals will require the commitment and collaboration of stakeholders from across a wide range of disciplines. Indeed, while being a first mover has traditionally burdened a stakeholder with more risk, a core tenet of the SDGs is to induce more countries to weigh this individualized risk against the risk we all face with collective inaction.

As our natural commons come under peril from various entities alike, there is a need for a global hegemonic institution to incentivize selfless action for the preservation of limited resources. The Ethereum blockchain, which is innately selfless, is a general purpose technology which could provide the necessary framework needed to collaboratively govern a common resource. The Ethereum Virtual Machine in particular is an operating system built on this technology for executing software in a distributed fashion. Smart contracts within the Ethereum ecosystem can facilitate a trust of outcomes between parties that before was only admissible by partisan handshake agreements. Stimulating collective action for the SDGs is paramount, and smart contracts, using globally distributed architecture, game theory, cryptographic security, and software determinism have the ability to not only automate agreements that developers may come to, but also guarantee trust that these agreements follow through as promised by using tokenized incentives. As a result, this enables a new paradigm for the scaling of collaborative governance and economics. The Ethereum platform is a nonpartisan institution, where developers are incentivized to design software collaboratively, and in turn, are able to program trust as a fundamental unit in all applications, effectively paving the road to cooperative stakeholder business models. Based on limitations within blockchains, oracles are identified as a key layer which can record externalities and allow for development of many independently governed common resource applications. To exemplify a unique application of a collaborative business model, LO3 Energy is analyzed as a decentralized application case study to show how individuals can collaborate using incentivized token mechanics in order to realize a shared goal, clean and efficient energy use. As we look toward the future of sustainability, public blockchain infrastructures such as Ethereum, along with oracles, can facilitate collaborative economies of scale, where all network participants share in the creation of value.

Keywords: Ethereum, blockchain, stakeholder, governance, Sustainable Development Goal, oracle

Word count: 11,888

"We can't solve problems by using the same kind of thinking we used when we created them."

- Albert Einstein

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1 Introduction

1.1 Thermodynamics and the Economy

The first law of thermodynamics tells us that energy can neither be created nor destroyed, meaning our stock of materials on our planet is finite. These materials can be used repeatedly, however, and the rate at which we cycle through them, known as material flow, is limited by available energy. The second law of thermodynamics postulates that entropy, the measure of disorder in a system via the unavailability of thermal energy to be converted into mechanical work, is always increasing. The fact that our economies deal with limited resources and follow laws of physics, rather than states of economic equilibrium, was laid out decades ago by the work of Georgescu-Roegen (1971,1975). This has failed, however, to transcend into a new logic of reasoning for our modern-day economic practices (Cojanu, 2009). The global commons - the ecosystems, biomes, and natural processes that keep our Earth system resilient - are being tested by endless growth economies. Scientists warn that the stable environmental conditions on Earth that have enabled human civilizations to prosper over the last 11,000 years (The Holocene) are being strained (Global Environment Facility (GEF), 2018). As Johan Rockström, the director of the Potsdam Institute for Climate Impact Research, said:

> “It is time to re-evaluate our economic and political models for the Anthropocene. The starting point must be our very notion of the global commons… Industrial societies now wield astonishing power. Earth’s future is in the balance and we must handle it with care and respect.” (GEF 2018)

1.2 Birth of Blockchain

In 2009, Satoshi Nakamoto released the Bitcoin software. In addition to being the first instance of a blockchain in practice, Bitcoin represented a new paradigm in foreign exchange markets, as it was not controlled by any central bank and inherently maintained a fixed supply. While Bitcoin began as a direct response to the financial crisis, the underlying technology that supports its functioning, known as blockchain, represented a whole new way to facilitate trust by distributing the governance of a system equally to each of its users. Governance refers to the mechanisms which balance the powers of stakeholders and provide checks and balances to preserve the integrity of a system (Bovaird, 2005). These mechanisms may include rules, norms, incentives, or actions which can be formal, like written laws or code, or informal, like a threat of violence. Traditional forms of governance have come in the form of organizational centralization and hierarchy, which use top-down authority to preserve system integrity. The assumption that organizations provide a centralized source of legitimacy has led to our establishment of "trusted" entities of governance, including multinational corporations, such as Amazon or Facebook, government bodies, such as the United States government or the United Nations, or even financial institutions, such as central and commercial banks (Seidel, 2018). These institutions have made governance a polarizing topic regarding who should retain authority over certain decisions. This begs a couple questions: should a select few individuals be trusted to ensure integrity? Or should individuals be able to collectively make decisions on a platform where trust is inherent? This idea parallels the ethos of blockchain: a technology used to automate trust and agreements to enable us to exceed the limits imposed by systems of delegating such tasks to centralized entities.

1.3 Blockchain and SDG 17

The path towards solving our encroachment of the Earth's planetary boundaries starts by addressing the United Nations (UN) Sustainable Development Goals (SDGs), a blueprint for achieving prosperity for all people and the planet. Defined by the UN World Commission on Environment and Development report in 1987, sustainability means "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Downes and Reed, 2018)." Governance of this sustainable transition will have to be transdisciplinary and multi-national, as posited by Abbott and Marchant, a "notable aspect of sustainability is its holistic and cross-cutting nature – it cannot be achieved by any single rule, statute, or agency (Downes and Reed, 2018)." It requires the participation of all stakeholders within the system to achieve not just environmental sustainability, but economic and social sustainability as well. Thus in order to achieve sustainability, we must establish trust practices among individuals who may be unknown to each other. It therefore follows that SDG 17 in particular is of the utmost importance: creating partnerships for addressing the goals. Although it was the last goal proffered by the UN, SDG 17 is indeed the linchpin of the entire set of goals, as our ability to achieve the other 16 goals is greatly influenced by our ability to cooperate across borders, institutions, and individual personnel.

In light of this, my research will look into the Ethereum blockchain, a distributed platform that will "reshape the global economy and reset the global competitive landscape" (Brody, 2020). Just as the World Wide Web was a platform used to facilitate global information access, blockchains are an alternative layer on the internet that will facilitate cooperation and agreements using that information, all in a manner that doesn't require trust in a centralized entity. Before starting, it is important to understand that blockchain is more than just a currency like Bitcoin, or a technology for automating industry practices. Rather, it has the potential to be a **general purpose technology** which could fundamentally change the way we structure societies, economies, and culture, just as the internet, the steam engine, or the printing press have previously done (Flament, 2017).

1.4 Aim and Research Question

Considering the overarching quality of SDG 17, it will be the aim of my research into how blockchain can facilitate a more cooperative future for human and planetary prosperity. Currently, countries, corporations, and individuals alike are lacking an eagerness to address the SDG's, as contemporary institutions foster competition and adversarial relationships. Without an ability to collectively prioritize purposes that may not be the most profitable, actors will be reluctant to act individually in ways that would benefit the whole. Therefore, finding a way to <u>incentivize collaboration</u> towards a common purpose is paramount in creating action for the SDGs. Based on this idea, I ask:

How do blockchains provide a better "modus operandi" for achieving SDG 17: strengthening the means of implementation and creating global partnerships for sustainability?

While previous studies on blockchain and sustainability have explored their ability to solve problems within and enhance certain sectors, such as supply chains and energy grids, this specificity gives readers a narrow view of the potential. Rather, blockchain should be viewed as an alternative "modus operandi" to our current business-as-usual paradigm that is able to tackle more deeply rooted problems that cross institutional, regulatory, and mental boundaries (Mougayar, 2016).

2 Background

2.1 Where Do Blockchains Fit?

To provide a context for understanding, following the invention of the Internet in 1983, the World Wide Web, invented in 1990 by Tim Berners-Lee, was the first significant layer on top of the Internet that allowed for wide information access (Mougayar, 2016). This brought about the *Internet of Information,* which has lasted for more than three decades. However, this didn't change how we do business, as it simply involves moving information, not value, among people (Tapscott & Tapscott, 2016). Just as the Web needed the internet, blockchains need the internet, and will be the second significant layer added to the internet. However, blockchain apps aim to re-write the Web, and represent a whole new version that is deemed the *Internet of Value* (Tapscott & Tapscott, 2016). The system aims to align stakeholders using incentives, creating a network that values all users for what they enable.

For example, quickly think about the business model of Facebook: they harvest **your data** to **create value**. 98.66% of their revenue was based on this principle (Cuofano, 2017). Now, imagine a new social network in which you are valued for what you bring to the table, in this case, data. This new network would have to request permission and pay for access to your digital identity (the data). This idea parallels the application of the blockchain-based web browser called Brave, which circumvents surveillance capitalism by requesting and paying users for their digital identity (Brave, 2019). Now ponder other industries and services we use today that rely so heavily on value that their clients create: Banks, Amazon, Uber, Spotify, Paypal, and digital media (music, books, articles, videos) publishers to name a few. Blockchain applications aim to disintermediate many of these industries and additionally create new ideas for how we value stakeholders, leading to a whole new wave of possible business models that award decentralized value creation.

To sum this up, unless you develop software, blockchains are not a product you physically use in day-to-day life. Blockchains, rather, will enable developers to create applications and services that people use, such as a new social network, ride-sharing service, e-commerce platform, energy market, supply chain, insurance product, voting process, as well as many others. One could be completely unaware that a blockchain is behind the product, just as most people are unaware of the digital complexity behind their use of WhatsApp, Amazon, or other digital applications.

2.2 Blockchain In-Depth

A blockchain is a distributed transaction-processing platform that not only computes the transactions, but maintains a continuously growing database (ledger) that is verified by the nodes (computers) participating in it (Tumasjan & Beutel, 2019; Yli-Huumo, Ko, Choi, Park & Smolander, 2016). These transactions are structured in chronological "blocks" that are linked on-chain by hashing, a method of cryptography that secures historical transactions (Andoni et al, 2019). No single party is validating transactions, rather, that power is spread equally to all users (nodes) in the network (Hagström and Dahlquist, 2017). Verification of a blockchain's transactions is incentivized by using a specific consensus protocol, a software design which binds computers together in order to confirm the transactions that are occuring (Mougayar, 2016). Consensus among thousands of computers is accomplished by game theoretical methods using cryptoeconomics, which combines cryptography (secure communication) and economic incentives, in order to build a system to have desired characteristics (Finestone, 2018).

Consensus is a fundamental requirement of blockchains due to the necessity to coordinate thousands of computers on the state of the ledger. Without consensus, a decentralized network such as a blockchain is unable to function. There are several consensus mechanisms that exist to create agreement among thousands of computers, such as proof-of-work (PoW)(Bitcoin), proof-of-stake (PoS), proof-of-authority, and many more. However, the focus of this research centers around PoS, as it is the method that will be employed upon release of "Ethereum 2.0" in 2020 (Junge, 2020). The technical summary for how these consensus mechanisms work can be found in the appendix of this thesis. In short, PoS incentivizes validators to create consensus by requiring them to put up economic value as collateral. If the validator tries to act maliciously, their collateral is lost, a method which disincentivizes bad behavior.

2.2.1 History of Blockchains

In order to understand blockchains and their capabilities today, it is helpful to know their historical development. It is a quickly developing technology that has, so far, gone through two stages of development and has reached the third. First, the public Bitcoin blockchain was released as a system that combines the technologies described before, such as distributed databases and cryptoeconomic consensus, along with a basic programming language called Script, to create the first world-wide digital currency based on a blockchain (Wang, Yang, Noor & Chen, 2019). This system has now existed for over

10 years and has proved its worth in relation to security, having remained untampared throughout its existence due to its PoW consensus algorithm.

The second stage came in 2015 when Ethereum, a new open-source public blockchain, introduced smart contracts into the world of blockchain. A smart contract is a computer program that is written in code on the blockchain that can collect, store, compute, and send values (Wang et al, 2019). This allowed for programmable code to be written onto a blockchain, an added layer that can support decentralized application (dApp) development through use of the coding language called Solidity, which works on the if-this-then-that logic (Talim, 2017). Out of the box, Solidity enabled contracts for uses such as voting, crowdfunding (creating tokens), and multi-signature wallets (secure wallets). With only a few lines of code, crowdfunding enabled projects to raise money in “Ether,” the native currency of Ethereum, and in turn, create a new token that would be given to the funders (Chittoda, 2019). This is why hundreds of tokens have been created in recent years. Unfortunately, the capabilities of these tokens are very limited, only being contractually “aware” of events within the same blockchain. Having no connection to real-world data and events limited the functionality to simply tokenizing (commodifying) assets or things, which allows for new and reliable possibilities for representing ownership and trading, but falls short of blockchain’s true potential for complex dApp development (Paul, 2019).

The third stage is now about creating a congruence between contemporary real-world data, such as supply chains, finance, or the overall internet of things, with blockchains in order to leverage its capabilities with actual events. Since smart contracts can’t access off-chain resources, they require an “oracle” which can relay non-native data (externalities) into the contracts on the blockchain. The team leading this oracle development is a network called Chainlink, which is looking to create a decentralized framework of data feeds to connect smart contracts to real world data in a way that preserves the reliability of using a blockchain in the first place (Nazarov, 2019). It should be noted that oracles like Chainlink are NOT blockchains, rather they are an added layer of nodes which can provide services such as filling data requests from smart contracts on the Ethereum blockchain. Additionally, Chainlink represents an “off-chain” solution for data aggregation and computation, a method which can result in an “almost complete elimination of gas costs” for Ethereum (Felten 2020). This elimination of gas cost for Ethereum is vital in conserving computation needs on the blockchain itself and allows it to scale without requiring excessive amounts of energy.

A common example of a smart contract is a trigger caused by the occurrence of a certain event; such as a contract entailing “if a shipment reaches a certain destination, then pay a certain entity “x” amount of dollars.” The oracle’s responsibility is to therefore retrieve this GPS tracking data for the

Ethereum contract to be able to execute on it. Oracle technology will expand the capabilities of smart contracts, moving from simple tokenization and voting towards complex smart contracts that can interact with real-world data feeds, IoT sensors, and application programming interfaces (APIs).

Unlike the simple Bitcoin programming language called Script, which provided external users with a set of predefined options in the form of transactions, Ethereum, along with oracles, provide a platform for complex dApp development, where developers can write complex contracts in Solidity or other WebAssembly programming standards (Chowdhury, 2019). A dApp can be thought of as a blockchain-enabled website or application, just like Twitter or Uber, and smart contracts (as opposed to APIs) are the engines that run the application and connect to a blockchain (the database). At its core, Ethereum utilizes a virtual machine called the Ethereum Virtual Machine (EVM), which is capable of executing code of arbitrary algorithmic complexity, or, in other words, is Turing-complete (like JavaScript or Python) (Chowdhury, 2019). Similar to how the VirtualBox program lets someone run a Windows operating system on a Mac OS device, the EVM allows all nodes in the network to execute software, meaning Ethereum has essentially created a decentralized computer. Ethereum's native "Ether" token is used by developers and validators to maintain the integrity of the EVM, a process which will be explained in the results section.

2.3 Lack of a Global Hegemonic Institution

The digital revolution of the 21st century has brought about a sharp increase in the connectivity of our societies and economies to one another. This has enabled individuals, corporations, and governments to develop global networks of subsidiaries and data supply chains in a process we term "globalization." While raising standards of living, this process has made palpable the various risks we put on our natural, economic, and societal systems. In a global survey of business and government leaders, environmental risks, such as extreme weather, biodiversity loss, and adapting to climate change, were identified as those with the largest possible impact and highest likelihood of occurrence (World Economic Forum, 2018).

Consumer demand for transparency regarding the goods and services they buy has been increasing in recent years, especially in regards to environmental and social qualities (Jeppsson & Olsson, 2017). An accompanying issue is that trust in corporations, governments, NGOs, and other institutions, however, are at an all time low (Dapp, 2019). What is true at each level of society is the need to trust not just other stakeholders who may be unknown to each other, but trust in the data and tools used to implement solutions and evaluate outcomes (Horner & Ryan, 2019). Without reliable information, the public has no ability to participate in sustainable development because none of the initiatives will take root unless there is proof of performance (Horner & Ryan, 2019).

Tackling the three pillars of sustainable development, which are economic development, social development, and environmental protection, will require inter-level and intra-level trust among various societal institutions at personal, local, national, regional, and global levels (Horner & Ryan, 2019). Institutions are defined as “humanly devised constraints that structure political, economic, and social interaction,” using both formal and informal rules to take individual behavior into account (North, 1991). In order to be accountable for decisions, there is a need for a global institution to evaluate the outcomes and performance to provide reliability and transparency.

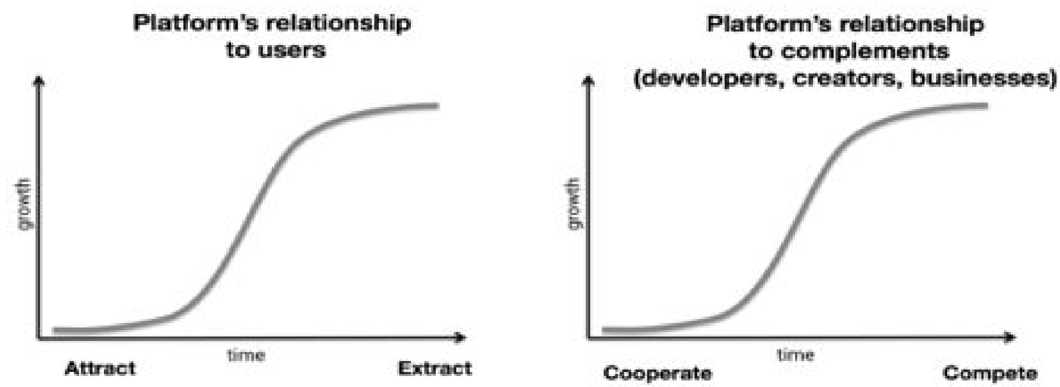

Figure 1: Centralized platform relationships with external entities (Dixon, 2018)

Upon the (de)centralization spectrum, actors within modern institutions, such as governments, corporations, and civil society, lie closer to centralization. It is a central assumption of economics that social organization and exchange are motivated by self-interests of the actors (Stroebe & Frey, 1982). Additionally, the inclination to free-ride increases with larger group size (Stroebe & Frey, 1982), which hypothesizes our current threat of collective inaction.

The main reason to advocate for decentralized institutions is pictured above, as practices within these institutions, especially in regards to corporations, often resort to value extraction and competition (Dixon, 2018). From the dawn of the internet to the turn of the century, internet protocols were built on open-source protocols controlled by the community, which saw the birth of Yahoo, Google, Amazon, Facebook, LinkedIn, and Youtube (Dixon, 2018). Since this time, for-profit tech companies, most notably Alphabet, Apple, Facebook, Microsoft, and Amazon, built software and services that outpaced their open-source counterparts (Dixon, 2018). This stifled innovation as these monopolistic platforms switched to competing with new developments, limiting their reach and profits. For example, Amazon has been using data from retailers to develop competing products, all the while vouching to Congress they don’t take part in this practice (Mattioli, 2020). Perhaps our quest for a sustainable hegemonic institution lies in a decentralized setting, where attraction and cooperation win over centralized self-interests, just as they did in the early days of the internet.

2.3.1 SDG 17

Goal 17, as provided by the UN, calls for a revitalization of global partnership by strengthening the means of implementation for sustainable development. While the targets and indicators of the goal include parameters of finance, technology, capacity building, trade, and systemic issues, the focus for this thesis lies on the indicators of systemic issues, as blockchain represents a medium for changing societal and economic structures. As posed on the UN website, these parameters include: (United Nations, n.d.)

- Policy and institutional coherence
    - Enhancing macroeconomic stability through policy coherence and coordination, while at the same time respecting individual countries’ policy boundaries.
- Multi-stakeholder partnerships
    - Enhance global partnerships among the public and private sectors of civil society.
- Data, monitoring, and accountability
    - Developing measures of progress to enhance capacity-building support.

Decision making for business sustainability follows a three-headed approach: decisions take into account risks, obligations, and opportunities for finance, society, and the environment (Horner & Ryan, 2019). Considering the shareholder primacy and profit-based monetary construct that businesses operate within, financial parameters are often favored over others (Friedman, 1970). Sustainable development has often been associated with adding a layer of cost to goods and services, which can be a deterrent for implementation (Curtis, 2010). This has resulted in collective inaction, as individuals, companies, and countries alike fear if they act prudently, then others will “free ride” off their sacrifice. This has reinforced the idea for global leaders that sustainability only pays off if the cost of achieving it is shared by all (Robèrt, 2016). Global investment in achieving the goals of sustainability is needed to ensure that any consequences from the cost of implementation are shared across borders and institutions. Therefore, committing resources towards SDG 17 should be an initial priority as this will help humanity in achieving its more nuanced sustainable development goals.

3 Theoretical Background

3.1 Tragedy of the Commons

The tragedy of the commons is another instance of the prisoner's dilemma, where two or more entities act in their own self-interest, resulting in the detriment of each. As an example in today's society, current global actors are competing for the sake of their own financial self interest, resulting in negative consequences felt by all of humanity, such as rising atmospheric temperatures, pollution, resource degradation, and the like.

The tragedy of the commons was first introduced by English economist William Foster Lloyd in 1833 (Hardin, 1968). He postulated a hypothetical example of cattle herders sharing a common piece of land for their animals. He theorized that each individual herder had incentive to put more of their cattle on the land, until eventually, the land would become overgrazed and barren, which is a detriment to all the herders together.

In 1968, American biologist Garrett Hardin released an article titled "The Tragedy of the Commons" which outlines human behavior in relation to "commons," or any shared and unregulated resource, such as the atmosphere, oceans, rivers, fish, roads, etc. He referenced Adam Smith in *The Wealth of Nations* in saying that individuals have been prescribed a dominant tendency towards acting in their own self interest, and in turn, they assume they are acting in the best will of society as a whole (Hardin, 1968). This results in a conflict of interest between the individual and the whole, as individuals adopt the thought of "If I don't, somebody else will." However, this collective predisposal has resulted in the depletion of many common resources we use today, such as fish stocks and the atmosphere. To solve this dilemma, Hardin proposed two solutions. (i) State regulation by imposing rules and regulations for using these commons, and (ii) converting the commons into individualized private property domains, which would eliminate the conflict of individual and group interests.

3.1.1 Ostrom Challenges Hardin

In her book Governing the Commons: The Evolution of Institutions for Collective Action (1990), Elinor Ostrom provided a response to Hardin, saying that collective action is indeed a third option for resolving the problem of common pool resources. She proposed the development of strict cooperative institutions that are organized and governed by the users of the resources themselves. By studying global common resources, such as Swiss grazing pastures, Japanese forests, and irrigation systems in the Philippines and Spain, she questioned how individuals in an interdependent situation can govern themselves while all users face temptations of self interest, free riding, or unwillingness. From this research, she was able to create a set of 8 design principles which were common to each of the situations she researched before: (Ostrom, 1990)

1. "Individuals or households who have rights to withdraw resource units from the common pool resource (CPR) must be clearly defined, as must the boundaries of the CPR itself."
2. "Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, materials, and/or money."
3. "Most individuals affected by the operational rules can participate in modifying the operational rules."
4. "Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators."
5. "Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or by both."
6. "Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials."
7. "The rights of appropriators to devise their own institutions are not challenged by external governmental authorities."
8. "Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises."

While these principles were originally designed for the natural commons, they have also been adapted to communities who adopt digital commons, for example, Wikipedia (Hess & Ostrom, 2007). Blockchain itself is a digital commons that provides rules of governance for maintaining a distributed ledger that remains valid across all users.

4 Methods

4.1 Case Description and Selection

Blockchain is in its pioneering stages of development, there is no way to anticipate exactly what kind of applications we will see in the future, just as one couldn't have predicted the expanse of applications on the World Wide Web in the early 1990's. Therefore, this thesis analyzes macro-social structures and practices, and additionally, analyzes the Ethereum blockchain's innate fundamentals as alternatives to the current "business as usual" paradigm. Focusing on a specific application of a blockchain would take away from its implication towards being a general purpose technology, or one which could disrupt current macroeconomic and macro-social structures. This justifies the reasoning behind analyzing blockchain's impact on SDG 17 - Global Partnerships for the Goals, as it represents a macro-phenomena (agreements) that could then have a "trickle-down" effect towards solving specific issues in SDGs 1-16.

Considering the problem of collective inaction, I initially considered how the Bitcoin blockchain enabled unknown actors to collectively govern a common resource, a currency. As Ethereum expanded this resource to a decentralized computer (the EVM), I questioned how the blockchain maintained a common platform where organizations and individuals alike can cooperate. To answer this, I looked into a common cooperative barrier faced in society, the tragedy of the commons. From this, I was able to focus on Elinor Ostrom's 8 principles provided in <u>Governing the Commons</u> (1990), by which she says groups of unknown actors can come together to govern common pool resources. The SDGs require global action among unknown actors, so this theoretical underpinning can exemplify the Ethereum blockchain's ability to incentivize collective maintenance of a global settlement platform.

4.2 Research Question

My research questions why blockchain is a suitable medium to achieve collaboration and agreements, as posed by the issuance of SDG 17. To answer this, I analyzed the fundamentals of the Ethereum blockchain by reading the white paper, the official in-depth report on the topic written by two of the founders, Vitalik Buterin and Gavin Wood. Ethereum was chosen for three reasons:

1. Ethereum is a public open-source blockchain that supports unabated development and participation from all users. Ethereum **will not** develop future dApps that govern commons, rather, Ethereum is looking to provide an **institutional platform** (the EVM)

from which other developers can seamlessly design methods and incentives to govern other applications.

2. Ethereum has a vast majority of blockchain developer activity compared to the rest. This is largely due to it being public and open-source, but also the blockchain research and software company called Consensys was created by Joseph Lubin, one of Ethereum's founders. It has over 600 members and 200,000 active developers from around the world focused on making collaboration the "foundational atomic unit of [information technology] (IT) infrastructure" (United Nations Foundation, 2018).
3. LO3 Energy, a blockchain-based energy grid application, is in collaboration with Consensys to proliferate blockchain and clean energy around the world (Ethereum, 2016). LO3 Energy will be discussed in detail in the discussion section of this thesis.

A document analysis was performed on Buterin and Wood's work. Document analysis is a form of qualitative research in which documents are interpreted by the researcher to give meaning to an assessed topic, in this case, the Ethereum blockchain (Bowen, 2009). Often, this analysis is done in combination with other evidence, such as other documents, interviews, or data sources, in order to provide 'a confluence of evidence that breeds credibility' (Eisner, 2017). For purposes of this research, I analyzed other documents, interviews, and data sources that have been published or verbally quoted from the Ethereum Foundation or one of the original founders of Ethereum, who include Vitalik Buterin, Anthony Di Lorio, Charles Hoskinson, Mihai Alisie, Amir Chetrit, Joseph Lubin, Gavin Wood, and Jeffery Wilke. This also includes references to the Ethereum Github, which is the main repository of Ethereum development. Based on this research, each of the eight principles from Elinor Ostrom was covered with a description of how Ethereum's blockchain provides service to its requirements in governing the EVM.

While focusing on Ethereum may seem exclusionary to other data sources, the justification lies in the fact that Ethereum seeks to provide maximum decentralization in order to foster itself as a global settlement layer, meaning it is open to all and other blockchains can attach to Ethereum and use it as a base layer for trustworthy data execution, storage, and interoperability (Consensys, 2019a). Because of this, much of the focus for the release of "Ethereum 2.0" revolves around improving user experience, privacy and confidentiality, and scalability, including implementing proof-of-stake and allowing for more transactions per second (Consensys, 2019a). The goal of collaboration is ultimately maximized when there is a shared global infrastructure on which users can rely and interact.

The discussion then looks into the implications of these results and their potential impacts on SDG 17. To start, the effects of decentralized digital infrastructure and its ability to create **determinism** is identified as a key element towards creating a hegemonic power that can facilitate agreements by aligning stakeholder incentives and enforcing a software design without the use of centralized intermediaries. To sum up the findings, I analyze a specific blockchain application in the real world, LO3 Energy. Keeping the targets and indicators of systemic issues in SDG 17, as well as the Ostrom's eight principles in mind, the case study exemplifies how blockchain is enabling organizations like LO3 Energy to rethink common societal structures and business models in order to facilitate cooperation. The distributed architecture and token incentives of blockchain allows them to foster cooperation among unknown individuals, by use of their data and DERs, in order to realize SDG 7 - affordable and clean energy, which portrays the "trickle down" effect of blockchain realizing SDG 17, and in turn, allowing these new ideas of economics, philosophy, and politics to infiltrate the other 16.

5 Results

5.1 - Fostering a Better "Modus Operandi" for Achieving SDG 17

This section will lay out the fundamentals of the Ethereum blockchain as sufficient in meeting the requirements of Ostrom's eight principles for governing common pool resources, which in this case is the EVM. Governance of the EVM establishes an institution for smart contract development, which represents a wholly superior form of agreement which guarantees the correct execution of its contractual terms by means of cryptography (Nazarov, 2019a). The ability for contractual outcomes, such as payments or supply chain provenance, to be guaranteed is an entirely new "modus operandi" that has yet to be explored by society.

5.1.1 Smart Contracts in the EVM as a "Commons" Resource

Smart contracts are an extremely reliable form of digital agreement. The code not only defines the terms of a contract, which resembles traditional contracts, but also enforces the obligations too. Take the shipping example mentioned before. Traditionally, the two parties could agree that a certain shipment entails "x" payments to certain entities, but the enforcement and payment process currently involves significant human exchange and paperwork. Using blockchain would streamline these processes within the function of a smart contract and an oracle in the EVM, which provides determinism in software, or in other words, **a guarantee for performance of contractual terms**. In short, the switch to smart contracts over current contractual agreements would "shift the market from probabilistic outcomes based on handshake agreements to deterministic automation based on unbiased data flows" (Chainlink, 2019).

Smart contracts can also provide an alternative legal system for developing markets where legal infrastructure is lacking. Many luxuries taken for granted in the developed world, such as crop insurance, are unavailable in countries that lack long-term stability (Nazarov, 2019b). Smart contracts replace the need for a central intermediary to track, verify, and approve any digital exchange of value. Intermediaries are liable to high operational costs, slow operation, and attacks. Blockchain networks open up a new field of cooperative governance that can be reliable, representative, and enable economic prosperity for new geographic regions (Walden, 2019). If a blockchain such as Ethereum acts as the "commons," then governing its resource, the EVM, requires 8 principles as proposed by Elinor Ostrom in Governing the Commons: (1990)

1. An institution of <u>rules and boundaries</u>
   a. **Defined boundaries (Ostrom Principle #1)**
   b. **Localized rules (#2)**
   c. **Stakeholder participation in rules (#3)**
   d. **Dispute resolution(#6)**
2. A <u>credible commitment</u>
   a. **Graduated sanctions for rule violators (#5)**
3. <u>Collective monitoring</u>
   a. **Develop monitoring system (#4)**
   b. **Rules accepted by external authorities (#7)**
   c. **Multiple layers of nested enterprises (#8)**

Ethereum meets these criteria by employing a design philosophy that revolves around the principles of **simplicity, universality, modularity, agility, and non-discrimination** (non-censorship) (Buterin, 2014).

Rules and boundaries are programmatic and written in open-source code, meaning an average programer could implement the specifications, "so as to realize the unprecedented democratizing potential that cryptocurrency brings and further the vision of Ethereum as a protocol that is open to all" (Buterin, 2014). Additionally, the universality philosophy follows that Ethereum is public and does not have "features" embedded into the base layer. Instead, Ethereum provides an internal Turing-complete scripting language, which a programmer can use to construct any smart contract or transaction type that can be mathematically defined (Buterin, 2014). Ethereum is modular, meaning developers can pick and choose features that they prefer for their application (Buterin, 2014). The rights to access are represented by a user's ownership of a cryptocurrency private key, whether they be a validator, developer, or investor (Buterin, 2014).

As distributed ledgers, blockchains allow for simple democratized voting and participation techniques to be leveraged in a network, which represents "on-chain" governance. On-chain governance, according to Ethereum founder Vitalik Buterin, favors those with more coin holdings and disrupts the decentralization model (Jameson, 2019; Rancea, 2019). Therefore, Ethereum employs an "off-chain" governance model based on the design philosophy of "agility," where opportunities to improve are taken from all stakeholders and exploited efficiently (Buterin, 2014). Core developers and community members alike submit Ethereum Improvement Proposals (EIP), which are then presented on a website called GitHub and taken into consideration and discussed on a larger scale for approval (Jameson, 2019; Rancea, 2019). Likewise, many EIPs start off as Ethereum Request for Comments (ERCs) which aim to set standards for applications on Ethereum. Many ERCs often become EIPs to cement their integration into the Ethereum protocol. After detailed discussions with all stakeholders, the EIP goes up for discussion within the developers in the project management room (https://github.com/ethereum/pm), where discussion is recorded and every meeting's agenda, notes, and video are made public. While slower than the on-chain alternative, off-chain governance gives more room for input from all stakeholders.

Lastly, Kleros is building a blockchain dispute resolution layer, enabling fast, open, and affordable justice for all users (Kleros, 2020). Their development can be followed by searching the Ethereum github for "ERC 792: Arbitration Standard."

Credible commitments are incentivized economically through collateral funds using the Ether token. Developers running Solidity code are required to stake Ether because that code requires computational power for every validator to process it in the EVM. The fundamental unit of computation is called gas, which is calculated based on the amount of computation required for the developer's code in the EVM (Buterin, 2014). The gas price is measured in "Gwei," a denomination of Ether where 1 Eth = 1e9 Gwei. This separates the speculative price of Ether from the cost of gas, therefore allowing for consistency in computation costs. So, developers must stake enough Ether that is comparable to their programmability design in order for the transactions to happen. In practice of the proof-of-stake mechanism that will be employed by Ethereum, validators are rewarded a small amount of Ether (paid by developer's gas costs) for running the EVM code and coming to consensus on the true outcomes (Buterin, 2016). The penalties for wrong-doing involve a complete loss of collateral, which means it is hundreds to thousands times larger than the rewards. Thus, the "one sentence philosophy" of proof of stake is that "security comes from putting up economic value-at-loss" (Buterin, 2016).

Collective monitoring is enabled by the public nature of Ethereum, where every validator within the network keeps verified copies of all transactions and the most recent "state" transition, which outlines the ownership of coins within the network at that current moment (Buterin, 2014). The historical ledger and all underlying contract code is therefore fully auditable by any external authority. As described under "rules and boundaries," the rule-making process is also very transparent and available on the Ethereum Github. Lastly, the monitoring is achieved through various nested enterprises, such as validators, developers, and investors. Developers have to pay small fees to utilize this shared platform while validators are incentivized to maintain the logic of the developed software.

6 Discussion

6.1 Ethereum as an Institutional Platform for Other Commons

As a foundational layer, Ethereum is a blockchain with a built-in programming language, allowing anyone to write smart contracts and create dApps where they can design rules for ownership, transaction formats, and state transition functions (Buterin, 2014). This implies that Ethereum is an institutional platform upon which others can build their own applications and governance models to cater to their specific use case. Elinor Ostrom described this polycentric governance model in some of her later work (2014):

> "Scholars are slowly shifting from positing simple systems to using more complex frameworks, theories, and models to understand the diversity of puzzles and problems facing humans interacting in contemporary societies. The humans we study have complex motivational structures and establish diverse private-for-profit, governmental, and community institutional arrangements that operate at multiple scales to generate productive and innovative as well as destructive and perverse outcomes"

That being said, Ostrom does recognize the complexity of human networks and interactions. Blockchain networks will be no different, as various applications can use different blockchains, but the networks will be made seamless through interoperability technology such as Polkadot, a project led by former Ethereum founder Gavin Wood. There isn't a "one size fits all" solution to governing global resources, and Ethereum has set up a commons platform (EVM) where developers can build localized parameters for governing their own resources. State regulation and private ownership, as identified by

Hardin as solutions to commons governance, too oftenly apply single policy prescriptions to all resource types (Ostrom, 2009). These institutions have historically nudged self-interested individuals towards certain outcomes, ignoring complex local motivational structures of humans (Ostrom, 2009). Ostrom instead argued that a core goal of public policy should be to facilitate the development of institutions that bring out the best in humans (Ostrom, 2009). Ethereum, one would argue, has a case for being that institution.

The five philosophical principles outlined by Vitalik Buterin mirror the vision of Ostrom in creating an institution that favors collaboration over competition. Just as Ethereum created rules and incentives to maintain a common shared computer, developers now have an institutional platform to create tokens and smart contracts that focus on other commons resources, and developers can utilize the tools provided by ethereum to promote their desired management through collaborative stakeholder behaviors. The blockchain layer of Ethereum ensures collective maintenance of the EVM, and the application layer allows developers to specialize rules, boundaries, and incentives to their local needs with guarantees that these rules will perform exactly as designed.

In order to represent these resources on a blockchain, oracles are imperative to be able to record externalities, such as CO_2 emissions, energy use, traffic, recycling, supply chain provenance, and more. Chainlink currently develops the most reliable oracle method, as it is a **decentralized** solution that maintains the **end-to-end** security and reliability of a blockchain (Nazarov, 2019a).

6.1.1 Blockchain Determinism = Blockchain Hegemon

Current institutional practices have shown to be prone to corruption by self-interests and a lack of reliability, hindering the path to collective sustainable solutions. Guillame Chapron, in his nature article “The environment needs cryptogovernance,” explains this well:

> “Lawyers guarantee contracts and states guarantee the rule of law in the same way as central banks guarantee currencies. Governing institutions need to establish trust between individuals, groups, firms and societies. If humans repeatedly fail to build trust, perhaps algorithms should replace them. The environmental crisis is growing partly because of a lack of trust — the increasing distance between multiple actors who are unknown to each other, from companies and governments to individual consumers, creates many opportunities for fraud and failed policies. The time is ripe for 'cryptogovernance', in which trust, law and enforcement are outsourced to computer code.” (Chapron, 2017)

Today, the idea that international cooperation requires the leadership of a predominant power to ensure and enforce compliance on agreements is called the Hegemonic Stability Theory (Vogler

2016). Consequently, the lack of hegemonic leadership from the economically and politically pre-eminent United States may provide an explanation to the failure to develop a comprehensive climate agreement (Volger, 2016). If companies or governments lack a “first-mover” approach, or if governing bodies such as the IPCC lack international enforceability, then perhaps maybe it is time to consider incentivizing stakeholders under blockchain, where entities can mutually agree on terms and outcomes and the hegemonic powers of monitoring and enforceability can be prescribed to the blockchain, a decentralized institution. Once written into code, the execution of smart contracts happens independent of the will, approval, or any action of the parties involved and it is impossible to back out of them (Chapron, 2017). The automation of agreements under trustable conditions is a powerful tool only capable using a blockchain, and this illustrates its key feature: determinism.

This emphasizes the importance of blockchain as a **global** settlement layer. The significance of creating a contract where you are deterministically (100%) guaranteed of outcomes cannot be overstated, especially since the ability to form contracts underpins most, if not all economic activity (SDG 8)(Nazarov, 2019b). The ability of a contract to function as planned often dictates whether the contract is entered into at all (crop insurance in developing countries) and dictates whether or not a contract prevents fraud, which has significant personal and societal consequences (e.g. the 2008 financial crisis)(Nazarov, 2019a). By creating a parallel “technologically enforced legal system” (Nazarov, 2019a), blockchain can reduce inequalities (SDG 10) and enable users within developing nations to establish individual agency, for example:

- Blockchains enable farmers to buy crop insurance, and weather data can reliably be fed via oracles into the contract to execute its terms, helping many poor farmers who are unprotected from natural climatic events.
- Blockchains are enabling supply chains within India to create tamper-proof methods to track the provenance of shipments and shippers, enabling payments to deserving parties (Knowledge@Wharton, 2018).
- Blockchains are helping the Indian states of Assam and Sikkim give tribal people access to land titles to secure their land, preventing mineral miners and other industries from taking it (Knowledge@Wharton, 2018).
- Blockchains enable financial inclusion, allowing remittances to be sent cheaper and faster without intermediaries. Additionally, decentralized finance enables a global lending platform, where users can get loans and develop credit history (Sandner, 2019).

6.1.2 Digital Centralization vs. Digital Decentralization

Decentralization, according to Ethereum founder Vitalik Buterin, can be analyzed in three different forms: architectural (de)centralization, political (de)centralization, and logical (de)centralization (Buterin, 2017). Architectural questions how many physical computers the network contains and how many of the computers shutting down the network can tolerate. Political questions how many entities control the computers the system is made of. Logical questions whether the network data structure is more like a monolithic object or a structureless object. Traditional corporations and their digital infrastructure we engage with today are politically centralized (CEOs), architecturally centralized (head office or server), and logically centralized (can't split them anywhere). Blockchains, on the other hand, are politically decentralized (no one person controls them), architecturally decentralized (no single point of failure), and logically centralized (the network has one agreed state and behaves like a single computer) (Buterin, 2017). With regard to developing sustainable systems, combining centralized logic with decentralized architecture and politics allows blockchains to be: (i) less likely to fail because they involve many separate components (political), (ii) harder to attack because the network is spread across various computers (architectural), and (iii) collectively focused on one purpose (logic) (Consensys 2018). While institutions today operate with common centralized tenets of logic, architecture, and politics, many are unable to provide transparency around their internal processes and fail to address the holistic, international, and multi-faceted challenges of sustainability.

In a time where data has become the world's most valuable asset, centralized architectures upon the "Web 2.0" pose a huge risk to individuals and developers alike. In order to participate, users give away their personal identity and power (Lubin, 2019a). Google, along with others like Amazon and Facebook, monetize our content in order to give us access. Without a native construct of money, the web turned to advertising as its core business model (Lubin, 2019a). Without a native construct for private identity, the web turned exploitative before we could recognize the cancerous advertising logic belittling many people today (Lubin, 2019a). This highlights the issue of institutions employing political and architectural centralization, in which current business models represent a winner-takes-all market where economies of scale and profit maximization foster markets dominated by powerful centralized platforms (Brynjolfsson and McAfee, 2014; Tumasjan & Beutel, 2019).

The alternative decentralized protocol involves collaboration mechanisms that enable shared architectures for computation and storage, all while ensuring privacy of confidential information (Brody, 2020). Instead of companies that interact with users and competitors in adversarial ways to maximize profits, actors in diverse roles can motivate collaborative activities through tokens, where no one person is in control and the platform offers a level playing field and transparent rules for all (Brody, 2020; Lubin, 2019a). As the platform gains value, so do all of the actors within as well. “Web 3.0” will be more user-centric, allowing all persons to develop and control their own self-sovereign identities (Lubin, 2019a). It will allow all users to have social, political, and economic agency, or influence, allowing for far broader participation in governance and greater wealth distribution (Lubin, 2019a).

The key to creating a lasting collaborative environment is through creating incentives to do so. To provide an example, imagine if operating systems like Mac OS or Microsoft’s Windows were open-source (like Linux) and had a native token to incentivize development. Not only would collaborative efforts have enabled greater development, but the value these networks generate would be reflected in the token, which serves the interest of all stakeholders who support the network’s functioning. Looking at S&P 500, Microsoft, Apple, Amazon, Alphabet, and Facebook now account for around 20.5% (over $5 trillion USD) of the index’s whole value (Krantz, 2020). Ethereum, as an operating system, aims to subvert these centralized counterparts while applications built on top of Ethereum can use tokenized incentives to subvert profit-minded companies like Amazon, Google, or Facebook.

6.2 Contribution to Sustainability and Academia

Ethereum greatly improved the abilities of blockchain as a technological resource, moving from simple transferring of number values between users (Bitcoin) to now creating a shared global infrastructure (the EVM) that allows for implementing smart contracts based on intentional designs (Glaser, Hawlitschek & Northeisen, 2019). Ethereum’s ability to foster agreements and help in realizing SDG 17 comes down to its ability to create native digital value on a base settlement layer that everyone can trust (Consensys 2019a). Shared infrastructure evolves business from a zero-sum competitive mindset towards a more positive-sum mindset where collaboration is a guiding principle (Consensys, 2019a). Instead of entities vying for profits through self-interested strategies, having native value within a platform (Ether, Bitcoin, or other token) allows its users to be incentivized to maintain the integrity of the platform’s mission, enabling collaborative economies of scale as a core fundamental from which society can build around. Instead of focusing solely on a growth economy, society can start to configure strong institutions (SDG 16) for maximizing physical, social, and environmental health rather than solely GDP (Consensys, 2019b).

Within academia, this thesis has provided an investigation into blockchain as an alternative institution which subverts the role of relying on centralized institutions for collective action. By utilizing

Ostrom's eight principles, this thesis proved how Ethereum has used a blockchain to maintain a decentralized computing platform, which enables a new paradigm for decentralized governance methods. Sustainable transitions have struggled to gain momentum, largely because of the competitive and extractive nature of our institutions. Ethereum has created an institution that brings out the best in humans, incentivizing collaboration as a fundamental tenet from which governance and economics can scale and address other SDGs. While also raising awareness for blockchain and its capabilities within the sustainability community, this thesis allows researchers to start considering solutions that enable climate action beyond the current "business as usual" paradigm, where profits and growth weigh more consideration than environmental and social prosperity.

6.3 Blockchain Application and Case Study: LO3 Energy

As the importance of a shared computing platform that incentivizes collaboration has now been solidified, I want to provide an example of blockchains facilitating collaboration in the world of sustainable energy grids.

6.3.1 Blockchain and Externalities

The idea of a steady-state economy was first proposed by Adam Smith as the final state of a saturated economy (Smith, 1776). Since the 1970's, the world's leading proponent of a steady-state economy has been ecological economist Herman Daly. A proponent of strong sustainability, Daly recognized the dependence of the economy and society on a limited biosphere, and therefore rejected the substitutability of natural capital for human capital (Dapp, 2019). According to Daly, it is clear that beyond a certain point of production, economic growth will become irrational as the costs of further expansion will outweigh the benefits (Daly, 2005). It can therefore be concluded that unlimited economic growth is not only impossible, but undesirable (Dapp, 2019). The reality is we are destined for a future of less growth. The question lies in whether we get there by natural force, as Adam Smith postulated in saying it is the end point of a saturated economy, or whether we intervene and create it by design (Smith, 1776).

A steady state economy must adhere to four clear rules: renewable resource extraction cannot exceed the regeneration rate, pollution outflows cannot exceed absorption capacity, neither extraction nor pollution can threaten essential ecosystem functions, and essential non-renewable resources cannot be depleted faster than we develop substitutes (Farley et al, 2013). Looking at these requirements, their variables (extraction rate, regeneration rate, pollution outflows, absorption capacity, depletion rate, etc.) for the most part can be represented by trackable numerical data that can be gathered by data feeds and IoT sensors. Blockchain technology can connect to data streams via oracles that relay externalities and is able to record, track, and process them in a trustworthy manner (Dapp, 2019). Externalities can include, but aren't limited to, CO2 emissions, electrons (electricity), traffic, reuse, recycling, and biodiversity (Dapp, 2019). It allows these externalities to be monitored and recorded on blockchains, and therefore valued and traded. Cryptoeconomic designs of these externalities, described below, will be the incentive for mitigating unsustainable activities on a large scale. Sensory networks under IoT makes measuring these externalities possible, but the question under current development lies in how you prove these "good work" externalities that have a positive impact towards sustainability. In order to fairly award users, stakeholders need proof that the work has happened and the data is unmanipulated before it enters the blockchain.

Currently, oracles are the method of providing proof of performance by transferring sensory data into blockchains, but the use of this functionality is currently limited to numerical sensory data. This is useful for externalities that can easily be tracked by IoT and data feeds, such as CO2 emissions, traffic, recycling, or energy use. What about in cases where the "good work" is not available in sensory numerical data, such as the act of planting trees or other acts of ecosystem services? Here, the act of social proof, or "human oracles," would be needed as community members can mutually verify an activity took place (Dapp, 2019). Currently, projects on blockchain mechanisms for voting and dispute resolutions are solving such issues (Dapp, 2019). Additionally, as Ostrom theorized in principle #8, rules and mechanisms need to be accepted by authorities within and external to the blockchain at all levels. In the future, the development of "off-chain" governance and legal systems around blockchain networks can enable better trust in situations where human input is needed to provide proof of performance.

Cryptoeconomic designs will involve tokenizing these externalities on the blockchain in different ways to incentivize sustainable behaviors. Conceptually, it can take form as a currency, an asset, or something more autonomous (Dapp, 2019). The logic of a currency is straightforward: users receive tokens for doing something the network values and users pay others for something they value. In this case, the externalities are traded in a market. Another method would be to represent externalities as an asset and award users with non-fungible tokens, which are tokens that can't be traded and rather constitute an identity-based reputation. Once decentralized governance mechanisms (consensus and cryptoeconomics) have been realized, a new type of organization, called a decentralized autonomous organization (DAO), which represents the third form of crypto-economic design, may be the new premise to avoid pitfalls of centralized organizations (Dapp, 2019; Tumasjan & Beutel, 2019; Voshmgir, 2017). It has been argued that these DAOs could flatten or remove entirely the hierarchical structures of digital economies by shifting the architecture and control equally to all peers in a network (Beck, Müller-Bloch & King, 2018; Tumasjan & Beutel, 2019). The possibility to earn income from positive externalities, such as reducing energy use during high demand times, could contribute to a scheme of universal basic income, tackle unemployment issues that arise with automation, and incentivize sustainable behavior at a global scale (Frey & Osborne, 2017).

6.3.2 Why the Energy Sector Needs Blockchain?

In order to integrate distributed energy resources (DERs) into the electricity sector, the International Energy Agency stresses that system transformations are needed in which economic, technical, and institutional requirements of these technologies must be accommodated (Acosta, Ortega, Bunsen, Koirala & Ghorbani, 2018). The generation and use of electricity is becoming digitized, distributed, and decarbonized as consumers acquire solar panels, wind turbines, batteries, electric vehicles, and IoT enabled smart devices. The traditional network setup in which power stations at the center of the grid provide energy to the edges of the grid via long distance power lines is becoming obsolete. Paralleling this with the growth of DERs in many of our communities around the world, energy consumers are now becoming producers as well, and the energy market should be treating them as such.

In order to make the network more efficient, data on how these DERs are being used, data on public energy consumption, and how these relate to the location of resources and their production capacities has to be readily available (Consensys, n.d.). Additionally, use of a common language among providers, consumers, and the devices they use is needed so the network cannot only share this information automatically, but act on it too (Consensys, n.d.). Today, this data is usually available via telemetry from the grid edge, however, it is locked up within the data centers of centralized utility services with no incentive or means to be shared (LO3 Energy, 2019). Ultimately, releasing this data will be what enables energy usage to be more efficient and, in turn, reduce the overall amount of energy we require.

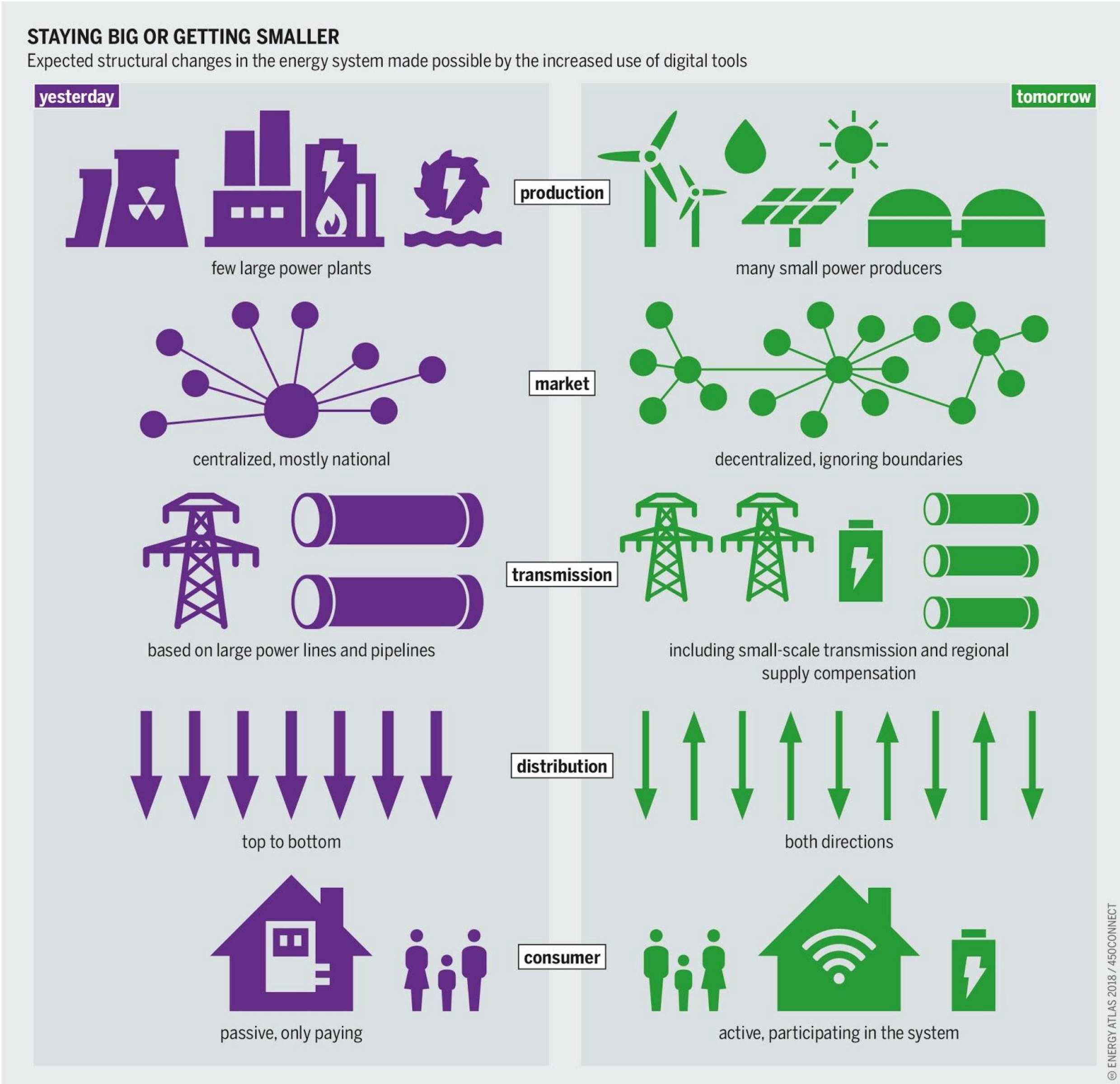

Figure 2: Comparing conventional grids to smart peer-to-peer grids. The emphasis herein lies in decentralizing power generation and allowing for bi-directional flows of energy among producers and consumers (Bartz and Stockmar).

Figure 2 highlights the major differences between conventional grids and peer-to-peer grids. Traditionally, centralized power plants send their energy via long-distance power lines to utility operators, who then disperse the energy to the grid edge consumers. Today, if a consumer has a DER and has unused energy they can sell, the utility will pay them a below market price for their energy and it is pooled together along with all the other electrons derived from large power plants, meaning consumers have no choice as to the source of their electricity. Peer-to-peer energy gives all producers and consumers direct access to the market in a way that allows a bi-directional flow of energy, where data can be utilized to provide automated trading of energy among producers, prosumers, and consumers alike. Based on a study in Brussels, setting up a peer-to-peer community network can enable an 11% reduction in energy cost for consumers and a 2% profitability increase for DER prosumers, although these numbers can obviously vary from region to region (Viviers, 2018).

6.3.3 LO3 Energy

LO3 Energy is a blockchain-based energy company that is headquartered in Portland, Oregon. They have developed a platform that allows for the integration of DERs, such as solar, wind, and battery storage, into the supply networks of the grid. Their technology, which was first integrated with the Brooklyn microgrid, allows residential homes and businesses to produce, consume, store, and sell energy to peers within their network. They are both a software and hardware company, using software to create a user-friendly marketplace, and building their own hardware meters in order to capture data that a blockchain can then use to balance the grid (LO3 Energy, 2018). With an aim to proliferate DERs across the globe, LO3 offers their software marketplace product called “Pando” to allow utilities and retailers to scale their local communities and enable grid support for these DERs (LO3 Energy, 2018). Pando is a marketplace application designed to connect customers to retailers and the rest of their community, all accessible by a phone or other personal device. On the app, utilities and retailers can easily organize a new community grid to their desired boundaries and consumers within can set a budget, make offers, and sell their own energy on the market (LO3 Energy, 2018).

This exemplifies the ease and flexibility of using a blockchain platform to organize unknown entities together to create boundaries, localize rules, and have stakeholders input in these rules. This ‘clustering’ of separate micro-grids that all share the same underlying governance medium allows for multiple local marketplaces to establish and grow in parallel with each other, all while the overall system benefits from the shared data and analytics on consumer behavior, device performance, and system needs (LO3 Energy, 2018). As an added dimension, LO3 developed another blockchain-based software layer to their product, which is called Exergy, to work in unison with their Pando platform.

6.3.3.1 LO3's Exergy Platform

Based on a 2018 study, 90% of the world's data ever produced came from the last 2 years, and within the energy sector, these growing numbers are no exception (Marr, 2018). In order to make energy networks efficient, data (externalities) regarding resource use, hotspot timing, resource locations, and production and storage capacities must be gathered and processed. Blockchain represents the common language, or platform, to enable devices to communicate their data with each other in order to prove their performance or performance potential, and in turn, be able to send electrons based on that data (LO3 Energy, 2017). It is through this automated data sharing that smart contracts on the blockchain are the medium of governance to execute tasks based on certain device performance. LO3's proposed solution to this is Exergy, a system that leverages blockchain which functions across all grid-connected hardware, a token economy for value transfer, and a foundation that will proliferate this paradigm along the way (LO3 Energy, 2018). With Exergy, a fully democratized energy marketplace is achievable. It should be noted, however, that Exergy works in conjunction with the Energy Web Foundation, a blockchain that derives from the Ethereum code base, but has a different technology stack that is geared towards meeting the needs of blockchain applications in the energy sector (Adamson & Bronski 2018).

Each DER within a network can be viewed as a node that, when properly connected and incentivized, can deliver huge value (network utility) to the grid in the form of energy production or storage capacity, autonomous grid-edge control, rapid restoration and resiliency, and other societal benefits, such as alternative income (LO3 Energy, 2019). 'Transactive Energy' is the new term to describe the new way we value, transact, and consume energy (LO3 Energy, 2019). Blockchain moves the control from the center of the grid to being shared equally on the grid edge. Sovereignty is given to all users as they are the ones who determine where their energy comes from and goes to, the prices and budget they are willing to pay and sell, and the personal usage data they are willing to share.

Automation is a trend that can change the way we use energy, moving away from customers being passive users of baseload energy systems (fossil fuel or nuclear plants), and moving towards stakeholder control of energy sourcing and pricing. It enables automatic response to supply conditions and the demand incentives that occur because of it. This allows for easy monitoring of excess capacity and the ability to trade this to other grids, which all contributes to more efficient energy use and less wasteful practices. In the future, blockchain technology could combine with artificial intelligence and machine learning to further optimize data trends into more efficient energy use and savings.

The XRG token, to be released by LO3, will provide the incentives for energy producers, consumers, “prosumers,” and commercial players to participate in an energy marketplace where the consumer is the sovereign entity. With a connected DER, the network will pay the user in XRG in order to access their device’s data. As a stakeholder in the network, your consumption, production, or storage capacity data that you constantly produce is yours. However, you are incentivized with XRG tokens to sell that data to the network, which then goes to improving grid optimization and resilience by way of automated logistics within the blockchain software application. This data also directly benefits the utility grid operator, highlighting possible risks before they occur and allowing the operator to act accordingly. Transactive energy is a market-based solution which moves the job of economic and control management equally to all prosumers on the grid edge, which enables broad participation in the network, all while blockchain uses smart contract embedded software to manage preferences from each user and execute tasks based on them. The blockchain is therefore an automated “collective monitor,” taking data (production, capacities, price preferences, etc), processing those logistics, and executing transfers of value (transfering XRG for valuable data) and electrons (energy), all under one swoop of hegemonic power.

Historically, under centrally controlled energy systems, this data has been difficult for consumers to access and monetize for their own benefit, which is the only fair practice considering it is their data. This represents the underlying value of the XRG token, and the utility of this data is predicted to be valued around $200 billion in 2025 (LO3 Energy, 2018). Allowing for incentives to make this data available to the whole network enables all users to contribute to network efficiency and be rewarded for their contribution. Additionally, a pool of XRG will be held by the LO3 team to be given as rewards for nodes that verify transactions on the blockchain. This means to start, consumers, regardless of whether they own a DER or not, only need access to a smartphone app and staked XRG tokens in order to participate and be rewarded for it. When a customer is earning XRG in exchange for their data or for verifying transactions in the market, the tokens received can be exchanged for new products and devices, such as efficient light bulbs or a new solar panel. Overall, the goal of tokenization is to make sure the incentives for all stakeholders in a network are aligned. In this case, they contribute solely to democratizing energy, increasing efficiency, reducing overhead, and proliferating DERs. This market design serves to empower all individuals for the value they bring to the market, whether they be a consumer, producer, utility operator, or retail entity, while also steering the energy landscape to become cleaner and more efficient.

6.4 Challenges Ahead

Currently, many challenges and risks remain in the development of blockchain. These include technology scalability, regulatory uncertainty, and unknowns in designing functional decentralized systems and incentive structures, especially since there is no historical precedent to learn from. Considering blockchain is a nascent technology, it is still in the pioneering stages of development. The overall development of blockchain technology seems to suffer from a tragedy of the commons, as individuals and companies aren't interested in leading development of a utility that will benefit entire industries as a whole (Higginson, Nadeau & Rajgopal, 2019). As a result, many companies are looking to narrow their use cases down to simply private needs. This is where private blockchains are becoming popular for many industries we use today as, for example, many financial institutions look to expedite their governance over derivative products such as stocks, bonds, commodities, currencies, interest rates, and market indexes. However, companies like Consensys exist in order to proliferate this paradigm of public blockchain development, where trust is maximally achieved.

LO3 Energy is a unique example of a company providing an original blockchain-based solution to a current paradigm, while also enabling an alternative business model for their company (selling software integration, hardware meters, and DER hardware). McKinsey consulting firm, largely considered the most prestigious management consultancy, proposed that rather than in private financial services, blockchain would demonstrate the most value in providing provenance proofs in supply chains (fair trade), enabling transparency and automation, and creating networks where sovereignty is shifted from centralized entities to customers (Higginson et al, 2019).

The main challenges that lie ahead in blockchain involve improving privacy and confidentiality, scalability, and usability (Lubin, 2019a). As a global ledger, blockchains need to be able to protect private user data in a way that preserves transparent monitoring. Techniques such as zero-knowledge proofs (ZK-snarks/starks), state channels, and layer 2 private chain architecture look to ensure this quality upon release of Ethereum 2.0. Layer 2 solutions will also provide scalability remedies to the Ethereum fabric layer. In addition to releasing the PoS consensus mechanism, Ethereum 2.0 will enable "sharding," which greatly increases the amount of transactions per second the network can handle, potentially seeing millions in the near future (Lubin, 2019b). In terms of usability, the current state of blockchain, with details such as "gas limits" and several wallet addresses, is comparable to early 90s dial up internet, with many manually moving parts required to operate. Many applications are exploring "progressive onboarding" techniques which will provide ease to start participating, and gradually hand back responsibility to the user as blockchain maturity grows.

This exemplifies the main barrier to blockchain as a whole, which is adoption. Being such a diverse alternative to the current economic and social paradigm means blockchain will take time to be adopted. During the 2018 World Economic Forum meeting in Davos, Switzerland, Consensys founder Joseph Lubin talked about the enormous amount of opportunities to reach the SDG goals, but cited adoption as the main barrier for blockchain to tap into this potential (United Nations Foundation, 2018). To achieve this, digital technologies need to move from siloed infrastructures, such as those seen in current "Web 2.0" businesses, to more shared infrastructures like the EVM, or "Web 3.0" (United Nations Foundation, 2018).

Working in its favor is the proliferation of smartphones and personal devices, all of which use applications that can be built on a blockchain (Chapron, 2017). Some governments and corporations will recognize the disruptive potential of blockchain and vehemently resist it, but many already have recognized this potential and are researching and developing around this new paradigm. The age of the internet allowed digital platform businesses to disrupt entire brick and mortar industries over the last couple of decades, and now blockchain is here to disrupt the disruptors in their own game, removing our dependence on many centralized business models. Blockchains can enhance our "modus operandi" for transitioning from an unsustainable society by democratizing value creation, enabling stakeholders to value social and environmental causes rather than simply profits (Sandner, 2018).

7 Conclusion

The Ethereum blockchain is a global settlement layer that can provide governments, companies, and individuals with a common frame of reference for reliably addressing the Sustainable Development Goals. It has truly global architecture that seeks to provide impartial guarantees to anyone willing to adopt its benefits. Ethereum has enabled governance of a platform for decentralized computation and storage, where businesses or individuals alike can mutually agree on contractual terms, and the hegemonic power of monitoring and enforcement is left to a nonpartisan blockchain. Whether it be creating a sustainable supply chain, giving individual agency to citizens in developing nations, or proliferating clean energy grids across the world, blockchains enable contractual guarantees that were once fallible to human greed, trust, or competition.

Blockchains have provided a 3-in-1 solution to the systemic issues outlined in the targets and indicators for SDG 17:

- Providing clear policy coherence to the rules and boundaries of a network, all while respecting local or regional policy boundaries
- Enabling multi-stakeholder partnerships and secure collaboration through incentivized token mechanics
- Providing a system of reliable accountability through an immutable ledger.

The first generation of blockchain allowed people to **send value in the form of currency** to anyone in the world without a currency. Under its own right of sustainability, I ask you to think about the difference between a currency with a fixed money supply like Bitcoin versus contemporary banking practices of inflating the money supply every few years. The latter pushes people through a perpetual cycle of debt and endless consumption of frivolous goods while the former can create an economy that is more efficiently connected to all users within.

With the added capability of programmable contracts, Ethereum opens up a new realm of economic possibilities to **monetize value**. Money, such as the US dollar or Bitcoin, is a form of value, but not all value is in the form of money (Mougayar 2016). As shown by LO3 Energy, blockchains enable the valuing of a stakeholder's data and DERs, allowing for the creation of a new paradigm in energy grids. Similar creative innovation is under blockchain development in other industries that can value the effort of stakeholders as well, such as fair trade supply chains and circular reuse and recycle schemes (Staub, 2019; World Economic Forum 2020).

The future sustainable state will require public institutional infrastructure that can facilitate collaborative economies of scale, and blockchains provide a dynamic platform where governance can be locally fit, but globally aware. In conclusion, blockchain is not just technology for exchanging currencies or enabling businesses to function better, it is a driver of change to the fundamentals of our social and economic paradigms.

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9 Appendix

9.1 Consensus Mechanisms

The degree of trust within a blockchain derives from the consensus, or in other words, the degree of decentralization (Consensys 2019a). Public blockchains, such as Bitcoin and Ethereum, sacrifice performance (greater transaction speed) for greater decentralization, and therefore trust. If Bitcoin or Ethereum maintain thousands of nodes within their networks, they would already be harder to manipulate than any system in history (Consensys 2019a). Maximum decentralization would occur if every person on the planet ran a node.

Bitcoin runs on a consensus algorithm called proof of work (PoW). The nodes within this network are called miners, who are in charge of verifying the transactions within the network. Mining involves the nodes generating "hash" values based on the previous block's hash, and whichever node determines the hash below the current target for the block has solved it, and the new block can then be sent to all the other nodes for verification (Hagström & Dahlquist 2017). A hash is a function of cryptography that simply takes data and converts it into a unique alphanumeric code that can be thought of like a fingerprint ID, as pictured below. Upon consensus, the new block is added to the chain and the miner who solved the hash is then awarded in Bitcoin (Hagström & Dahlquist 2017). The environmental drawback of PoW, however, is the perpetually increasing difficulty of hashing as the chain grows larger, which incentivizes miners to invest in more computing power to secure the network and be rewarded with Bitcoin in the future. Additionally, PoW systems are liable to a reduction in decentralization due to costs of buying hardware and energy, which creates a barrier to participation in consensus for many people in the world.

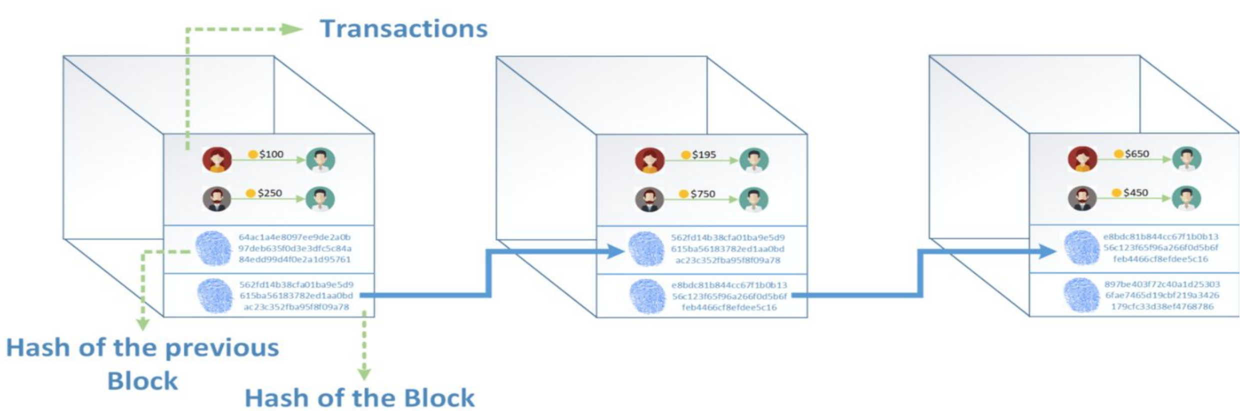

Figure 3: A visual representation of a blockchain (Haris 2019)

As pictured above, a block contains the list of transactions between users, the hash of the previous block, and the hash of the current block. In this sense, each block is linked together cryptographically in a chronological chain, hence "blockchain," a simple and secure way to store and structure data.

Another consensus algorithm, called proof of stake (PoS), is under development and is going live on the Ethereum blockchain platform soon. Since each blockchain is composed of a group of distributed nodes, there needs to be incentive for these nodes to verify transactions truthfully. The way in which a "miner" or "validator" confirms transactions and how they are incentivized is the main distinction between PoW and PoS.

PoS is a method in which nodes, or "validators" (instead of miners), will lock up their tokens in a wallet as collateral for being able to verify transactions on the network. Tokens, in this case, are "pre-mined" and are available for purchase on exchanges. This removes the need to mine the coins, which is a very energy intensive mechanism unique to PoW. Rather, validators take small transaction fees to preserve the integrity of the network. Depending on the blockchain, the PoS algorithm chooses validators based on various criteria, such as how many coins one is staking, how long they have been staked, and the reputation of the validator. If a validator acts maliciously and tries to verify an untrue transaction, his collateral of tokens is taken, a process which disincentivizes bad behavior. PoS mechanisms remove the barriers for participation that were present under PoW. The barrier for entry is low enough where nearly anyone is able to participate in validating transactions to help secure the network (Lubin 2019a).

To compare bad behavior on PoW and PoS, a malicious miner in PoW would have to possess 51% or more of the network computing power to be able to immutably verify an untrue transaction, a task that is practically impossible and still has yet to be done. In PoS, a malicious actor would have to control 51% or more of the tokens in order to immutably verify an untrue reaction.

Currently, Bitcoin's PoW mechanism consumes equal energy to the entire country of Venezuela, while Ethereum's PoW mechanism is equal to that of Zimbabwe (Digiconomist 2020). As stated earlier, Ethereum is scheduled to change its consensus algorithm from PoW to PoS, a move that will reduce its energy consumption by around 99% and allow it to scale in order to support more applications and transactions per second (Fairley 2019).

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