Blockchain and Payments for Environmental Services:

Tools and opportunities for environmental protection

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Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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IKI INTERNATIONAL CLIMATE INITIATIVE

ZMT LEIBNIZ CENTRE for Tropical Marine Research

Leibniz Association

This document shares the lessons learned during research activities associated to the MIMAC project. The MIMAC project is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH as part of the International Climate Protection Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and Consumer Protection (BMUV), in conjunction with Colombian and German counterparts.

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Foreword

Human life critically depends on a range of ecosystem services, be it, water, biodiversity or fresh air. The provision of those services is increasingly threatened due to human activity. Payments for Environmental Services (PES) are mechanisms to incentivise people to help the provision of those services. Additionally, PES can provide alternative livelihoods to environmental service providers. Instead of cutting mangroves it might pay to plant them. From this perspective, PES provide an important contribution to the sustainable use of tropical marine ecosystems, ZMT's main concern.

Small-scale PES schemes are smart because they can more directly connect users with particular environmental services (ES). Levies on using water, for instance, have been established for decades. Visitors of national parks usually pay an entrance fee. In comparison, more complex PES schemes cannot always connect ES providers and buyers. How would users pay for the value of remote wetlands, for the environmental integrity in the place of origin of fancy consumer products, or for the environmental services provided by beautiful coral reefs? The challenges in setting up appropriate schemes are almost insurmountable: high efforts of combining actors with nature's services, uneven knowledge across societies, lack of trust among relevant actors, underestimation of efforts to maintain essential services.

Against such background, blockchain offers solutions based on digitalisation and technology. If working well, blockchains allow participants to share relevant knowledge and transact in real-time and almost seamlessly. Blockchain has been tested in responsible supply chain efforts as well as in business and finance.

This book is one of the very first attempts of applying blockchain thinking to PES. Based on a PhD conducted by Julian Granados, he and Achim Schlüter undertake an excellent introduction into the technology and carefully analyze applications towards a sustainable use of natural services. Using a plain language, they explain how the technology works and introduce main terms – useful for layperson outside the world of tech. Their book goes on to discuss blockchain's contributions to environmental services, including payments across borders and viability of long-term funding. In the best spirit of ZMT they also move on to implementation issues along socio-economic dimensions and architectural design. As an additional feature, this book is short in words and rich in images – clearly an asset during our busy times.

From the perspective of tropical marine research, our wish is to see more such analysis applied to particular conditions in coastal communities across the world. With sweeping interest in offsetting carbon emissions done in the North by claiming environmental integrity in the South, proper standards are needed. A trustworthy and reliable mechanism to monitor any such activities is at stake. ZMT is well positioned to contribute to ambitious standards and to assess the quality of coastal environmental services in an integrated manner. Digital solutions will become common in the 21st century across the entire world. May this book find many readers and inspire follow-up conversations!

Prof. Dr. Raimund Bleischwitz - ZMT

Scientific Director

01.

Summary

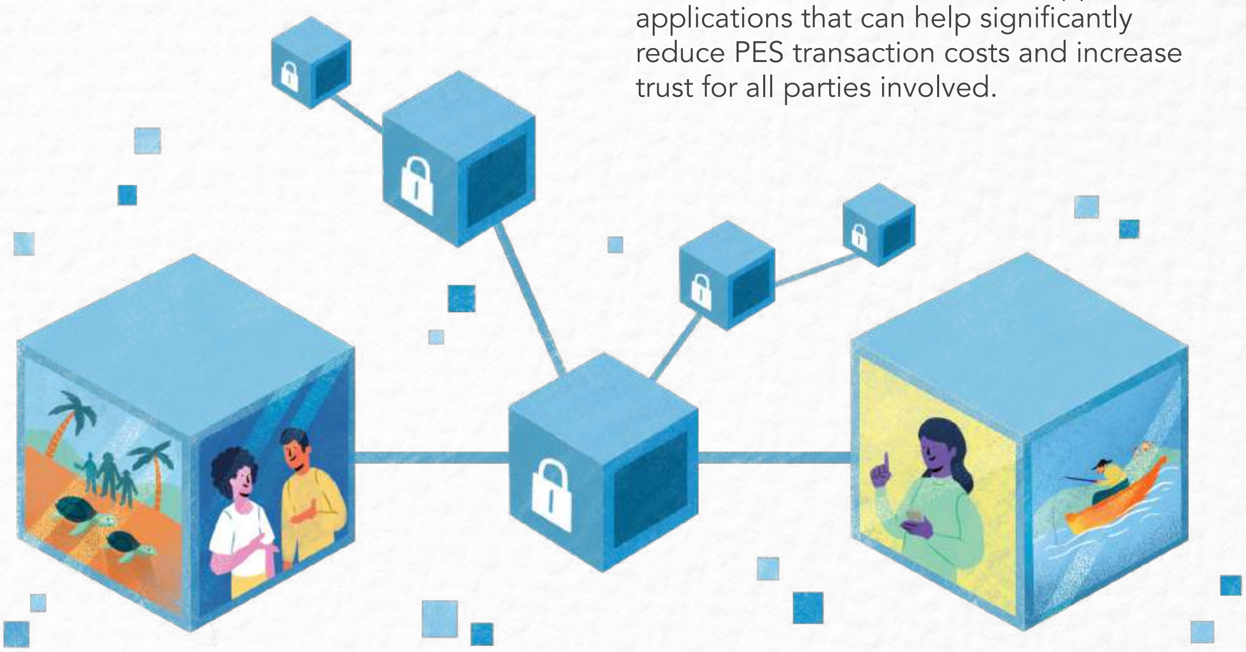
This study investigates how blockchains can contribute to improve the environmental and social outcomes of Payments for Environmental Services (PES) schemes.

Blockchains are a system of electronic records to establish a consensus around a shared digital ledger of transactions. Transactional information is recorded in blocks and chained together using cryptographic means. Blockchains were first proposed in 2008 as a technology to coordinate decentralized economic transactions through the internet.

Payments for Environmental Services (PES) are widely used incentive-altering mechanisms for influencing human activities to achieve environmental goals. They influence the payment matrix on environment-related activities by offsetting incurred costs and generating additional economic incentives for environmentally friendly activities. The received environmental payments give service-providers the opportunity to diversify their income while reducing their dependency on extractive or environmentally harmful activities. PES are a particularly relevant tool to ensure the provision of public-good environmental services, which otherwise would not be provided.

Despite increasing global demand and willingness-to-pay for environmental services, might it be by individuals or states, global PES schemes are very slow to emerge. Bulky transaction costs and insufficient institutional alternatives for conducting environmental transactions are a reason for this imbalance. Difficulties and expenses in finding a conservation counterpart, establishing contract conditions, monitoring outcomes and transferring funds hinder the establishment of such exchanges. Blockchains can help counter these difficulties.

Blockchains offer a decentralized and fraud resistant way of organising and monitoring transactions. Distributed ledgers, smart contracts (automated & only to be changed based on consensus), crypto wallets, and programmable money (which can only be spent or earned under predefined circumstances) are blockchain-supported applications that can help significantly reduce PES transaction costs and increase trust for all parties involved.



This study confronts recurring PES issues and PES design advice with potential blockchain-supported solutions and implementation-favouring tools.

Readers will also find a series of considerations to take into account when planning the usage of blockchains in PES schemes.

This study proposes that the adoption of blockchain technology could allow PES practitioners to design and implement PES schemes in ways that promise to be more effective, efficient and aligned with social co-objectives. The large transaction costs associated with deploying and maintaining reliable structures for payment, monitoring and compliance can be reduced, thus altogether lowering the costs of PES implementation and increasing the incentives for conservation.

Disintermediation and increased contractual automatization can open the door to new governance structures for peer-to-peer environmental transactions and for the appearance of new market-like structures for environmental service.

02.

Introduction

The natural environment "contributes to good quality of life in many ways, from providing the basic life support system for humanity to providing material goods and spiritual inspiration" (IPBES, 2019a; 317). Yet, humans are managing natural resources in an unsustainable way. "Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide" (IPBES, 2019b; 10). Our impact on the ecosystems and on the climate is unprecedented. It is now unequivocal that human influence has warmed the atmosphere, and is contributing to the destabilization of natural processes (IPCC, 2021). It therefore seems important to promote alternatives that contribute to the sustainable management of natural resources, upon which the provision of nature´s services depend.

The American botanist and ecologist Walter Emil Westman formulated the concept of nature´s "services" in 1977 (Westman, 1977). What is the value that societies adjudge to benefits they perceive from nature? How much is a flower worth to a poet? How much are clean air or untamed wildlife worth? Despite considering these questions to be "safely relegated to the realm of the unanswerable", (Westman 1977: 960) Westman acknowledged the importance of accounting for nature´s benefits in order to establish an objective basis upon which to support decision-making processes. His statement that "measuring the social benefits of ecosystem functioning is both controversial and illuminating" (Westman 1977: 960) seems to hold true until today and is reflected in scientific and political debates about ecosystem services.

The concept of ecosystem services denotes ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing (Costanza et al., 1997). The concept of environmental services (ES) underlines the idea that the provision of many services provided by nature often depend on human contributions. Such human contributions are thus environmental services.

Many ecosystem services are public goods supplied by nature. They cannot be transacted in markets and have therefore no market value. This lack of market value leads to gradual degradation, particularly when degradation is associated to a profitable activity that brings high private gains.

One instrument to correct this market failure are payments for environmental services (PES)[1]; mechanism to internalize the cost of providing environmental services and outweighing the opportunity costs associated to their provision.

Engel (2016; 133) defines PES as "positive economic incentives where environmental service providers can voluntarily apply for a payment that is conditional either on ES provision or on an activity clearly linked to ES provision".

By offsetting incurred costs and generating additional economic motivations for providing environmentally friendly activities, PES incentives compensate parties providing an ES and encourage participants who would otherwise not consider providing it.

Some PES initiatives are environmentally asset building (e.g., planting mangroves), while others reduce detrimental activities (e.g., avoiding deforestation). PES schemes can thus compensate actors for contributing to the provision of positive externalities (harnessing ecological processes for providing public goods) or for avoiding negative ones.

PES schemes can also be categorized in those that compensate an input activity (e.g. paying for constructing protective barriers around sea-turtle eggs) or those performance-based that compensate ES outputs (e.g. paying for the amount of turtle hatchlings that reach the ocean).

Although PES are not a panacea to address all environmental problems (Engel, Pagiola, & Wunder, 2008), they are important tools for changing incentive structures in favour of providing public goods. They help distribute the economic burden of environmental service provision between those who perceive their benefits.

Wunder, Börner, Ezzine-de-Blas, Feder, and Pagiola (2020) argue that despite the obvious shortcomings of PES schemes, the available scientific studies still show higher positive environmental impact rates for PES schemes than for most other management instruments.

As they propose: "Surely, this beauty contest of conservation impact evaluations is still not a pretty sight…, but now PES might just aspire to be crowned as the least ugly of the listed candidates" Wunder et al. (2020;19).

1 Derissen and Latacz-Lohmann (2013) highlight that payments are made for environmental services and not ecosystem services because of their man-made nature.

Distribute Ledger Technologies (DLTs) are systems of electronic records to securely establish a consensus around a shared digital ledger of transactions without necessarily relying on a coordinating central authority (Rauchs et al., 2018). Blockchains are a subset of DLTs that bundles transaction-information in blocks[2].

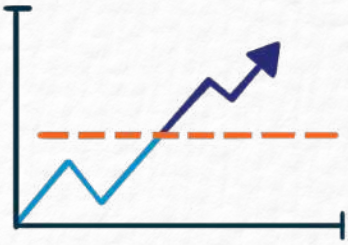
This publication offers an overview of the tools offered by blockchains and Distributed Ledger Technologies (DLTs) for improving the performance of PES schemes.

We here highlight how blockchain-supported applications can be harnessed to achieve better PES outcomes. In doing so, it aims to provide guidance for those interested in improving current PES schemes and exploring the possibilities of blockchain technologies.

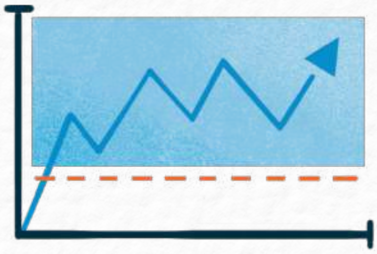
Davidson, De Filippi et al. (2018) and Berg, Davidson et al. (2019) propose that blockchains are to be understood as a new type of institutional technology that offers new alternative forms of economic organization alongside markets and firms. As such, they open the door to new institutional options for coordinating transactions and interactions. They offer individuals, organizations and companies new governance structures for organizing their activities towards a common goal. The various applications that emanate from them can be harnessed to increase the chances of PES *success*.

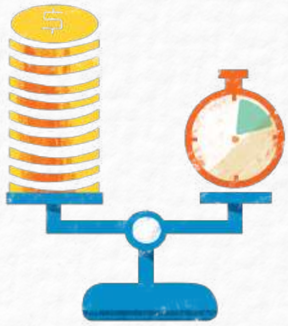
2 Blockchains are currently the best-known type of DLT structure. While other types of DLT structures are quickly gaining relevance, blockchain remains the DLT type that attracts most attention. This study thus refers to blockchains for simplicity.

What is understood under ***success*** highly depends on the initial objective of the PES scheme. Grima, Singh, Smetschka, and Ringhofer (2016; 26) define PES success as "a combination of (a) the extent to which the original or defined goals of the PES scheme were met, and (b) the added value in terms of an overall improvement of the ecological, economic and social conditions of the region, beyond intended objectives".



Most PES reviews associate *success* to environmental ***additionality*** (e.g. Engel et al., 2008; Ezzine-de-Blas, Wunder, Ruiz-Pérez, & Moreno-Sanchez, 2016; Wunder et al., 2020). *Additionality* refers to the difference in provision of the ES between a PES scenario and a hypothetical baseline representing the status quo (Wunder, 2005). Additionality is typically the most relevant characteristic of environmental success.





Permanence of results is also commonly related to PES success. Any environmental improvement that is reversed after a certain period of time is not additional in the long run. *Permanence* refers to the assurance that environmental service provision paid for is not reversed in the future and non-permanence can be understood as *leakage*[3] in time (Engel, 2016).

Effectiveness and *efficiency* are other criteria commonly used as measurement of PES success.

Efficiency is thus related to the relative cost at which the additional ES provision is achieved. Payments above the minimum amount that suppliers are willing to accept reduce the efficiency of PES programs through reducing the maximal ES provision that can be achieved through a given budget (Paul J. Ferraro, 2008). Although efficiency is a laudable economic goal, authors such as Muradian et al. (2013) have invited to caution in exclusively pursuing economic efficiency since it often comes at the expense of other relevant dimensions of PES design, such as equity and broader ecological functions.

Effectiveness is given if the PES scheme delivers the environmental benefits it is designed to achieve. For Börner et al. (2017;360), environmental effectiveness is defined "as the change in provision of services induced by the program, compared to a counterfactual without PES". To be *efficient*, a scheme must be able to deliver a level of ES provision at a lower cost than alternative policies .

The ***Attainment of social co-objectives*** and the *equitable distribution of benefits* are also considered components of PES success (Adhikari & Boag, 2013; McDermott, Mahanty, & Schreckenberg, 2013; Pascual et al., 2014).

Equity of PES has been portrayed as a social goal in itself, but an equitable distribution of PES disbursements is also associated to the sustainability of the schemes. In cases where stakeholders perceive benefits to be equitably distributed, the chances of continuous participation and permanence of results increases.

3 Leakage refers to "impacts of a PES intervention on its target variables occurring outside its spatial scope of action" (Wunder et al. 2020; 13). The following section on issues and obstacles handles leakage in more detail.

This study acknowledges the diverse characteristics related to PES success and tries to understand whether blockchains can take us one step further in any of these directions. The one characteristic which is here highlighted as indispensable to PES success is environmental additionality. The primary objective of PES, is sustainable environmental management. If this objective is not met, PES schemes lose their existential reason.

In general a PES scheme can be considered successful if it leads to the provision of additional environmental services on a permanent basis, in an effective, efficient and equitable manner.

The ideas of Transaction Cost Theory and Institutional Crypto-economics are here harnessed to better frame how blockchains can influence PES schemes.

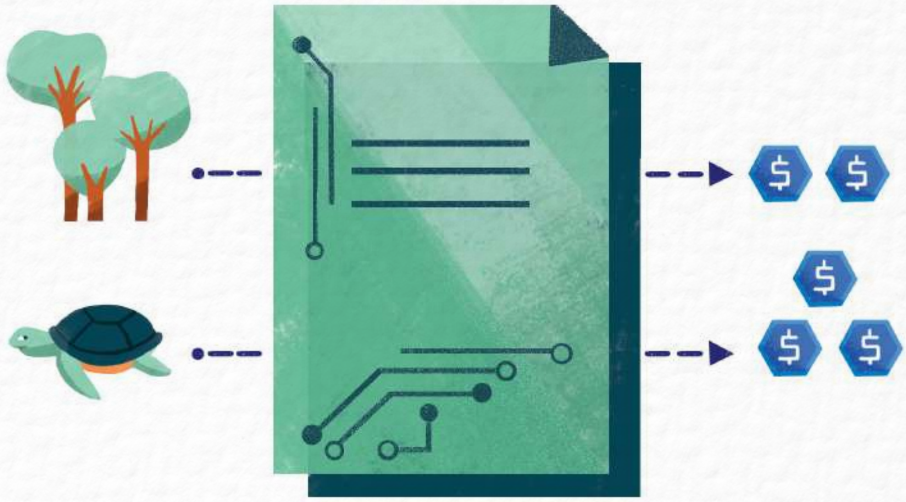
For Transaction Cost Theory the costs associated to facilitating transactions are the cornerstone of institutional design[4]. **Transaction costs are "the resources used to define, establish, maintain, and transfer property rights" (McCann, Colby, Easter, Kasterine, & Kuperan, 2005), or the "comparative costs of planning, adapting, and monitoring task completion under alternative governance structures" (Williamson 1989; 142). In relation to PES schemes, transaction costs have been residually defined as all costs associated to the scheme that are not part of the direct compensation for ES provision (Wunder, Engel, & Pagiola, 2008).**

Transaction Cost Theory helps understand PES issues and blockchain-supported solutions, because some of the most prominent issues in the development of PES schemes are related to the high transaction costs experienced when trading environmental services against money. Transaction Cost Theory further proposes that the institutional setting in which a transaction occurs has direct implications on the costs associated with the exchange of goods and services. The underlying proposition is that economic institutions should be shaped so as to reduce transaction costs and facilitate transactions (Williamson, 1985).

Institutional crypto-economics proposes that blockchains are a new institutional technology that offers new coordination mechanism for managing the common economic activities between a network of participants. They are a new category of governance institutions which facilitates the pursuit of diverse objectives using within a framework of rules established in the code of the blockchain (Davidson, De Filippi, & Potts, 2018) (Berg, Davidson, & Potts, 2019)

Transactions in such institutional alternatives are secured by the self-executing security of smart contracts **(computer scripts that when triggered by a given input, automatically execute a predefined output).** They occur in a type of collaborative organization based upon an accounting backbone: the blockchain ledger. Self-executing digital contracts act as safeguards that reduce the dangers posed by opportunism. Participants to a transaction are less exposed to opportunistic behaviours, because the automatic execution of agreements is secured through a technology that obeys a clear causal relation between a given input and a pre-established output. Additionally, given that any opportunistic activity remains coded on the blockchain for everyone to see, the private costs of behaving opportunistically increase.

4 Institutions in this sense are understood as "the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction" North (1990;3) or as a special type of social structure that helps shape expectations about how others are going to behave under given circumstances and, in doing so, they both constrain and enable behaviour, impose consistency on human activities and change aspirations (Hodgson 2006).



Using a distributed ledger, fully independent actors or individuals can operate as one vertically integrated organisation using blockchain technology to coordinate their interactions on a common purpose. Blockchains thus expand the set of available institutional and organizational arrangements of various types of transactions including PES.

Buterin (2015) proposes that "blockchains are not about bringing to the world any one particular ruleset, they're about creating the freedom to create a new mechanism with a new ruleset extremely quickly and pushing it out. They're Lego Mindstorms for building economic and social institutions." Such freedom to create institutional frameworks will facilitate the transaction of environmental services.

> Despite the various tools that blockchains offer to improve PES schemes, it is important to underline that they are no silver bullet to immediately improve the environmental outcome of all PES schemes. The impact of their utilization will highly depend on the ecological and socio-economic characteristics framing the PES scheme and the intrinsic shortcomings of blockchains as a digital technology.

As an example, it is still unclear whether blockchains´ contributions for facilitating market transaction for environmental services can lead in some cases to the displacement of non-market incentives for environmental protection. In such cases, their utilization can lead to a marketization of ES that supplants sustainable traditional practices for environmental protection.

Additionally, some of the benefits of blockchains, such as increasing trust through contract digitalization and automatization might only apply under the premise that the possible eventualities of PES contracts can be foreseen. For scenarios where relevant eventualities cannot be glimpsed prior to contract signing, classical intermediation and arbitration mechanisms are indispensable, thus reducing the benefits of implementation.

Also, the energy consumption associated to certain blockchain validation processes is very high and may run counter to the environmental objectives of some PES schemes[5].

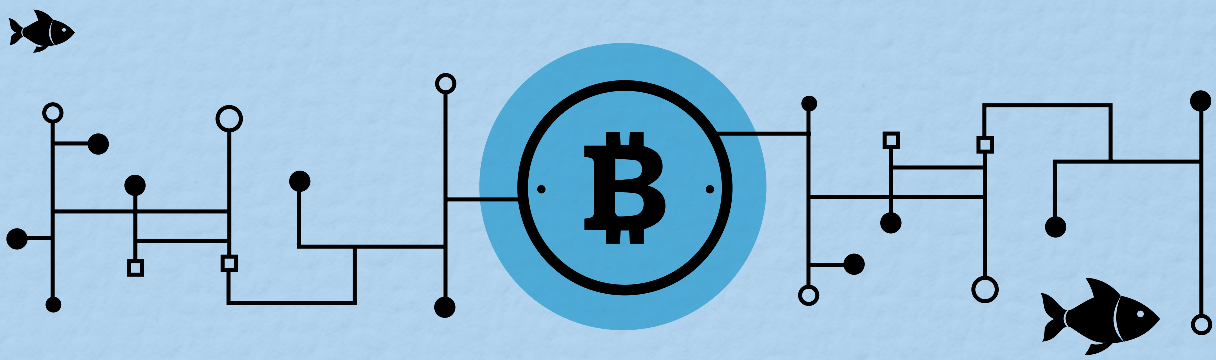
> This study does therefore not plead for the implementation of blockchains in PES schemes. It merely seeks to shed light on the potential benefits that arise with blockchain from an institutional economic perspective. Any decision regarding the benefit that might emanate from implementation is strictly dependant on the context on which it will operate.

The appearance of the first blockchain-supported PES schemes in the coming years will teach us more about the benefits and shortcomings of blockchain implementation.

5 High energy consumption in the form of electricity is typical for certain blockchain architectures. New architectural alternatives rely on alternative mechanisms that are less energy intensive.

03.
Blockchains and DLTs:
A short introduction

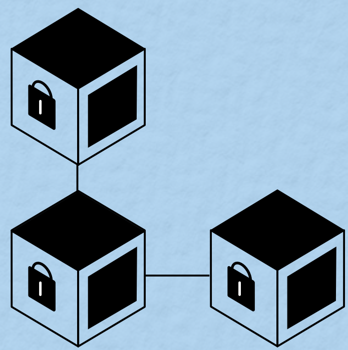
2008 ▶ Nakamoto and Bitcoin



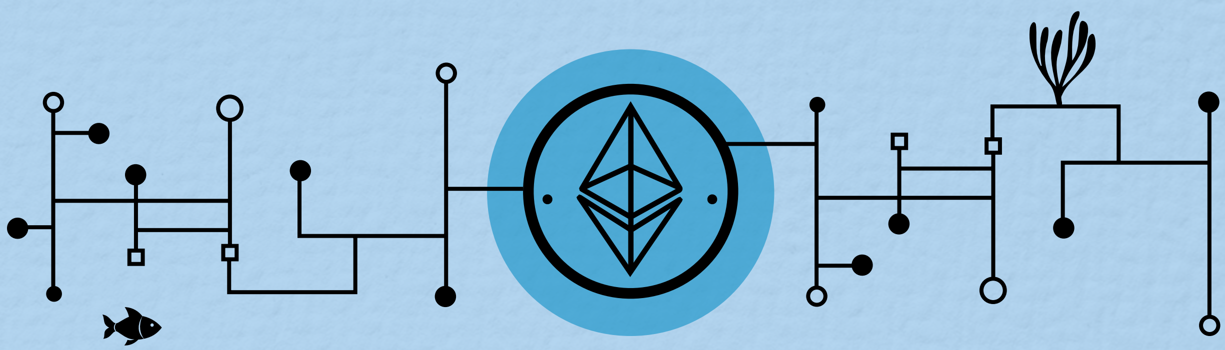
On October 31, 2008, at the midst of the global financial crisis, a paper written under the pseudonymous of Satoshi Nakamoto (Nakamoto, 2008) was released proposing a purely peer-to-peer version of electronic cash that allowed online payments to be sent directly from one party to another without going through a financial institution. This paper gave birth to the cryptocurrency Bitcoin and to a cascade of projects based on decentralized electronic transactions. It marked the beginning of blockchains and DLTs as we know them today.

Nakamoto´s whitepaper offered a handbook for the creation of a fully functioning, decentralized digital currency system. It proposed a combination of technologies around a common ledger of transactions that was secured though cryptographic mechanisms and game-theoretical incentive mechanisms. What began as a virtual currency, has developed into a countless amount of projects that seek to revolutionize the way people and organizations transact and interact.

Rauchs et al. (2018; 24) describe DLTs as "A system of electronic records that enables a network of independent participants to establish a consensus around the authoritative ordering of cryptographically validated ('signed') transactions. These records are made persistent by replicating the data across multiple nodes and tamper-evident by linking them by cryptographic hashes. The shared result of the reconciliation/consensus process - the 'ledger' - serves as the authoritative version for these records".



2015 ▶ The appearance of Ethereum

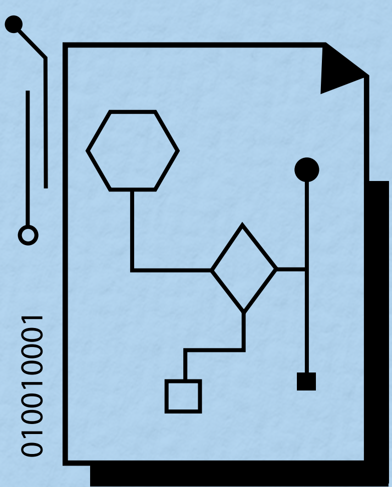


The appearance of ethereum, a distributed computing platform, arguably represented another milestone of blockchain development. Ethereum allowed applications to be built upon a blockchain ledger.

Ethereum went a step further than the first generation of blockchains, such as Bitcoin. It provided a general purpose platform (a virtual machine) that facilitates the design and execution of a large variety of programmatically executed transactions known as smart contracts[6]. The Ethereum Virtual Machine (EVM) serves as a decentralized world computer that maintains the uncorrupted state of all transactions in the Ethereum network and provides the infrastructure to maintain a unique canonical state of balances. All participants to the Ethereum blockchain make part of this virtual machine and contribute to the network or profit from it in different ways.

While early blockchains were designed uniquely to maintain the state of account balances, they provided no support for programmable transactions and offered few options for managing additional data, or serving other purposes (Xu et al., 2017). Ethereum´s programmable infrastructure provided an environment for the development of smart contracts that "can express triggers, conditions and business logic to enable more complex programmable transactions" (Xu et al., 2017; 244). In doing so, Ethereum facilitates the digital transfer of non-financial assets and maintains the state of all smart contracts in the network.

Some studies have been dedicated to elucidate how blockchain technologies can influence environmental policies and contribute to environmental sustainability (e.g. Chapron, 2017; Le Sève, Mason, & Nassiry, 2018; PwC, 2018). This study describes how blockchain technologies are likely to influence PES schemes´.



6 Smart contracts are handled in detail in the coming sections of this chapter. They are computer scripts that when triggered by a given input, automatically execute a predefined output.

Blockchain: basic classifications

Blockchains have been divided according to multiple criteria. A simple and recurring characterization divides them in private, public, and hybrid blockchains.

Public networks

Are portrayed as fully accessible networks. Anyone who wishes to participate in one, can do so without restriction. Transactions in public networks can be validated, read and written by any participant, with no exception. All network members have equal rights and they can join and leave the network freely. Participants choose the depth of involvement they assume in the network, with some assuming validating activities, contributing to governance decision taking, or participating as simple users. Validating participants receive incentives for incurring the costs of securing transactions.

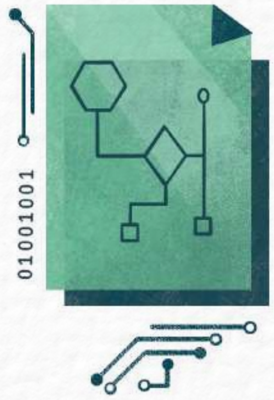
Private networks

Are described as invitation-only groups where access rights are restricted. Members typically require authorisations to either read transactions, propose them and/or validate them. Such authorizations are provided by appointed authorities. These authorities grant participation-rights and thus exercise some control over the data structures. They also play an institutional role as gatekeepers. Consensus is reached through a somehow centralized process where authorities have the final word on the authoritative version of records. Due to the existence of such an intermediary, the degree of decentralization of a private blockchain is low. The concentration of power in intermediary structures can lead to less transparency, security and immutability. The centralized structure is also more prone to manipulation, leading to a lower resistance to collusion and abuse of power. Yet, private blockchains can complete more transactions per unit of time, increasing performance. The existence of central authorities can also facilitate arbitration instances.

Hybrid networks

Elements of both public and private networks are found. Hybrid structures are partially open and accessible to the broader public, with coordination being often assumed by a group of leaders. There are various types of hybrid networks. A common example of such networks are permissioned-public blockchains which allow free viewing access for all users, while the right to propose and validate transactions is restricted to some selected participants. In such common hybrid structures, transparency is granted and proposing transactions is unrestricted, while transaction-validation is restricted and rights are granted by a leading consortium. Behaving against network rules implies exclusion from the network, which incentivises pro-network behaviour.

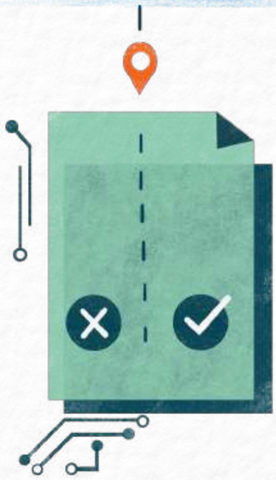
Smart contracts



Programmatically-executed transactions, also referred to as smart contracts, were first proposed by the cryptographer Nick Szabo as a computerised protocol that executes the terms of a contract and satisfies common contractual conditions automatically (Szabo, 1994). They are computer scripts that when triggered by a given input, execute a predefined output.

The execution of each contract statement is recorded as an immutable transaction stored on the blockchain. When the code operates accordingly to the intentions of all parties, "the deterministic nature of the execution reduces the level of trust required for individual participants to interact with each other" (Rauchs, Glidden et al. 2018; 37). Their usage reduces the risk of error, manipulation and non-compliance. In doing so, they can reduce enforcement- and monitoring-related transaction costs. The likelihood of legal disputes over contract compliance will be largely reduced.

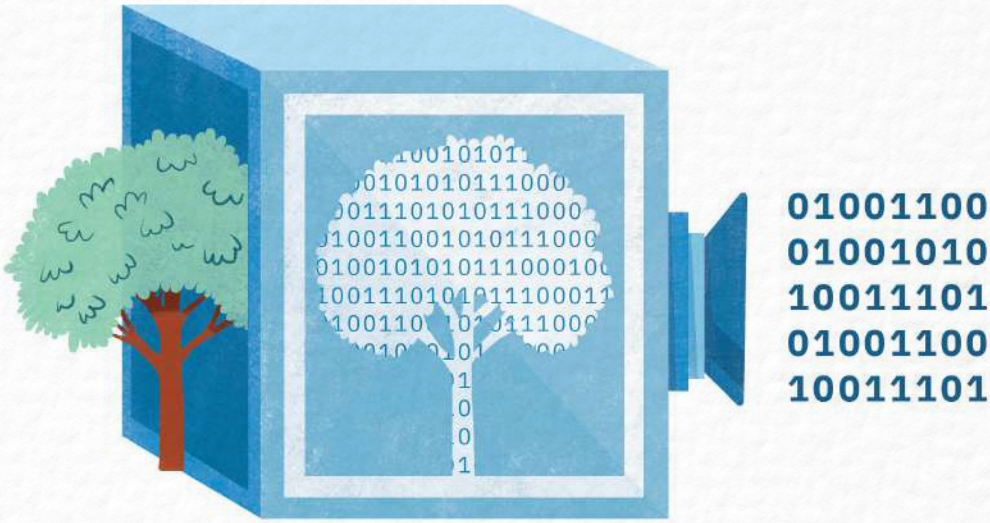
In a PES related example, a fisher who incurs costs with the creation of a marine protected area could receive economic PES incentives for fishing outside the protected area and thus contributing to biodiversity protection. The fisherman's boat can be marked with a GPS that determines his fishing coordinates. If the GPS dictates that the fishing journeys have been carried outside the protected area, a smart contract can use this information to automatically trigger compensation payments. If the GPS shows fishing journeys within the protected area, these compensations are not granted. This happens automatically without further involvement of intermediaries. Digital currencies or tokens could be harnessed to facilitate such payments.



Jani (2020) highlight a series of benefits of smart contracts when compared to conventional contracts. These benefits include: compliance risk reduction; higher traceability and auditability due to inalterability of smart contracts; administration- and service costs reduction due to less costs associated with intermediaries and mediators; increased efficiency originating from reduced intermediaries and middlemen; accuracy increase through manual errors reduction; lowers the risk of manipulation, non-compliance or errors due to decentralized execution; cost reduction through automatization; and new business models supported on reliable transactions at low cost.

These are indeed valuable benefits, yet, for complex, high value transactions, for which multiple unfolding scenarios are difficult to anticipate and the respective appropriate contingency measures are difficult to implement, automation of contracts in digital smart contracts will be difficult to realize. Traditional contract governance institutions will remain indispensable for securing smart contract governance arrangements.

By providing the mechanisms to automatize contract execution through digital means, smart contracts are likely to first impact the low-hanging fruits of PES schemes, where information can be digitalized and contracts are not overly complex. This is likely to reduce transaction costs, including the costs associated to maintaining institutions to generate confidence among stakeholders.



Oracles

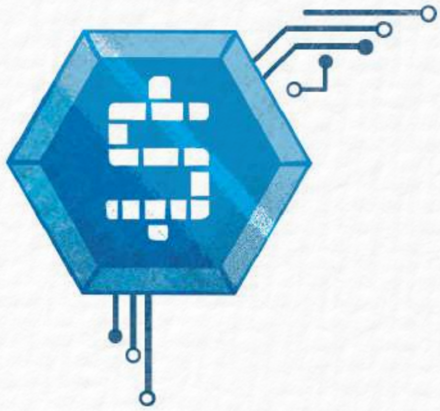
Blockchains require a mechanism to integrate real-life information into the digital realm. Blockchain records may reference internal, endogenous information (such as a native crypto-currency), or external, exogenous information foreign to the system (such as information on the weather). A prerequisite for the integration of exogenous real-life information into the digital realm of blockchains is the effective development and implementation of so-called *oracles*.

Oracles are gateways that bridge the gap between the blockchain system and external systems by serving as sources of information (Rauchs, Glidden et al. 2018). They are third party mechanisms to feed the digital world of blockchains with offline information. Oracles provide gateways through which real world information on assets, facts, events, problems, etc... can find its way into the blockchain. They request, verify, and authenticate external information before communicating it to the blockchain.

PES schemes require trustable oracles for translating information on the managed natural resources and on the provided environmental services on bits and bytes. Developing a reliable oracle system is key to ensure the quality of information upon which the schemes´ decisions are taken.

All information that gets uploaded to the blockchain via a valid oracle cannot thereafter be altered or deleted, because blockchains (particularly public, permission-less ones) are mostly immutable and tamperproof. Information is taken as a valid given once it is uploaded. It is therefore important for oracle mechanisms to transmit reliable, valid and correct information. This is particularly relevant given that such systems obviate intermediaries, who otherwise help maintain a certain data-quality level in the system. Data quality controls play an important roles in designing oracle mechanisms.

For blockchain information that references exogenous objects, enforcement depends on external agents and relies on legal and socio-economic structures or other arrangements outside of the DLT system (Rauchs et al., 2018).



Tokens

Cryptographic tokens are digital representations of assets or access rights that are managed by a smart contract in a DLT supported ecosystem (Voshmgir, 2020). Tokens serve various purposes in blockchains depending on their characteristics and their role in the DLT system.

The Swiss Financial Market Supervisory Authority (FINMA 2017) categorizes tokens based on the underlying economic function of the token. They distinguish between payment tokens, utility tokens, and asset tokens.

Type of Tokens

Payment tokens

(Also commonly known as cryptocurrencies) are, as their name implies, intended to serve as simple means of payment. They serve a similar function in value transfer as money.

Utility tokens

Allow participation to an application or service in a given blockchain ecosystem. Their underlying purpose is to confer digital access rights to an application or service. They are like the tickets that allow participation in a fair. Once you have them, you can access the possibilities that the fair offers and can vote on decision-making processes. If, for example, a blockchain is used to coordinate elements of a PES scheme, utility tokens can be programmed to represent voting rights on the scheme.

Asset tokens

Are digital representations of various types of assets (e.g. forests, a house, fishing grounds, land). They represent ownership of an asset, debt or form of equity. The value of the conferred token depends on an underlying represented asset. Ownership rights to a particular area, where the ES is produced could be proven with the help of asset tokens.

An alternative categorization of tokens is based on the degree of endogeneity (Rauchs et al., 2018). Tokens are thereafter endogenous, exogenous or hybrid.

Type of Tokens

Endogenous tokens

Are contained within the system and are used to finance transaction fees and align the incentives of participants, particularly those of validators who are compensated in endogenous tokens for securing transactions. The network protocol foments trust between participants by a coherent strategy of motivation alignment in which tokens serve as the incentive for honest participation. Through a game theoretical approach, public, and permission-less blockchains reward privately maximizing actors with endogenous tokens for validating transactions and securing the network. Such is the case of Bitcoin nodes who incur costs in electricity and computing equipment to validate network transactions and receive endogenous Bitcoins as compensation for their efforts.

Exogenous

Exogenous accounting tokens are used for recordkeeping purposes (i.e. tracking real life objects). Enforcement is entirely dependent on gateways and off-chain processes.

The use of exogenous tokens requires assets to be *tokenised*. *Tokenisation* refers to the process of giving rights to tangible assets with economic value to a virtual representation in the form of a digital token that can be handled in a blockchain. These *tokenised* assets can be managed through smart contracts, which enables the automatization of procedures, cost reduction and increases visibility and predictability of transactions.

Through tokenisation, transactions can profit from some blockchain-related advantages such as immutability, transparency and lower transaction costs. The global and digital nature of blockchains also eliminates territorial barriers and facilitates transactions beyond national jurisdictions, of particular importance, when thinking about global PES schemes. Tokenised assets can also be subdivided into arbitrarily small parts increasing their liquidity, and permitting more market participants to hold fractional ownership of assets (Swan, 2019).

Programmable money and escrow services

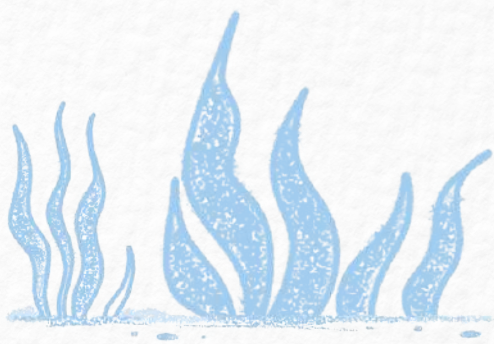
"Smart money, or programmable money, is digital money that can be programmed to be spent only when certain conditions are met… Once programmed, smart money can know who it can be spent by, what it can be spent on, when it can be spent, how much of it can be spent and any other conditions that may be set by the party funding the payment. As smart money is designed not to be misspent, it can reduce friction and enable funders to empower spenders in conditional payment environments" (Royal et al., 2018; 5-6).

Programmable money respects conditions that limit its liquidity and increase the control that can be exercised over its use. Policies for programmable money can be linked directly to the money itself. For example, programmable money can be coded to make sure that up-front payments for the provision of an ES can only be spent for the inputs needed to provide the service.

Such digital payments increase money´s conditionality and link the condition directly to the value carrier itself. This increases the traceability of resources and the flexibility to quickly adapt conditions.

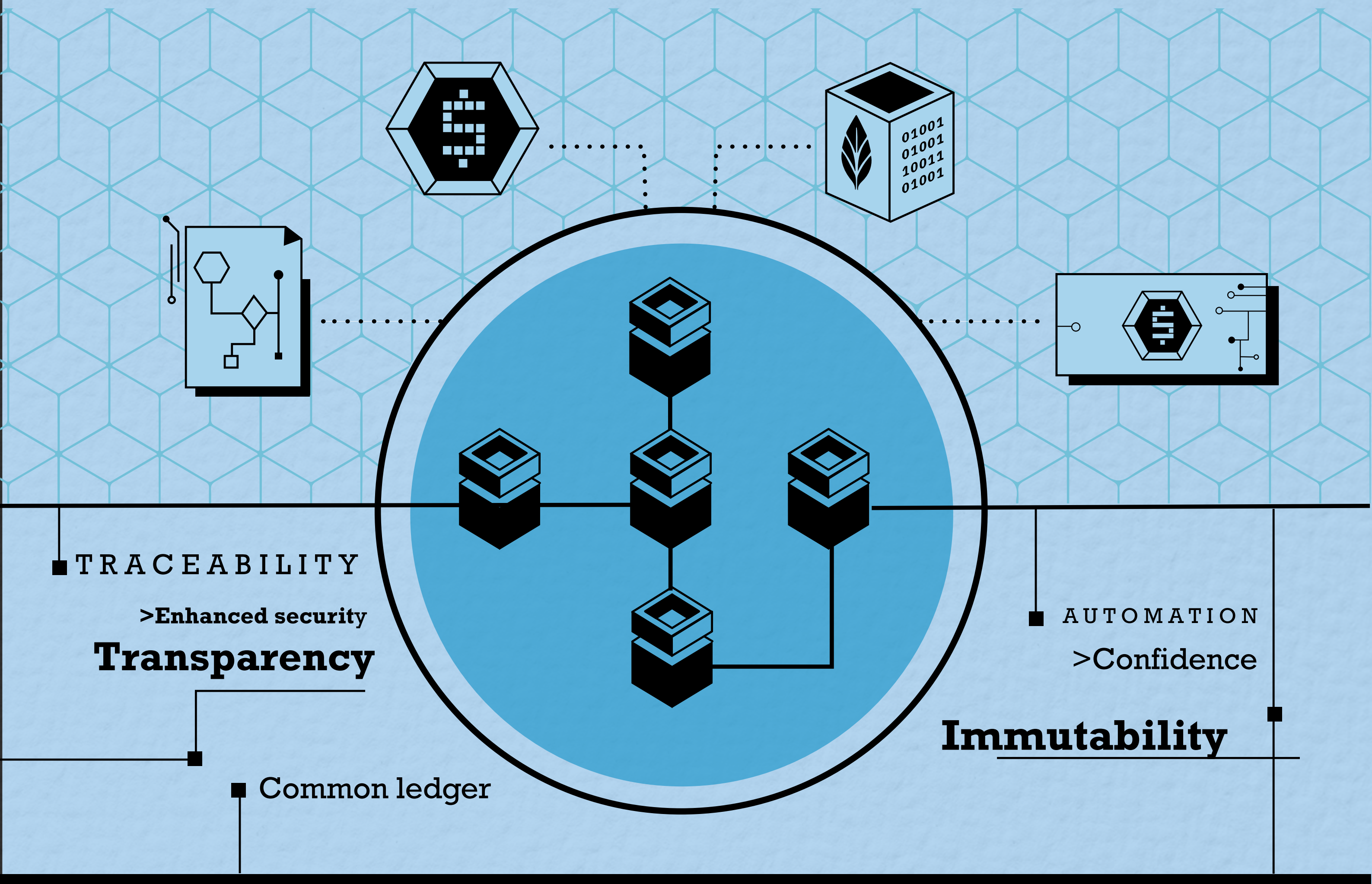
Programmable money thus opens the door to new degrees of conditionality and monitoring. While compliance on conditionality for money spending is today guaranteed post transaction, programmable money can guarantee that conditions are complied-with prior to any transaction.

Blockchain-based escrow services, are escrows that hold resources in distributed ledgers. Smart contracts can be used to automatically manage escrow funds according to pre-established criteria. A blockchain escrow service that is guided by code on a smart contract is bounded to automatically retain or release fund according to the predefined conditions, irrespective of external fluctuations. This is likely to increase confidence in such mechanisms, while at the same time reducing the administrative and transaction costs of escrow services.



A recount of blockchain benefits

Various benefits emanate from the utilization of blockchain technologies. These are a function of the architectural options that characterize them.



These benefits include a greater accounting transparency through distributed ledgers and the possibility of viewing all transactions; enhanced security through the use of cryptographic tools; improved traceability, and increased automation from smart contracts.

Xu et al. (2017) highlight additional beneficial properties supported by blockchains: immutability and non-repudiation. Information added to the blockchain becomes immutable due to its append-only structure and to the cryptographic safeguards that protect the information from unpermitted alterations. In turn, the immutability of transactions, together with the identification offered by digital signatures, results in non-repudiation of actions. Cryptographic security also helps protect the integrity of data.

Because of these benefits, blockchains have been described as being a technology of trust (Werbach, 2018). A transparent, immutable, common ledger, together with self-executing smart contracts, restricts the room for opportunistic behaviour.

By automatizing executive procedures, blockchain-enabled smart contracts reduce post-contract disagreements. Smart contracts are self-enforcing. Once triggered, they will execute without the interference of the contracting parties. This reduces costs associated to fraud and enforcement, and eliminates issues of ex-post opportunism (Szabo, 1994). Disputes that rely on court arbitration are reduced, thus sinking transaction costs.

De Filippi, Mannan, and Reijers (2020) advanced research on blockchain and trust by proposing that blockchains are not trust-producing mechanisms, but instead "confidence machines". Confidence relies on building a predictable cognitive state of expectation derived from progressively gathered experience and accumulated knowledge.

De Filippi et al. (2020; 6) thus propose that blockchain-based systems "are intended to produce 'confidence' in a particular system—not by eliminating trust altogether, but rather by maximizing the degree of confidence in the system as a means to indirectly reduce the need for trust. Such a higher degree of confidence allows transactions to take place more easily, by reducing the perceptions of risk associated with these transactions".

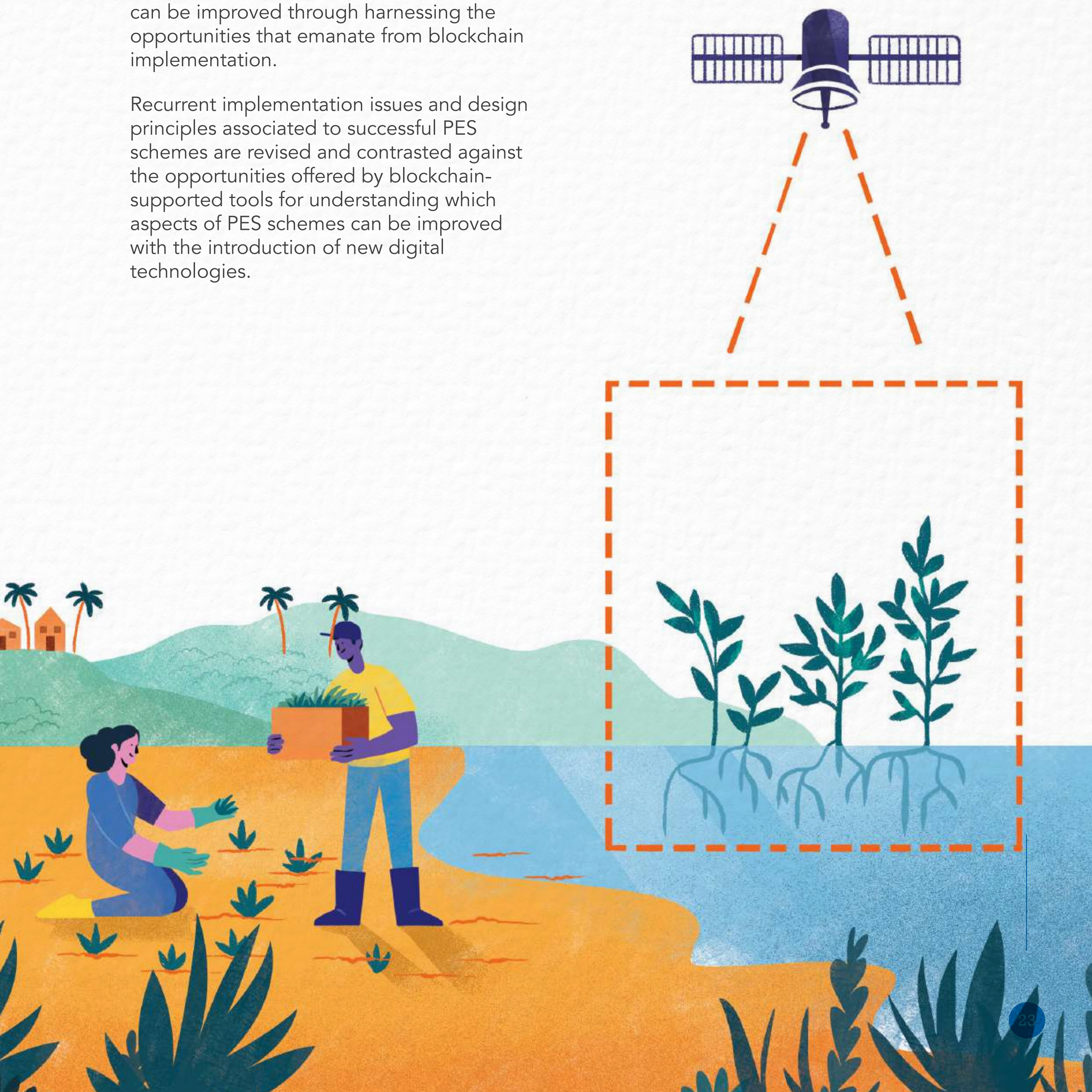
> Confidence in blockchain-based systems is understood as confidence in the mathematical rigour of the hashing algorithms and confidence in the economic incentives that lead participants to act in favour of the network, so as to maximize their private financial rewards.

04.

Blockchain´s contributions to PES implementation

This section highlights how PES schemes can be improved through harnessing the opportunities that emanate from blockchain implementation.

Recurrent implementation issues and design principles associated to successful PES schemes are revised and contrasted against the opportunities offered by blockchain-supported tools for understanding which aspects of PES schemes can be improved with the introduction of new digital technologies.

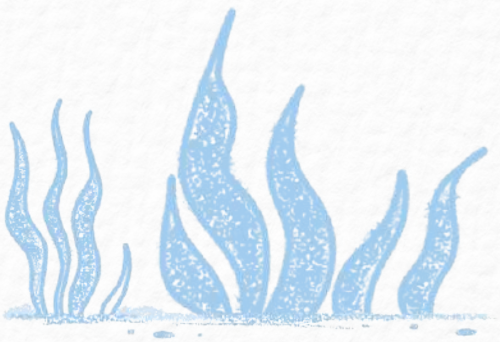


Transaction-costs reduction

Transaction costs are a recurring obstacle of PES schemes. High transaction costs consume resources otherwise available to finance additional ES provision and are thus often blamed for reducing the positive impacts of PES schemes. Transaction costs also obstruct the appearance of direct PES schemes and make participation less attractive for both ES buyers and ES providers.

PES transaction costs are all costs associated to the scheme that are not part of the direct compensation for ES provision (Wunder et al., 2008). Jack, Kousky, and Sims (2008) understand transaction costs as the expenses of negotiating contracts, perform scientific baseline calculations, and conducting monitoring and enforcement activities. Costs associated with the negotiation of PES contracts include: efforts in organising and connecting buyers and sellers, assessing pre-scheme practices, designing contracts, filing documents, and implementing project related decisions (Adhikari & Boag, 2013).

From all transaction costs, monitoring costs are often among the highest of PES schemes (Gjertsen et al., 2016). They include the costs of certification, and the monitoring of contractual obligations of providers and buyers. Participants to a PES scheme must invest large amounts of money in securing the system. Monitoring the activities of contractual partners is a necessary evil that consumes a good part of available funds.



Transaction costs lead also to negative social outcomes, such as reduced participation of vulnerable groups. Adhikari and Agrawal (2013), Pagiola, Rios, and Arcenas (2008, 2010) have shown that high transaction costs are one of the main barriers impeding participation in PES schemes of poor ES providers and small landholders. Contracts with large ES providers reduce the amount of involved parties and thus the administrative (transaction) costs associated to contracting. This generates incentives for ES buyers and intermediaries to exclude small participants that can only provide small amounts of ES. Maintaining relations with better-off, large scale providers turns out to be cost-effective under high transaction costs of participation, which leads to the exclusion of the poor. For their study on a silvo-pastoral PES project in Nicaragua Pagiola et al. (2008;2) affirm that since transaction costs are largely per contract rather than per unit of environmental service provision, schemes "find it attractive to focus on large land holdings. Keeping transaction costs low—in addition to being desirable in itself—is thus imperative if poorer households are not be shut out of many PES programs".

Additionally, transaction costs are a main impediment for the appearance of direct PES schemes in which ES buyers and ES providers transact environmental services directly. Transaction costs generate transactional friction and makes exchanges so expensive that the potential benefits of transacting are lost. Some PES schemes that could potentially lead to improving living standards and protecting natural resources thus never come to happen due to the high costs of arranging, maintaining and securing the supporting institutional PES setting.

Transaction costs can be reduced through creating institutions that minimize transactional friction (Williamson, 1981, 1985, 1998). An institutional setting with low transaction costs is also one of the main characteristics favouring the scaling up of PES schemes (Salzman, Bennett, Carroll, Goldstein, & Jenkins, 2018). A main reason why government-run water PES schemes have scaled over the last years is precisely the presence of existing institutional structures that reduce the transaction costs associated to gathering resources from ES beneficiaries and distributing them to ES providers (Salzman et al., 2018).

Blockchains offer various tools for reducing PES transaction costs. By reducing financial intermediary costs, transfers of value through blockchain networks can reduce financial transaction costs to a fraction of existing alternatives for national and international transactions.

Financial transactions are typically conducted through banks, money-transfer companies and other intermediaries that charge a percentage of the transaction amount for themselves. This costs are reduced to a minimum when sending money through a digital token. Additionally, the costs of banking PES participants or connecting them to money-transfer services can be high. These costs are greatly reduced with the usage of digital crypto-wallets.

Crypto-wallets are digital applications (apps) that store addresses, private- and public keys, and allow users to interact with the distributed ledger and manage tokens[7]. Through downloading these apps to their phones, PES participants can take part in transactions with anyone in the world at a fraction of the costs of alternative mechanisms.

> Monitoring information gained through oracles can be secured using distributed ledgers. This can lead to significant cost-reductions in monitoring-mechanisms and open the door for alternative, inexpensive new types of monitoring alternatives. While some monitoring systems rely on human intermediaries to gather and record monitoring information, oracles can automatically capture such data and record it in the authoritative ledger without further intermediation costs. The gathered information can also be used to automatically trigger electronic contracts, thus further reducing intermediation costs while increasing confidence in contract fulfilment and incrementing trust.

The distributed-ness of ledgers also allows the simultaneous visualization and management of information, the costs associated with sharing, validating and securing information, as well as the costs emanating from information asymmetries are reduced.

Furthermore, the transparency and non-repudiation of transactions, along with the immutability of data and the deterministic nature of smart contracts foster trust in the scheme and further reduce transaction costs. Promoting transactional trust is one of the main benefits associated with the use of blockchains and will be presented in detail later.

Reducing Information asymmetries

Information asymmetries are another overarching PES issue. Participants to a scheme do not have identical access to relevant information on other participants, on the state of the environmental resource

7 Voshmgir (2020) proposes, the term wallet is misleading. The word keychain would be more appropriate, since it acts as a secure key storage and as a communication tool with the blockchain instead of holding any tokens.

or on other relevant aspects of the scheme. Some participants hold exclusive information which they employ to generate additional rents for themselves. Counterparts are thus unable to take informed decisions and incur costs in safeguarding themselves from the dangers of misinformation. These safeguards are costly and diminish the resources available for financing the provision of ES.

As an example, the buyer of an ES has less information than the ES provider about the state of the resource and about the activities that the ES provider is conducting to ensure ES provision. The ES buyer might thus see the need to introduce monitoring schemes in order monitor contract compliance.

> Blockchains are likely to reduce the impact of information asymmetries by offering a distributed, redundant and transparent mechanism for simultaneously accessing relevant information about the PES scheme.

When information is coded in a distributed ledger, participants can easily access the common record of transactions and activities. They can better follow up on the status of the scheme and can trust the validity of information coded in the ledger. This joint access to information can reduce many risks associated to the asymmetric distribution of information.

As an example, all participants to a scheme can instantly observe money flows within the scheme and access available real-life information on environmental variables uploaded via oracles. The increased visibility and traceability is likely to lead to increased coordination and trust between participants as well as to increased confidence in PES results.

These benefits apply particularly to public networks, where all participants have unrestricted access to viewing the information and revising all transactions. They are helpful in suppressing the obstacles and the costs that spring from information asymmetries. The information must still be gathered by the scheme and be observable in the ledger, but once it is available (sometimes through automatized means) it can be simultaneously accessed and scrutinized by all participants that have the rights to do so.

Facilitating Conditionality arrangements

Payments for environmental services should only be granted if the expected environmental services are provided in return. This is a basic presumption of any economic transaction. If payments are conditional on ES delivery, then the consequences of non-compliance to the PES contract should be the discontinuation of payments.

Yet, in a study on 70 PES schemes, Wunder et al. (2018) found that only one fourth of the schemes had sanctioned non-compliance of contractual agreements. Many schemes do not have a robust system to ensure conditionality because of the costs it implies. The difficulties associated to create and enforce conditionality lead to scenarios where ES providers do not comply with the established parameters of the PES contract and still receive payments. This leads to a reduced environmental impact and puts into question the suitability and success of the PES scheme (Wunder et al., 2020).

Blockchains can prove to be a disruptive technology for increasing conditionality of PES schemes by reducing monitoring cost, facilitating sanctioning mechanisms and automatizing conditional payments.

Monitoring PES progress is important to observe ES provision. Yet, it is often technically difficult and economically costly. The more money invested in PES monitoring, the less funds are left for financing the de facto provision of environmental services.

As an example, a PES scheme for the protection of tropical forests typically required costly on-site monitoring to warrant the health of forests. Envoys would usually have to visit project sites in order to monitor the state of trees and the ecosystem as a whole. Such monitoring rounds are typically expensive, risky and unlikely to cover information for large areas.

Digital technologies increase our ability to observe nature and its transformations. Satellite images and sensors are examples of potential oracles that allow us both to monitor nature and to transform the monitored real-life information into digital information. Satellite imagery facilitates monitoring strategies from an eagle-eye perspective. Large forest areas can be visually monitored from anywhere in the world. Sensors (e.g. humidity) and digital cameras offer additional digital information on the state of the ecological variables. By using such technologies, monitoring entities can better understand the state of large portions of forest with a fraction of the effort and costs of traditional systems

Blockchains help harness digital information for monitoring purposes. They help secure the gathered information and help manage it in a transparent and joint way with less human intermediation. Oracle systems based on satellite images can add transactions with real life information to a blockchain-supported PES scheme and allow stakeholders to access information on the state of the natural resource in real time, while also facilitating its management securely and at low cost. The usage of blockchain tools helps make the information unalterable, allows to share it in a distributed manner and use it as input in automatic transactions through smart contracts. The information provided by oracles can so become the ingredients for semi-automatic monitoring and conditionality schemes.

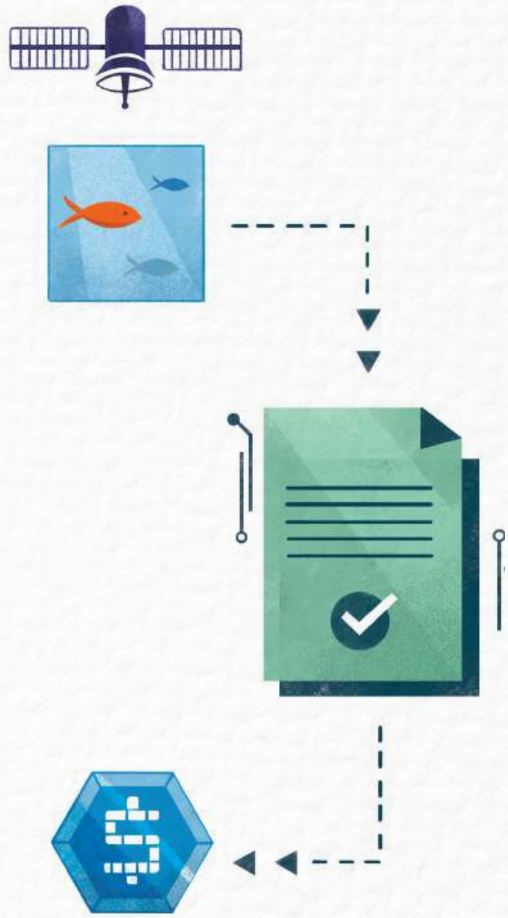
Sanctioning non-compliance is often costly in political and social terms, for it implies taking unpopular measures such as discontinuing payments and applying penalties. The authorities, politicians or stakeholders in charge of implementing sanctions must often bear the social cost of implementation. They lose acceptance or popularity.

Smart contracts and programmable money can help solve such difficulties by automatizing sanctioning mechanisms. Self-executing smart contracts can be coded to ensure that payments are only released after a valid certification of service provision is uploaded. Service providers can automatically receive the agreed payments after service completion, without delay or hassle (this is particularly relevant in scenarios where ES providers do not trust the ES buyer or the intermediary organization). Additionally, smart contracts can make sanctioning mechanisms less costly in political and relational terms, for sanctions are automatically triggered by automatized, self-executing smart contracts instead of human representatives. Such automatized mechanisms are based on a transparent and fully accessible code. This transparency could make conditionality agreements more foreseeable and acceptable.

Revisiting the example of a PES scheme for forest conservation, digital images could serve as input for smart contracts that trigger PES payments. If the oracles provide information that testifies the provision of the environmental service, the payments associated to ES provision are automatically released without delay and without high transaction costs. If oracles show otherwise, payments are retained by the contract (and not by a person or entity, thus reducing the dangers of hoarding or corruption).

This opens the door to conditionality arrangement that are not only less expensive, but also more strict and precise.

Programmable money can further help ensure conditionality. It can help protect the initial funding of a PES scheme by earmarking resources and securing their allocation towards ES provision. Many PES schemes have high initial costs that have to be tackled in the first stages of the scheme (e.g. the acquisition of personnel, equipment investments or other initial expenses). A large proportion of funds is granted prior to project commencement to enable participants to set the foundations of the project. These are typically sunk payments that can rarely be retrieved once they are granted (particularly if they are used to finance investments with high asset specificity or to finance in-kind payments). They are thus often de-facto detached from any conditionality arrangement. If such payments are conditioned through programmable money to only be spent under established criteria, then there is a lower risk of deviating funds to unrelated purposes, thus increasing the chance that they are effectively used to promote the delivery of environmental services.



> Unlike cash, where the bearer can use it for paying everywhere that the currency is accepted, with programmable money "the transfer only succeeds if funds are available, the spender is authorized, and all attached policies are fulfilled" (Weber & Staples, 2021; 9). Programmable money thus limits the liquidity of financial resources and bounds them to a specific purpose, thus contributing to enhance conditionality.

Imagine a scheme for biodiversity protection where communities in a developing country receive European funds to protect sea turtles. Such projects require initial funding for facilitating the acquisition of turtle-friendly fishing equipment or other devices such as cages to protect turtle nests. Blockchain-supported tokens can provide digital money that could only be spent for such supplies, thus avoiding that it is spent otherwise.

The usage of blockchain-supported escrow services will further secure that the guarded resources are only released given predefined conditions, thus ensuring the correct destination of money to the originally foreseen purposes and thus increasing conditionality. A blockchain escrow service guided by a smart contract can be coded to retain or release funds according to the predefined, conditionality-related criteria.

Furthermore, conditionality is also influenced by the directness of transfer between buyers and suppliers. The incentives to maximize conditionality are higher when the ES buyer, who has the greatest interest in the provision of the environmental service, is the one who finances and oversees the transaction. Direct transactions between ES buyers and suppliers could set better incentives for ensuring conditionality and blockchains facilitate the digital infrastructure to facilitate such direct transactions, as will be proposed ahead.

Facilitating direct PES schemes

Blockchains can facilitate the appearance of direct transactions between ES providers and ES buyers at a local and global level. Substantial transaction-cost-reduction and the emergence of new platforms for transacting environmental services will likely facilitate the emergence of PES schemes in which individual buyers and providers around the world transact directly with each other.

Direct PES schemes are those where ES buyers and sellers transact directly without resorting to intermediaries and without state involvement as an intermediary agent (Engel et al., 2008; Schomers & Matzdorf, 2013).

Engel et al. (2008: 666) affirm that such direct PES approaches are more "likely to be efficient, as the actors with the most information about the value of the service are directly involved, have a clear incentive to ensure that the mechanism is functioning well, can observe directly whether the service is being delivered, and have the ability to re-negotiate (or terminate) the agreement if needed".

Nevertheless, there are relatively few examples of direct PES schemes. Few actors actually enter into voluntary direct negotiations for ES provision and the few direct PES schemes that do exist generally refer to small projects at local scale.

This study proposes that the new types of digital institutional structures offered by blockchains will encourage the appearance of direct ES transactions at local, regional and global levels.

The digital infrastructure offered by blockchains not only offers a common ledger on which to account for transactions, but also an institutional infrastructure that reduces the need for classic intermediation. By taking advantage of blockchain infrastructures, individuals around the world can more easily organize themselves in networks to pursue common objectives, like promoting the provision of an ES.

A collective management tool based on a collectively edited and reviewed distributed ledger facilitates accounting. The safety and transparency of a common ledger promotes trust between participants and confidence in the scheme´s arrangements. It allows transacting parties to visualize and scrutinize the flows of money and services without necessarily relying on an external witness. Economic transactions occur at low cost through the usage of payment tokens and tokenised assets. Conflicting situations, in which the intervention of an arbitrator is required for solving contract discrepancies, are reduced by automating agreements with smart contracts. Relevant real-life information about the environmental resource are added directly to the accounting ledger through oracle systems, possibly circumventing the need for third party monitoring. Mobile phones and wallets overtake certain financial services offered by intermediary banks.

Additionally, the digital and virtual character of these tools means that they operate seamlessly in different jurisdictions. This represents "the idea that any application that runs on such a platform will be global in reach, i.e. without national or geopolitical boundaries, and extend without bound into the future" (Davidson, De Filippi, & Potts, 2016; 8).

This means that we might soon witness how more and more people around the world come together through blockchain infrastructures to organize direct transactions of environmental services.

Such direct transactions can very well occur between parties located in opposite corners of the world.

Documenting property rights

The absence of clear property rights is a restriction to the development of PES schemes which can lead the failure of PES schems and to many PES schemes not starting at all. (Adhikari & Agrawal, 2013; Wunder, 2013; Wunder et al., 2020).

The basic economic idea behind PES lies on a transaction between the provider of an environmental service and a person willing to pay for the provision of such a service. In order to participate in PES transactions, the provider of the environmental service should have rights over the environmental basis from where the services emanate and must have the rights to alter his activities over the environmental resource.

Legal uncertainty on property rights discourages investment in the provision of ES and can hinder providers from both conducting certain management activities and legally collecting payments for their stewardship. Tenure clarity and security is a prerequisite for the accountability of actions of service providers. Without it, ES providers lack the right to exclude actions from third-parties and thus lack the control over services delivery to make them reliable partners in PES transactions (Wunder, 2013).

Some environmental services are provided by communities with communal property rights or with traditional ownership of the resource. Tenure clarity does not need to come from private property rights. It can as much be secured through clear evidence of communal property rights.

Property rights are granted by social contracts outside the realm of digital technologies. Granting and recognizing property rights remains an issue for analogous (government) institutions. Yet, securing existing property rights, as well as documenting ownership and usage rights is likely to be impacted by blockchain technologies (Daniel & Ifejika Speranza, 2020).

Blockchains offer a fully transparent and append-only registry where information on property ownership and transactions is visible and secure. Additions to the ledger need the decentralized validation of network nodes. Dishonest participants thus find it much more difficult to corrupt property registers. Mistakes can also be easily tracked and owners can rely on the immutability of transactions and on an undisrupted thread of ownership to prove property rights.

This ownership-registration services can be harnessed for PES schemes. If proof of ownership is uploaded to a distributed ledger, all PES-scheme participants enjoy benefits of increased security. Evidence of property rights can be added to the blockchain, thus allowing all participants to see the claims to property over which the scheme is based. Additionally, any transaction of property rights that is a consequences of the PES scheme can be tracked and visualized by all stakeholders. This does not necessarily mean that claims are always honest or legally binding, but the immutability and non-repudiation of transactions means that claims to ownership cannot be disowned and all participants have clear proof of the original ownership claims presented at the scheme´s beginning and during its implementation. This *notarial* service might increase transparency and strengthen claims to property rights, thus contributing to tackle ownership issues.

Promoting transactional trust

If transaction partners can trust each other to act in their mutual best interest despite incentive fluctuations and despite unforeseen eventualities, then there is no urgency in creating institutions to cope with uncertainty in contract completion (Williamson 1985). But trust is a scarce and expensive good and there are costs associated to generating and maintaining trust. Many transaction partners cannot rely on trust to safeguard trade relations. They must take additional precautions to make sure that partners do not take advantage of advantageous handling positions and information asymmetries.

In economic transactions, the costs of creating and maintaining trust appear while finding adequate partners, negotiating and coding contractual terms, inspecting the traded goods and services, and enforcing the terms of agreements.

Trust related costs exist prior to contract completion and post contract agreement. Referees and courts are the institutional arrangements in charge or resolving ex post contractual disagreements. They can be effective, but the costs and time involved in delegating dispute resolution to courts are high.

In PES schemes, trust between ES providers and service consumers is as a preconditions for PES to work for conservation (Wunder, 2013). The lack of trust between stakeholders complicates PES design, and is major reason for the existence of high monitoring costs.

Trust in the PES context is fragile due to the differences in motivations between service buyers, providers and intermediaries.

Distrust harms PES outcomes, because it reduces the available funds for compensation by increasing monitoring and operational costs. It also impedes the occurrence of certain transactions that can lead to positive social or environmental improvements. Additional precautions to counter distrust add to the transaction costs and can be so high that the benefits of exchange are completely corroded by the costs of ensuring cooperation.

Intermediaries have been proposed as a contributions to creating trust among participants (e.g. Schomers, Sattler, & Matzdorf, 2015; Vatn, 2010; Wunder, 2013). Yet, intermediaries typically redistribute trust towards themselves and can also be expensive.

In this scenario, blockchains offer a set of benefits that, as a whole, will increase confidence in the operation of the PES scheme.

Blockchains have been proposed as machines to increase trust (Werbach, 2018) and confidence (De Filippi et al., 2020). The transparency and non-repudiation of transactions, along with the immutability of data and the deterministic nature of smart contracts are likely to foment trust between participants, and confidence in the outcomes of the scheme. This is likely to reduce the costs associated to creating or maintaining trust through intermediation and litigation instances.

In public schemes, transparency will increase trust by allowing all participants to examine accounts, scrutinize expenses and access relevant information on transactions. Transactions related to the scheme will be fully auditable.

Programmable money can be used to manage and secure PES money allocation in a trustable way. Confidence that payments will be delivered on time and that the money that has been earmarked for a person or an activity is used in the way it was budgeted will increase due to programmable money.

Smart contracts will be able to enhance confidence and predictability in the consequences of scheme-related actions. Improved blockchain-supported monitoring mechanisms will make schemes more affordable and effective and will increase trust in the system in the long term.

The costs of such monitoring mechanisms will be reduced by using oracle systems that harness digital information and trigger self-executing clauses in smart contracts. Compliance will be upheld through the automatization of consequences for PES-related actions.

Transactions between asymmetrically powerful partakers in which one party is much stronger than the other become less risky for the weaker party. By codifying agreements into automated smart contracts, less powerful parties can trust the inevitability of contract compliance and can trust that agreements will be honoured with less risk of resorting to costly compromise instances such as courts, where powerful actors have the upper hand.

For some public, permission-less schemes, PES participants can restructure trust relationships in an innovative manner. In cases where trust issues undermine the relationship between ES providers, intermediaries and buyers, stakeholders can outsource the validation of key transactions to a neutral verifier who participates as a validating intermediary. This validator maximizes its personal benefit by making sure that transactions are valid according to an established protocol. As an independent entity, they manufacture trust as a service for PES participants (Berg, Davidson, & Potts, 2017).

These trust-increasing benefits will likely bring a "higher value proposition for the developing world than for the developed world. Why? Because blockchain has the potential to make up for a lack of effective formal institutions—rules, laws, regulations, and their enforcement" which are often not found or not reliable in a developing context (Kshetri & Voas, 2018; 1). As a trustworthy substitute for certain institutional arrangements, blockchains can indeed serve as an instrument to tackle the lack of trust between PES participants.

Additionally, the utilization of blockchains offers alternatives to structure payments that can lead to increase transactional trust. Cash payments in fiat money are very difficult to track. This leads to a lack of transparency and might open the door to corrupt practices. Cash payments in digital money are trackable, thus allowing stakeholders to follow payments. The transparency of payments could also contribute to increase the perception of fairness and support collective action, if everyone can visualize how resources are received and spent.

Facilitating payments across borders

The benefits of ES are very often not localized. Environmental services carried out in one place can have positive repercussions in distant places.

ES buyers are often confronted with high costs when transacting with partners across the globe. An institutional arrangement that can operate above jurisdictional barriers and under low transaction costs can allow buyers to co-finance global environmental services. If global buyers can easily finance the provision of an ES disregarding national barriers, the amount of resources for its provision could increase rapidly.

The digital and decentralized nature of blockchains allows them to operate above national jurisdictions and with low transaction costs. Blockchain technologies could thus facilitate cross-border payments for global environmental services by reducing the financial and legal hurdles of doing so.

Digital currencies and tokens can further facilitate transactions across borders by offering a common international currency that can operate parallel to traditional currencies. By reducing the transaction costs associated to exchange rates and multi-national regulations, digital currencies enable a more fluent transaction of services. As an example, the project Celo[8] offers a mobile application and a programmable token to facilitate payments at a small cost between anyone in the world who has access to a mobile phone and an internet connection. The costs of each transaction are close to one US dollar cent per transaction and require only a few seconds to be completed.

The appearance of international PES transactions, is now thus more affordable with blockchain infrastructures. Anyone around the world willing to finance the provision of an ES can now potentially do so from their phone. Compensating a community in a developing country which protects an endangered species or an ecologically valuable asset can simply require joining a blockchain supported network by using a wallet on the mobile phone. As a participant to such a PES network, anyone can send resources, while receiving cryptographically-secured evidence of the completion of the environmental service. Jurisdictional borders and their consequent friction are therefore de-facto bypassed through the usage of such a technology.

By facilitating payments across borders, valuable new pools of private resources could herewith be tapped for conservation and sustainable environmental management.

Disencourage free-riding

Many ecosystem services can be characterized as public goods or common pool resources. It is difficult to exclude anyone from their benefits and it is thus difficult to charge for their enjoyment. When beneficiaries of a service are difficult to exclude, free-riding and opportunistic behaviour often emerge, and coordination mechanisms tend to be less effective.

Free riding impedes the establishment of some PES initiatives and makes existing PES schemes less effective. The stream of resources available for maintaining environmental integrity is reduced when actors free-ride on the efforts of others. A sense of unfairness can also harm motivations to support the delivery of the ES.

Salzman et al. (2018) highlight that for services that are not localized (like most international ES related to biodiversity and climate regulation), diffused beneficiaries have little incentives to contribute to financing the provision of the ES (particularly since jurisdictional borders protect them from being forced to do so) and free-riding appears for them as their dominating behavioural strategy. This means that for global ES services, finding the adequate institutional structure that counters the incentives for free-riding is of crucial importance.

So, for example, biodiversity provides diverse services to humanity, and the benefits are diffused among millions of people in many countries. Beneficiaries cannot be forced to contribute to biodiversity conservation measures outside their local jurisdictions and might thus decide to continue profiting from

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biodiversity services without contributing to its provision.

An institutional structure that helps integrate diffused beneficiaries is likely to contribute to reducing free-riding.

This study proposes a distinction between two types of free-riding: intentional and unintentional. Intentional free-riding refers to those cases where the actor enjoying the benefits of the ES takes advantage of its low excludability and actively avoids contributing to its provision (maybe considering it is the role of the state and not of an individual to confer payments).

Unintentional free-riding is here described as the situation where those actors that, being aware of the benefit associated to the environmental service would like to contribute to its provision, but do not find a suitable way to do so. Such is the case when beneficiaries of a global environmental service wish to finance ES provision projects, but lack information on ES providers and are confronted with high transaction costs that make their contributions in other countries unfeasible.

This differentiation allows to distinguish between alternative solutions for the two forms of free-riding. While intentional free-riding requires complex formal rules for countering it, unintentional free-riding requires the creation of meeting points between those who want to participate in financing ES provision, and those who commit to providing them.

Stakeholders can resort to blockchain technologies to create mechanisms through which ES buyers can contribute to financing ES provision without incurring very high transaction costs.

Engel et al. (2008) suggest that such schemes emerge in situations where users perceive large ES benefits, so that they are willing to pay for their provision and do not expect to free ride on the efforts of others. The appreciation of environmental services and cognizance on the need to protect them has arguably increased in the last decades. Awareness of the benefits that we receive from nature has increased and the willingness to pay (WTP) for their provision has increased as well. DLTs are a good tool to connect providers and buyers and thus reduce unintentional free-riding.

Blockchains are institutional technologies (Davidson, De Filippi et al. 2018 and Berg, Davidson et al. 2019) that allow people to organize interactions on a common goal over a digital institutional backbone. They will further facilitate the interaction of people around the globe that wish to cooperate on the provision of an environmental service.

We might soon be seeing the first examples of blockchain-supported ES financial mechanisms where mobile phones are used to send digital funds and receive cryptographically secured evidence of environmental service provision from one corner of the world to the other without incurring in prohibitively high costs.

The ease with which information on PES projects can be accessed, the security offered by the immutability and non-repudiation of blockchains, and the diminished networking- and transaction costs are likely to reduce the barriers that previously led to unintentional free-riding.

Additionally, community member can be encouraged to Community members can be encouraged to contribute to a communal PES scheme if they perceive their participation as being acknowledged or their non-participation as being exposed. This could reduce the incentives for free-riding.

Reducing Leakage

If PES schemes are to contribute to environmental sustainability, they must provide additional environmental benefits compared to the status quo. Leakage is a spill-over effect that endangers the environmental additionality of PES schemes.

Leakage refers to the risk of PES leading to a displacement of the environmentally harmful activity to another place (Engel, 2016).

Various studies have highlighted that leakage could jeopardize the environmental success of PES schemes (e.g. Börner et al., 2017; Engel, 2016; Wunder, 2008b; Wunder et al., 2020). Ecosystem services emanate from geographically dispersed ecosystems, but PES schemes often only have local jurisdiction. If the incentives to conduct an environmentally damaging activity are unchanged, a PES scheme that seeks to reduce negative activities in a given zone might displace harmful activities to other areas leading to no net positive environmental gains. So, for example, any payments that are granted for reducing mangrove deforestation in a given area can locally reduce mangrove destruction, but might lead to increased deforestation pressure on mangroves just outside the PES demarked area. If deforestation increases in neighbouring arear, the net global benefit of the scheme is reduced or even cancelled. The environmental effectiveness of the PES schemes are thus questionable under leakage (Wunder et al., 2020).

Wunder (2008ba) highlights alternatives for reducing leakage including additional monitoring, increasing the scale of schemes to cover more territory and discount leakage from payments.

DLT technologies can help increase the scope of monitoring by reducing some monitoring costs, enabling monitoring mechanisms that harness oracle systems, and enabling the emergence of functional self-monitoring mechanisms.

One could also leverage the opportunities that arise with programmable money to discount leakage from payments. If payments are conditioned in such a way that payment amount are reduced proportional to the degree of leakage, then PES participants have no incentive to displace their harmful activities to outside the project area.

Leakage can still fall on the actions of other non-participating actors, but stakeholders involved loose incentives to carry out harmful activities themselves and are faced with increased incentives to discourage leakage in neighbouring areas.

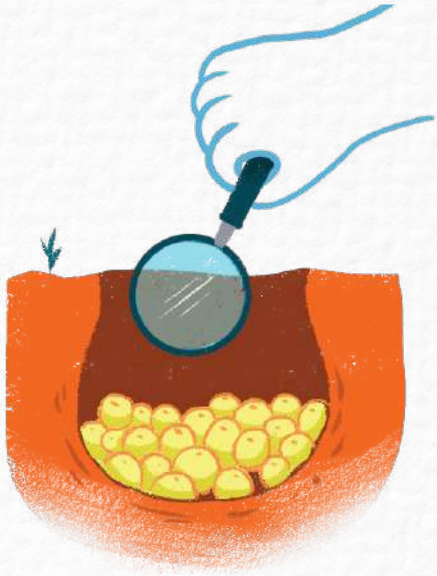
Programmable money can accentuate the certainty of payment reduction under leakage, thus making it more credible. It can also do so without risking the rupture of relationships with communities, since payment-stop is an impersonal consequence of leakage, instead of it being an action decided and carried out by an intermediary or stakeholder.

Reducing risk exposure for ES providers

Blockchains can contribute to improving PES outcomes by reducing the risk exposure of ES providers that commit to result-based contracts and to long-term PES contractual arrangements.

PES schemes can be structured in such a way that ES providers are payed based on activities they conduct to enhance or maintain an ecosystem service (paying for input), or they are paid for a measurable environmental result itself (paying for output).

As an example, governments can pay farmers and landowners for setting and maintaining natural "wild" corridors in their fields to enhance biodiversity protection and connectivity (paying for inputs), or they can pay them based on the amount of species that are found on their fields (paying for outputs). While the expected environmental service is related to increased biodiversity, the PES scheme expects and controls the physical characteristics of the corridor, which is easier to observe.



Granting payments on the basis of environmental output is expected to lead to better PES results than granting payments for input activities (e.g. Engel et al., 2008; Sattler, Trampnau, Schomers, Meyer, & Matzdorf, 2013) particularly if the linkages between inputs and outputs are uncertain. Payments based on ES outputs have also been proposed to be more innovation friendly, because they allow providers to develop and implement alternative ways to meet their commitments (Paul J. Ferraro, 2008), thus leading to cost-effectiveness in the long run.

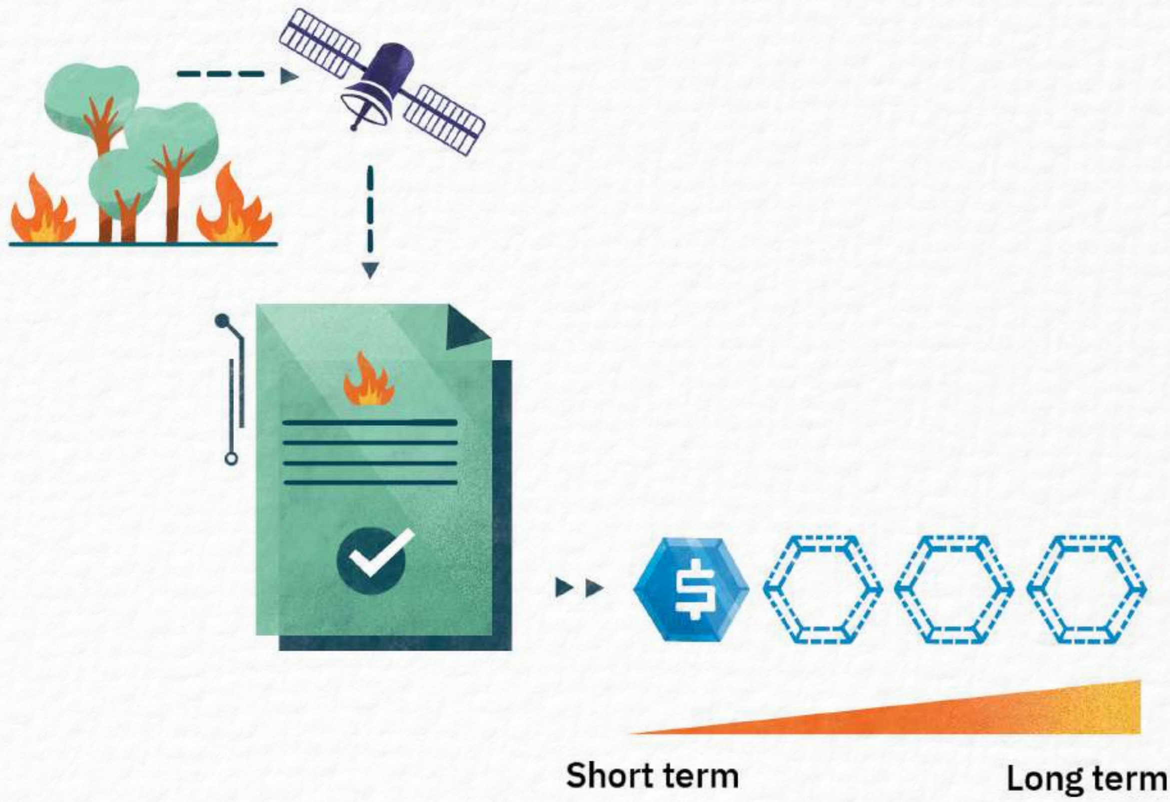
Yet, result-based contracts also imply that ES providers incur the risk of carrying the environmental service and receiving no payment when a natural catastrophe or another unexpected event impact the expected environmental results. Wunder et al. (2020) highlight that paying for ES delivery is particularly difficult when ES delivery fluctuates over time due to external factors.

Take, for example, a community entrusted with caring for an endangered species. The community might carry out activities that promote the sustainable management of the species such as sampling the health of individuals, conducting monitoring expeditions, creating protective barriers, etc. If the community signs a contract based on the provision of these input activities, then the mere act of carrying them out entitles them to receive compensation. But ES buyers are not finally interested in financing monitoring expeditions or protective barriers. They are interested in increasing the number of individuals of the threatened species. ES buyers are better served with a PES contract in which payments are given according to the number of protected individuals in a period of time. Under such circumstances, providers are free to choose the activities that they consider most appropriate to achieve the conservation purpose of the scheme. This can be favourable for them as it allows them to find the cheapest and most effective way of completing their part of the deal. Yet, if an unforeseen eventuality decreases the population of the species, their effort and dedication can be in vain.

For providers that are risk-averse, payments for input activities are more attractive, because it lies on their own hands to complete the activity or not. Contracts based on input activities thus reduce the perceived risk for ES providers.

Blockchains could reduce the risk exposure of ES providers that agree to ES outputs. ES providers could consider payments for ES provision less risky if a backup clause reduces their liability in case that external ecological factors threaten ES provision. Commitments engraved in self-executing smart contracts are credible and reduce contractual risks for ES providers that opt to sign agreements based on ES output.

Reducing risk through insurance is already possible without blockchains. Yet, smart contracts increase confidence in such insurance mechanisms, especially if funds are locked in crypto escrow services so as to make sure that they are only triggered (and always triggered) in case of devastating events. The intermediation costs of insurance policies based on smart contracts can also be



much less than those charged by traditional intermediary insurance companies.

What blockchain infrastructures can offer is thus additional security and confidence in the compensations triggered by disturbing eventualities, as well as lower intermediation insurance costs.

The additional trust restructures incentives in favour of accepting payments for proven ES provision, instead of simple input activities.

In the same way, blockchains can reduce the risk associated to long-term commitments of ES provision. Sattler et al. (2013) find that long-term 10-30 year projects are overrepresented in their study of successful PES schemes. For them, the planning security of longer contracts seems to contribute to positive environmental outcomes. Yet, high long-term opportunity costs and the increasing probability of occurrence of disturbing events are variables that increase uncertainty and provision expenses for ES providers.

One way of increasing planning security for stakeholders without paying high ex-ante insurance premiums for long term contracting could be to guarantee the adaptation of payments to the up-to-date environmental situation through smart contracts. Participants to the PES scheme can agree on increasing payments according to the eventualities that arise, and they can secure such agreements through immutable smart contracts and escrow services. Money that has been set aside and secured in smart-contracts and escrow services can only be withdrawn for the purposes established in the agreement and will automatically be transferred if the requisites are given. Automatization reduces the transaction costs associated and promotes credibility even between largely disparate transacting partners. This has the additional benefit that if compensation policies are coded in smart contracts, the administrative costs of maintain and executing such policies over a large period of time are greatly reduced.

As an example, a PES project to protect a forest area might offer payments to those communities that sustainably manage their territories over a 10-15 years period. The 10-15 years period should contribute to the permanence of environmental gains. For the ES provider, the longer scheme period increases the risk of experiencing unforeseeable climatic events that lead to the diminishment of the forest and thus to payment stop. Because of that, the provider would likely prefer a much shorter contract length. If ES providers perceive technical assurance that their risk exposure is credibly covered by automatic additional payments in case of fires or other events, then they are likely to agree to long-term agreements that promote permanence.

Contribute to viable long-term funding

Goldman-Benner et al. (2012) underline the importance of securing long-term contracts to ensure permanence and allow practitioners and policy makers to integrate slow ecological developments into their decision-making processes. They highlight funds as effective long-term finance mechanism, even when they do not embody typical PES structures.

Funds provide a sustainable financial basis for long-term payments. The interests and principal of the fund offer the base for a sustainable income flow which can lead ES providers to participate in schemes and accept low, but secure long-term payments. The amount secured in a fund in time frame A can be used in one period or spread in the periods A+1,… A+X.

Blockchains enrich the spectrum of management possibilities for funds. The distributed nature of blockchains, their transparency and the security in transactions allow participants to a network to create and effectively management a fund without necessarily relying on a centralized management structure. The management can be distributed and decisions on expenditures and investments can be coded in smart contracts. New types of institutional arrangements can empower individuals to create and manage funds at a low cost, thus contributing to securing resources for long-term funding.

The rules on which the fund´s resources are managed can be codified in smart contracts and in the underlying source code, making them more secure and reducing transaction costs and management costs. Information related to fund management is visible to all contributors and PES participants.

By being able to dose the payment amounts according to existing needs and the respective current service provision, the PES scheme can spread resources in time and potentially secure long term funding. This comes at low administrative cost if the condition upon which resources are released can be triggered by an automated digital oracle.

Facilitate institutional innovation for PES schemes

The underlying code of a blockchain dictates the institutional framework that governs the relationships and transactions between the participants of the distributed network.

Articulating institutions and implementing rules can be less costly when using a distributed ledger technology. Networks can test, amend and improve institutional arrangements by simply altering the source code. They can even copy-paste positive elements of existing institutional structures and adapt them to their own social reality without incurring high costs. Blockchains thus allow for low-cost institutional innovation and implementation (Berg, Davidson, & Potts, 2018).

The relative simplicity with which institutional frameworks can be created, copied and evolved will facilitate the emergence of local networks that engage on different projects, including the provision of environmental services. Such networks will be able to build upon digital infrastructures from similar projects for formulating and developing their own favourable institutional frameworks. By doing so, they will be able to take their own institutional preferences and imprint them on a digital infrastructure for managing PES schemes. Institutional evolution will be enhanced through blockchains and PES schemes will profit from this.

> The bottom-up creation of networks for the provision of environmental services will be made simpler. Such bottom-up initiatives can be crafted from within the local social-institutional framework and can bring the essence of innate institutions within themselves, thus promoting the utilization of native institutional alternatives.

Incentive alignment through disintermediation

Intermediaries play a central role in the development and management of PES schemes (Engel et al., 2008).

"In simple terms PES intermediaries can be defined as those actors performing functions that facilitate transactions between buyers and providers of ecosystem services"; Cook, Couldrick et, al, (2017; 6).

Due to their importance, Vatn (2010) describes intermediaries as the dominant agents in PES schemes.

The involvement of an honest intermediary is often characteristic of successful PES schemes (Sattler et al., 2013; Wunder, 2008a). Yet, the drivers of their motivations are diverse. Intermediaries are generally not neutral actors, but entities with their own commercial, political or charitable agendas (Moss, Medd, Guy, & Marvin, 2009). They must maintain their own costly administrative structure and finance parallel organizational objectives (Wunder & Albán, 2008). Intermediaries follow their own incentives, which are themselves dependent on their source of funding (Pham, Campbell, Garnett, Aslin, & Hoang, 2010) and their social reason (Bosselmann & Lund, 2013). When remunerations of intermediaries are directly linked to the continuation of PES schemes, a misalignment of incentives can lead to failed reporting of non-compliance, for it leads to reduced income for intermediaries.

An intermediary structure that is completely aligned with the incentives of buyers and providers is thus ideal, but difficult to find.

Blockchains provide a technical solution to outsource intermediary functions to digital systems with no intrinsic motivations, thus facilitating the alignment of ES buyer-provider incentives. The agenda and objectives of intermediary organizations in the PES process are thus obviated, and intermediation costs are reduced. In open blockchain networks third parties validate transactions across the network according with the constitutional rules and without contributing own agendas aside from the profit-maximization associated to implementing the rules of the network.

Blockchains further provide tools to reduce intermediary transaction costs associated to monitoring and compliance as proposed before. In doing this, they offer a digital alternative to traditional intermediation roles, while maintaining trust and confidence between participants (Berg et al., 2017; De Filippi et al., 2020; Werbach, 2018).

Advances in blockchain technologies and their dependent applications allow the creation of innovative PES schemes that can more effectively achieve environmental results.

Consider a PES scheme occurring in a coastal community where fishermen are compensated for fishing outside an ecologically sensitive area and community members are payed for replanting degraded mangrove forests.

GPS positioning and satellite images can be harnessed to verify the coordinates of the fishing routes and the state of mangrove forests.

Such coordinates and images trigger smart contracts that release payments in accordance to pre-established scheme conditions. Payments are sent to participants using a crypto-wallet application. This reduces bank transaction costs and allows unbanked participants to participate and receive their money directly. Costs for international transactions are further capped through the usage of payment tokens. Programmable money is used to secure the adequate usage of initial payments.

Smart contracts increase contractual security and increase the conditionality of payments. ES provision is always compensated and only compensated if the digital information testifies that fishers are avoiding the protected area and mangrove cover is increasing. Non-compliance leads automatically to stop the payment via the smart contract. This reduces the risk of corruption and avoids the social costs of sanctioning non-compliance for authorities and other stakeholders.

The usage of satellite-based oracles reduces monitoring costs to a fraction of traditional monitoring systems. This happens with minimal human intervention thus further reducing monitoring- and intermediation costs, reducing the chances of human failure and increasing trust in monitoring results.

The transparency and immutability of transactions and information handled in the blockchain facilitates verification processes and increases trust in authentication procedures. Information is equally available to all stakeholders thus reducing the consequences of information asymmetries.

When used adequately and in accordance to the local social preferences, blockchain technologies could enable the establishment of new forms of PES schemes, therewith leading to increased ES service provision and to the emergence of alternative income possibilities for environmental protection.

05.

Considerations for blockchain implementation

Now that we have reviewed the multiple tools that blockchains offer to improve PES schemes , it is time to present some general considerations that are worth taking into account when planning the utilization of blockchains for PES.

This study proposes a series of technical, social and economic considerations. The list is not meant to provide a comprehensive account of requirements for successful implementation. It is more a first attempt to highlight the elements that facilitate and impede the implementation of blockchain-supported PES schemes.

The lack of examples of blockchain-supported PES schemes from which we can draw conclusions or lessons-learned means that this list will need to be reviewed and updated as early projects reveal their experiences, and as the technology matures.

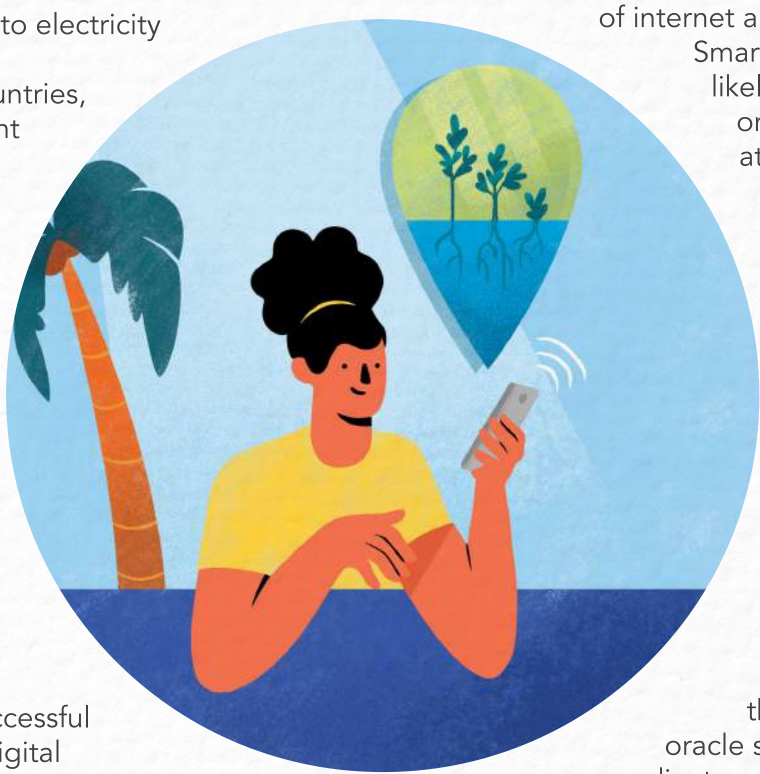
The below mentioned considerations will hopefully help the reader better understand whether the characteristics and requirements of their projects justify the usage of the technology. In this sense, this study agrees with Koens and Poll (2020; 6) in emphasising that "defining use case requirements must precede any technological choice."

Technical considerations

Internet, electricity and hardware

PES schemes exist in very diverse socio-ecological scenarios. From the rainforest to the coast, from highly populated to unpopulated areas and in developing and industrialized countries. It is thus worth highlighting a few basic technical preconditions for the implementation of blockchain technologies.

The use of digital technologies implies the usage of electricity and hardware that allows access to the internet. Although access to electricity is widespread in industrialized countries, there are sufficient examples of regions in developing countries with little or no electrification, particularly in isolated rural regions. Such regions are often environmentally valuable and can host PES schemes. If electricity is not available, the successful introduction of digital technologies is improbable if not impossible.



The same applies for internet access. A minimal reliability on internet access is essential for the participation in blockchain networks. While such connection must not be constant, participants must at least be able to interact with the network whenever they want to participate in a transaction or want to visualize the ledger.

Another prerequisite is linked to the availability of hardware for interacting with other stakeholders and the distributed ledger. The basic hardware necessary to participate in a digital network is not particularly specialized. Computers, tablets, or mobile phones that enable a connection to the internet are sufficient to participate in blockchain supported networks. Mobile phones are almost ubiquitous around the world. It is not uncommon to find communities around the world lacking basic sanitation but enjoying the benefits of internet and smart phones. Smart phones are thus likely to be available, or can be provided at reasonable cost. These devices not only allow access to the distributed ledger through wallet applications, but also offer a series of additional tools to measure and share real-life information, thus enabling the appearance of oracle systems (e.g. GPS coordinates, time and location stamped photos, etc..). Griffiths et al. (2013) propose that smartphones and apps could replace many traditional handheld sensors, calculators, and data storage devices which are commonly used in ecological surveys. These tools are likely to increase the scope of possible options for oracle systems, even in isolated areas.

Feasibility of reliable oracle systems

The feasibility of creating reliable oracle systems is another technical consideration to bear in mind when planning the usage of distributed ledger technologies in a PES scheme. In order to use PES-related information in digital distributed ledgers, it is necessary to be able to translate real-life events and real–life information into the digital realm of blockchains in a secure and reliable manner.

> Oracles can be organized in a centralized or decentralized manner. They can rely on automatic sensors or can be based on information provided by participants of the scheme. The key is that the oracle system has the capacity to deliver the required information safely; that the information is reliable and of high quality; and that the costs are not prohibitively high.

For those schemes where a reliable oracle system cannot easily be implemented, digitalizing external real-life information will result improbable and the benefits of utilizing a blockchain for the management of environmental services are questionable.

Technical partnerships

Due to the novelty of blockchain technologies, most organizations interested in harnessing them for the realization of PES schemes will have to create partnerships with programmers or organizations with enough technical capacity to develop and maintain the technical infrastructure of the networks.

The development of blockchain protocols, of clients and of end-user applications must generally be outsourced to such technical partners. Trusted partnerships must emerge with companies that can provide the technical support required for blockchain development. Yet, finding adequate partners to do so is not always easy. Blockchain developers are one of the most sought-after professions and one of the best paid. The demand for their services exceeds the available supply. This is particularly the case in developing countries. It is important to ensure that the project will have access to technical experts who can accompany the project for as long as necessary. If it is not possible to find such partners (and pay them), the probability of success decreases considerably.

These technical partnerships are not only difficult to find, but for some organizations it may be difficult to manage them successfully. Hallwright and Carnaby (2019) highlight that, for some organizations, engaging in non-traditional partnerships with new types of partners such as programmers and IT-start-ups is difficult. For their study on Oxfam Australia's experience in piloting blockchain, they underline that "the experience of this project highlighted just how diverse the private sector is and some of the challenges associated with working with small start-up tech companies that do not yet have proven track records, are unfamiliar with institutional donor compliance and have structurally different motivations" (Hallwright & Carnaby, 2019; 4).

Making sure that technical partners are available and that the interaction with them is harmonious and effective is a key consideration when deciding on blockchain implementation for PES.

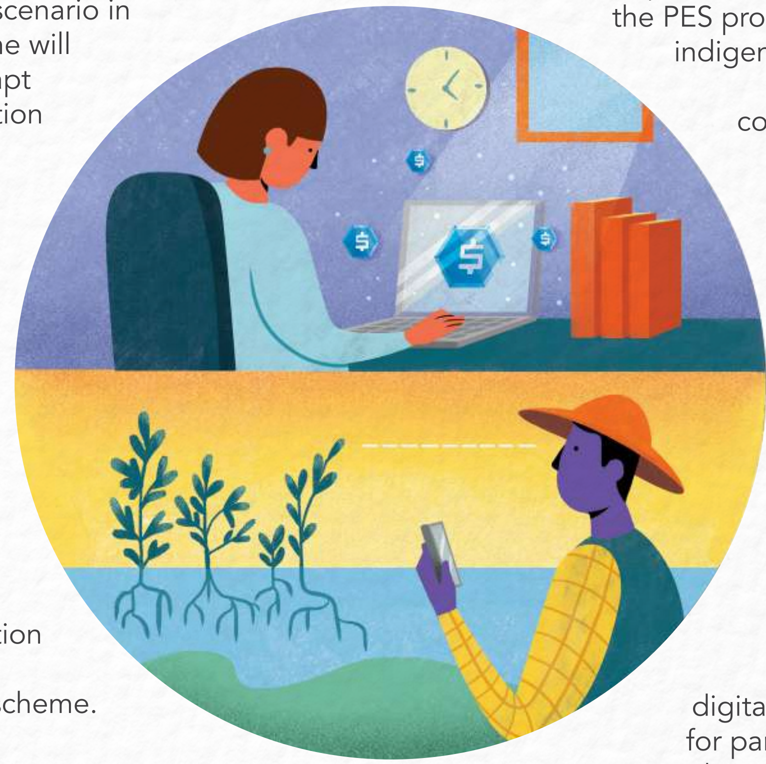
The maturity of the desired technological solution at the time of implementation

Distributed technologies are undergoing a phase of constant and rapid development. New projects appear daily and technologies improve at a fast pace. With barely over a decade of existence since their inception, blockchains could be considered a "new" technology. Development is currently expensive and in some cases it quickly becomes obsolete due to rapid technological evolution. User interfaces are sometimes inadequate, it is difficult and expensive to get expert advice and the legal frameworks for utilizing certain applications are constantly changing.

It is thus important to consider whether,at the time of PES implementation, and given the stage of technological maturity, a blockchain solution is a feasible option for effectively tackling the issues that the scheme presents, or whether alternative, more traditional technologies are still a better option for tackling a certain issue or for implementing an idea.

Social considerations

When considering the use of a new digital technology for a PES scheme, it is important to take into account the socioeconomic scenario in which the scheme will operate and adapt the implementation activities to the socio-economic reality of stakeholders. A series of considerations are here presented to highlight the relevance of social characteristics in technology adoption and in the implementation of a blockchain-supported PES scheme.



Basic digital literacy

To begin with, it is necessary to ensure that the participants of the scheme have a basic knowledge of digital technologies that allows them to participate in a distributed network and take advantage of the benefits it offers. Basic digital literacy is of paramount importance to increase the chances that the scheme can be developed satisfactorily. Participants to a PES scheme can be diverse with varied backgrounds, educational qualifications and upbringings. In many cases, the PES providers are rural or indigenous communities in developing countries with basic education and little knowledge of digital technologies. Such participants might find participation in a blockchain-supported PES scheme difficult without previous training.

The degree of digital literacy required for participating in such a scheme depends on the degree of involvement that the organization or individual might want to assume in the network.

While being able to utilize a simple App may be enough for the mere participation as an end-user in the sense of Rauchs, Glidden et al. (2018), those who want to assume other more prominent roles in the network (such as developers, administrators, gateways or record producers)[9] might need a more advanced understanding of DLTs and might even need programming experience.

This means that while the degree of digital specialization can be very high to perform certain roles in the network, anyone who can use the basic functions of their mobile phone should soon be able to participate actively as an end-user in a blockchains network (provided the user-interfaces are simple and user friendly). This is a key advantage for projects that work in environments with low technical endowment, such as some indigenous communities in developing countries.

In cases where knowledge is insufficient, it is important to consider whether this may imply low adoption rates and lack of support for technological solutions, and whether such lack of knowledge can be remedied with education and training. In those cases, in which participants require extensive training processes to be able to interact with new digital technologies, one must weigh the benefits that emanate from blockchain implementation and contrast them with the respective training costs.

Such trainings can also benefit participants in multiple ways, not only in relation to their participation in the PES scheme, since the ability to use digital technologies is increasingly important in all areas of life. Trainings can thus be a type of in-kind payment that might increase acceptance in the PES scheme and interest in the technology.

Acceptance towards technology adoption

When attempting to use new technologies such as blockchains in environmental or social projects, one should first try to understand whether stakeholders welcome their usage, for this is a main factor affecting technology adoption (di Prisco & Strangio, 2021; Janssen, Weerakkody, Ismagilova, Sivarajah, & Irani, 2020).

9 This categorization of roles and duties is based on the one proposed by Rauchs, Glidden et al. (2018)

There are multiple reasons why individuals, organizations or communities might refuse to accept the adoption of new technologies. These can be cultural, historical, economic, or of other nature.

If, for any reason, stakeholders refuse the adoption of new technologies, a blockchain supported project faces obstacles that can make it unfeasible. Whether a technical solution is desirable thus highly depends on the social and institutional framework that governs participant´s interactions.

Blockchain infrastructures play a very central a role in the management of networks. The introduction of a new distributed digital technology has repercussions on a scheme´s governance and is likely to affect the perception of communities towards the PES scheme. The perceived impact of the technology in relevant questions (such as equity or economic sustainability) will likely impact the desirability of adoption. If stakeholders are reluctant to the usage of the technology, its usage is less desirable. Imposing the utilization of blockchains on participants who refuse to accept them is likely a recipe for failure.

On the other hand, a positive perception of the technology facilitates implementation and increases the chances of success.

Blockchains are thus desirable when they not only offer solutions to technical or economic PES needs, but when they are also an accepted alternative to do so. The technology used should therefore be adapted to the needs and wishes of participants and not the other way around.

> This study emphasizes the need to ensure social acceptance towards technology adoption prior to scheme begin. For those cases where acceptance is not given and it cannot be promoted, more traditional alternatives are likely to generate better results.

No legal restrains for DLTs

Many countries have regulated the use of cryptocurrencies and other blockchain applications in recent years. This is in order to protect their citizens from the repercussions of a disruptive technology that was often related to unregulated (and many times illegal) economic transactions. The usage of cryptocurrencies for conducting transactions in the Darknet triggered the interest of governments and regulators since the early stages of Bitcoin. The rapid increase in the number of cryptocurrencies and of Initial Coin Offerings (ICOs)[10] also led regulators to cap their usage and discourage their implementation in many places. While regulations were often targeted towards cryptocurrency projects and ICOs, many other applications, and even the general usage of distributed ledger technologies, was often banned or restricted.

If the national or local governments of the territories where the PES schemes are developed have rules against the use of blockchains or some of their applications (for example, prohibitions on the use of cryptocurrencies or token applications), these rules must be taken into account at the time of planning and implementing the PES scheme.

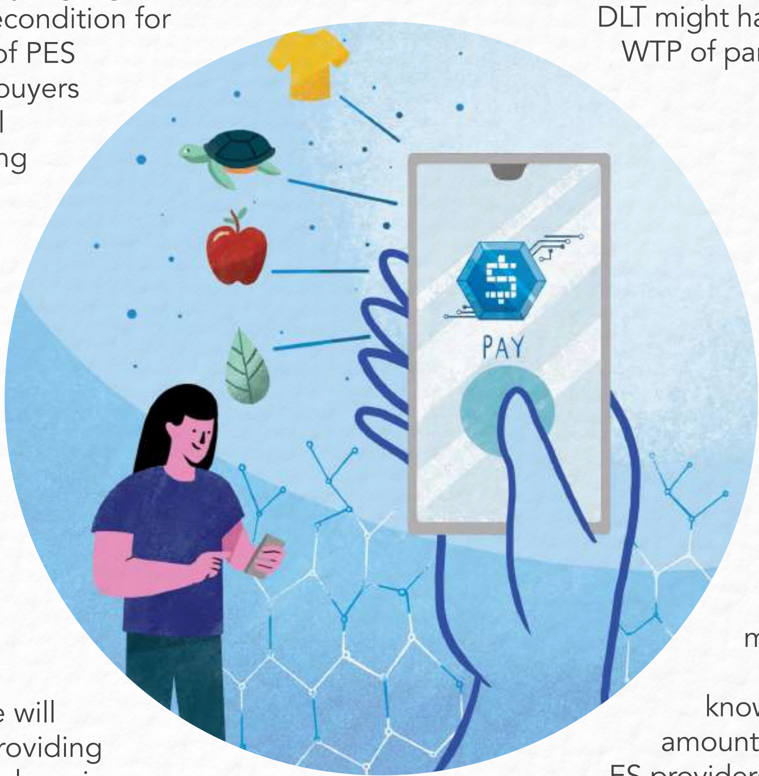
It is fair to say that any scheme that runs contrary to local laws is bound to fail sooner than later. It is true that many blockchain networks operate effectively despite restrictions in the jurisdictions where they operate (such as Bitcoin in some Asian countries), but these networks generally only transact purely digital and endogenous tokens. A blockchain-supported PES scheme is different as it is based on real-life transactions based on environmental- and social goods and services. It is thus unlikely that blockchain supported PES schemes can circumvent restrictive legislation.

10 Initial Coin Offerings are mechanisms for funding crypto projects in which money is raised in exchange for a project related *token*.

Economic considerations

Blockchain implications on WTA and WTP

A basic precondition for any type of economic transaction is that the willingness to pay (WTP) for the given good or service is higher than the willingness to accept (WTA) payments by providers. Wunder (2010) had already highlighted that an economic precondition for the emergence of PES schemes is that buyers of environmental services are willing to pay a value above the minimum amount which suppliers require to accept their participation in the scheme. Buyers must, at least, cover the opportunity costs of services providers. Otherwise, these will not commit to providing the environmental services, since this would imply costs higher than their potential earnings.



Blockchains can potentially transform the values corresponding to WTP and WTA. As an example, it is conceivable that the transparency that blockchain-supported accounting offers can potentially increase trust in the PES scheme and drive the WTP of ES buyers upwards. In the same way, the WTA for the provision on an environmental service can fluctuate in a blockchain supported scheme. If the ES provider experiences less uncertainty due to increased transparency or due to the inevitability of automatized contracts, they might be willing to accept a lower payment for the provision of the ES. It is thus relevant to consider the expected impact that the DLT might have on the WTA or WTP of participants and plan accordingly.

A more adequate equation includes the transaction costs in the comparison between WTP and WTA. A better equation is thus WTP–TC > WTA. This equation implies that the transaction costs must be subtracted from the WTP to know the net available amount for compensating ES providers. This net amount must be equal to or greater than the minimum amount that lenders are willing to accept. Since blockchains influence transaction costs in multiple ways, as shown above, the use of a blockchains can have a significant effect on all three variables in the equation above.

Understanding how DLTs impact WTA and WTP can be a difficult task, but empirical studies will likely increase our knowledge once the first blockchain supported PES schemes are rolled out.

Redeemability of Tokens

When employing tokens in a PES scheme, it is important for stakeholders to be able to exchange their tokens for other currencies, for goods, or for services that allow them to enjoy the fruits of their work. Crypto tokens are not always accepted as payment methods. Since the tokens do not have an inherent market value, the redeemability of the tokens is essential for the correct operation of the network and for maintaining the incentives of the PES scheme and of the blockchain network.

It might thus be necessary to enter partnerships with companies, stores, currency exchanges or other organizations that can redeem tokens against other valuables in order to ensure that tokens hold the value and liquidity to buy real-life goods and services. If tokens cannot be exchanged against other valuables, it is unlikely that participants will accept them as a form of compensation.

The availability of such partners dictates the chances of successful implementation of many blockchains-supported schemes. If partnerships cannot easily be built, then holding tokens does not represent any economic advantage and token-supported structures are likely to fail.

The availability of funds to maintain the DLT infrastructure

The costs of running a blockchain infrastructure can be assumed by an intermediary entity (if it is built with a certain degree of centralization) or are assumed by the participants themselves. In the case of a decentralized distributed structure, the architecture relies on economic motivations to coordinate the activities of different types of participants and incentivize them to act cooperatively in favour of the network. Participants conduct activities necessary to the well-functioning of the scheme as a result of the economic incentives they perceive for doing so. They might also assume the costs of governing the source code. Such economic incentives are transaction costs associated with blockchain technologies, and, while they tend to be lower than the costs represented by maintaining a centralized structure, they could potentially represent a participation hurdle to some participants.

In the case of more centralized structures around intermediaries, these intermediaries must have the necessary resources to finance the costs involved in assuming their intermediary roles. These can include costs for personnel, hardware, electricity, and so on, as well as costs associated with managing and maintaining the source code (e.g. hiring coders). A PES intermediary that undertakes the responsibility to provide these brokerage services must have the resources available to do this in a sustainable manner during the duration of the project. Their absence implies the cancellation and discontinuation of activities vital to the use of the technology, with all the institutional repercussions that this entails for the PES project.

The costs of alternative mechanisms

The costs associated with the use of a technology are, among other things, a function of the maturity of the same, the availability in the offer and the existing alternatives.

There are several non-distributed alternatives for handling information. Central databases, shared ledgers, cloud-technology supported services, and other alternatives can provide services that meet requirements of many PES schemes. For the cases in which these more traditional technologies meet the expectations of the scheme, it is worth contrasting them with the creation of a blockchain infrastructure, since the latter tend to be much more expensive in their development and in the training necessary for them to become operational.

Considerations for DLT implementation

Technical Considerations

Social Considerations

Economic Considerations

Technical Considerations

Access to electricity, internet and hardware

Basic requirement for participating in a digital network (to charge mobile phone/computer).

Maturity of the desired technological solution

Consider whether the technological option is mature enough for implementation

Feasibility of reliable oracle systems

Environmental data regarding the state of the environmental resources, and data regarding the environmental service must be interpreted and transformed into digital information that can be transacted in a DLT.

Technical partnerships available

The development of DLT protocols, of clients and of end-user applications must generally be outsourced to technical partners. Trusted partnerships must emerge with companies that can provide the technical support required for DLT development.

Social Considerations

Basic digital literacy

Participants must bring a minimal understanding of the usage of digital technologies in order to cope with the participation requirements. Trainings in DLTs are likely to be needed, but the basic ability to use smart phones and the internet are a pre-requisite. The degree of digital literacy required for participation depends on the role that the participant intends to assume and can variate from very simple (being able to use a simple application like Whatsapp) to advanced (commanding programing languages).

Acceptance towards technology adoption

The extent to which individuals or communities embrace or reject the adoption of digital solutions determines the possibility to succeed in structuring real life situations through DLTs. The degree to which participants perceive the benefits of a distributed system to improve their lives dictates the acceptability of the system.

No legal restrains for DLTs

Legal restrictions on the usage of blockchains and their applications make the successful usage of blockchains for PES unlikely.

Economic Considerations

Blockchain implications on WTP and WTA

WTA<WTP-TC … Blockchains can influence the values of WTP, WTA and TC.

The availability of funds to maintain the DLT infrastructure

In networks that are not decentralized, intermediaries must have the necessary resources to finance the costs involved in assuming their intermediary roles in the long run.

Redeemability of tokens

For those schemes where tokens are used for compensating ES providers or incentivizing validators, the tokens used must be redeemable for valuable assets, fiat money or other. Redeemability can be in some cases installed by integrating the services of token.

The costs of alternative mechanisms

Contrast the costs of alternative technologies against those associated to the creation of a DLT solution.

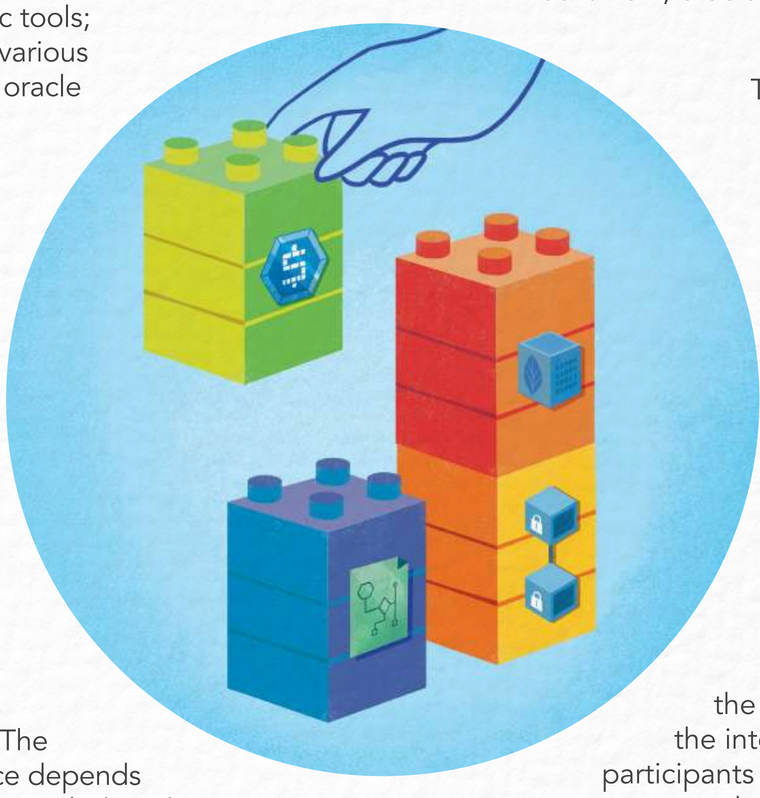
Considerations for architectural design

As mentioned in previous sections, blockchains can be structured in various ways. They can be private or public; they can be permissioned or permission-less; they can use different consensus mechanisms and cryptographic tools; they can assume various different types of oracle structures, etc… There are thus several structural decisions to consider when deciding on an appropriate blockchain architecture for the particular needs of a PES project.

The architectural design has stark institutional implications for the PES scheme. The appropriate choice depends on multiple factors, including the accessibility preferences, the relationships between participants, the socio-economic characteristics of stakeholders, the availability of oracle systems, costs, technical knowledge and others more.

Given the many possible architectural combinations, the ideal structures for each scheme may be unique for each PES scheme.

This section proposes architectural consideration for the implementation of blockchains. This set of considerations was adapted and adjusted to the particular needs of PES schemes using the work of Rauchs et al. (2018) and Wieninger, Schuh, and Fischer (2019).



Seven architectural considerations are grouped in: governance of the source code; network access, identity awareness, token type & validation incentive, consensus mechanism, oracle system, and user interfaces.

They are aimed at giving the reader a first glimpse of the various options that are available when implementing this digital technology.

Governance of the source code

The source code is the constitutional protocol where the rules that govern the interaction between participants of the blockchain network are programmed. Changes to this code imply that the entire operation of the blockchain is changed and the institutional structures that depend on them are changed.

Although the source code, or protocol, is generally stable (like the constitution of a country), there are times when it is necessary to review it and adapt it to the changing needs of the network.

"Protocol governance refers to the set of decision-making processes which enable alteration of the protocol in an orderly and legitimate manner"(Rauchs et al., 2018; 55).

The procedures that allow the code to be changed must be clearly defined before commencing operations. This is particularly relevant for schemes that pursue a higher degree of decentralization and where no intermediary organization (e.g. NGO or government body) can claim the right to manage the source code.

It should be clarified whether governance falls into the hands of a centralized entity that manages it on behalf of all the participants (for example, when the PES is organized by an intermediary in charge of maintaining all the technical elements of the scheme), if the governance is managed by certain chosen participants or if it is managed by all participants together.

Rauchs et al. (2018) propose that protocol-governance can be organized in various ways, including: a democratic one in which changes are voted on by majorities of the participants; a federated one, in which agents of a steering committee vote on decisions relevant to the network; a hierarchical one, in which a recognized leadership is in charge of managing the code; an anarchic one, where "change proposals are provided and approved on a cooperative and voluntary basis due to absence of a central authority" (Rauchs, Glidden et al. 2018; 55); and others.

Bearing in mind that PES are established within an existing institutional context, the existing social structures in the project areas should be taken into account when designing the protocol´s governance mechanism. Implementing a protocol governance without taking into account the existing governance contexts and the existing institutional frameworks is an inappropriate recipe for achieving acceptance of the scheme and the technology.

The perceived legitimacy of the governance structure is thus a key criterion for choosing the governance structure. A legitimate governance system will often be built on decision-making structures that stakeholders know and accept.

In this sense, it is also important to consider the transparency associated with decision-making processes. While a democratic process is more transparent and can enhance the credibility on the networks governance, a hierarchical process can be more efficient in implementing necessary changes to the network.

Likewise, it is important to consider to what extent the multiple participants are capable (and interested) in being part of the code's governance processes. There might be cases in which participants do not want to deal with these types of governance issues and prefer that such governance responsibilities fall on someone else. This might be the case for stakeholders that lack the technical knowledge to participate in such processes, or those who perceive high costs for doing so. If a participant enjoys the trust of other co-participants, the later ones might prefer to delegate governance powers to the first one in order to avoid incurring the costs of participating in the protocol's governance.

Network Access

Another element to consider when designing the blockchain infrastructure is the distribution of the access-rights to the network.

The network must clarify who has authorization to view the transactions that are coded in the ledger, who has authorization to propose transactions, and who has authorization to validate the proposed transactions.

For each of these design options, creators must decide whether access is open (with no restrictions), closed (restricted to certain groups or individuals), or semi-open (partially restricted depending on given criteria). For all restrictions on access rights, the authority in charge of granting them or denying them should also be specified.

A scheme that seeks the greatest possible transparency (for example to promote trust or counteract corruption) will benefit from not limiting authorizations to view transactions. The same applies when considering the accountability of stakeholders. A scheme where no authorization is required to see the transactions is more suitable to promote accountability.

On the other hand, those schemes with privacy concerns regarding the information managed by the network, or those schemes that seek to comply with data protection regulations, may be inclined to restrict the rights to view transactions.

Regarding the authorization to propose transactions, it must be decided whether anyone can propose a transaction or wither only a limited group of participants can do so.

The specific needs of the PES scheme will dictate who should have permission to propose transactions. The intended reach of the scheme will influence the permission structure for proposing transactions. If, for example, a PES scheme seeks to channel global interest and WTP for a global environmental service, then it might profit from reduced impediments to participation by removing any authorization requirements to propose transactions.

The right to validate transactions can be restricted in order to secure the scheme and protect it from actors who might want to corrupt transactions.

Identity awareness

Another structural decision with important repercussions is related to the awareness that the participants have about the identity of other co-stakeholders. The network must decide whether the identities of participants are to be known, or whether participants can by anonymous or participate under a pseudonym.

This decision will generally be the consequence of the offline relationship that the participants have prior to the use of the technology. If the participants in a scheme all know each other before building a blockchain network, the identity is obviously known. But if they don't know each other, it

is necessary to decide if they are required to reveal their identities before participating, or if they can participate without having to prove who they are. A process for reliably validating the identities of the respective participants is then necessary.

On this decision, it is important to take into account that the awareness of identities has implications for the Sybil-control mechanism. An architecture where the participants do not know the identity of the other participants must establish a secure Sybil-control mechanism that ensures that no participant assumes multiple false identities to manipulate the network consensus.

Sybil-control mechanisms

A main problem encountered by anonymous, distributed networks is the impossibility to know who is a co-participant of the network and what objectives they pursue. Given the ease of creating false digital identities, permission-less blockchains are exposed to a single person assuming many identities for covering misconduct or for gaining additional voting weight over the network, thus being able to manipulate it in their favour. A Sybil attack thus refers to a situation where an individual uses these numerous false identities to manipulate the network in its favour or to hide misconduct.

Sybil control mechanisms have been developed in order to ensure that no participant is able to amass enough voting power to corrupt the network. Mechanisms developed for countering

Sybil attacks include proof-of-work (PoW) and proof-of-stake (PoS), which are arguably the most relevant at the time of writing.

The idea behind PoW is to impede the proliferation of false identities by asking participants to invest resources for every action they undertake under an anonymous digital identity. This is typically associated to providing the computational solution to tasks that are difficult to solve, but trivial to verify, whenever they participate in transaction validation. Such mechanisms typically consist in finding a solution to a complicated cryptographic puzzle. Each attempted answer is associated to computational costs in the form of hardware and electricity. Since all validation attempts consumes costly resources, it is impossible to use multiple identities at zero cost. By making each validation attempt costly, the PoW mechanism promotes that validators are associated with real identities.

The proposition of Proof of Stake (PoS) is to replace the external resources that are used to secure the network (specialized computers and electricity), with an internal resource in the form of the native cryptocurrency of the project. A peer who wants to participate as a validator must pawn a certain amount of currency to be able to participate in the validation of a new block. This deposit fulfils the same role that computational power and electricity play in PoW in preventing a person from assuming multiple digital identities at no cost.

Legal requirements to establish the identities of the participants must also be observed. For some blockchain networks (for example those that use a payment token) legislation can require networks to identify their participants with the use of official documents.

It is also important to take into account those legal requirements that establish the "right to be forgotten", as established in the General Data Protection Regulation, of the 2014 judgment from the EU Court of Justice. If the information stored in a blockchain or a DLT is indelible, how can the right to be forgotten be ensured? This is not clear yet, but it can play an important role when deciding on identity awareness.

> Finally, it is important to bear in mind that knowing the identities of the participants contributes to the transparency of the scheme and is the basis for non-repudiation of information.

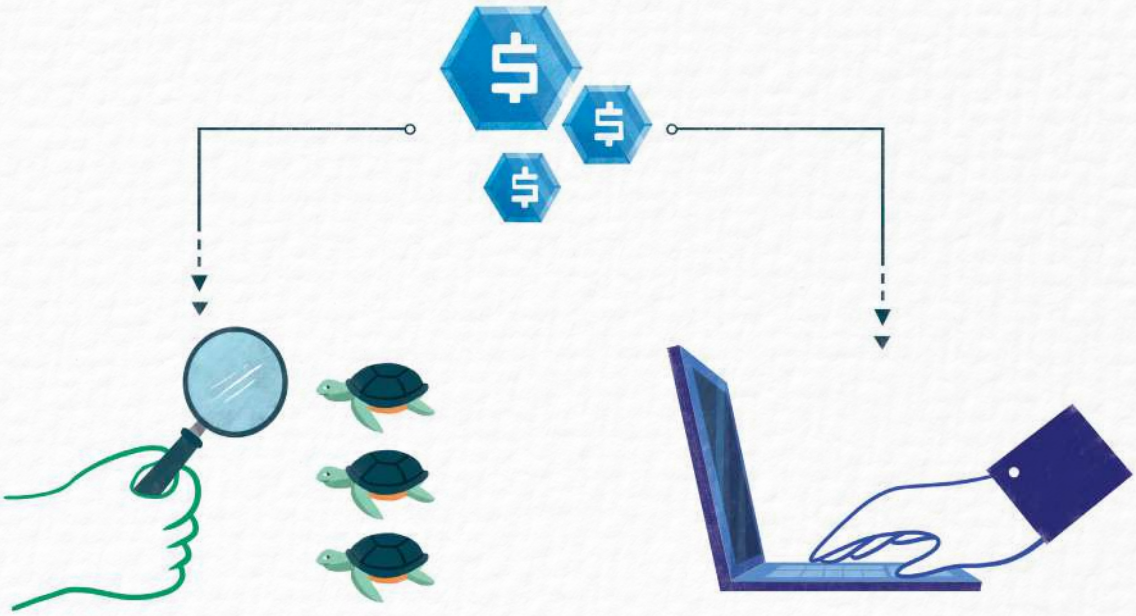
Token type & validation incentive

The choice of the right type of token for the project is linked not only to the need to tokenize real-life elements, but also to the needs of the blockchain incentive mechanism.

A distributed network requires participants to contribute to the management of the network. Management activities generate costs and must be compensated to ensure that participants perceive an incentive in managing elements of the network. Tokens are used as incentives in many networks.

Endogenous tokens are used to finance transaction fees and align the incentives of participants, particularly those of validators securing transactions (e.g. Bitcoin or Ethereum). Exogenous tokens are used for recordkeeping purposes (i.e. tracking real life objects) (Rauchs et al., 2018).

For networks with exclusively exogenous tokens, the enforcement of rules is entirely dependent on off-chain processes and relations. Offline contractual agreements



that facilitate honest interaction without the need to incur in monetary incentive mechanisms are needed.

In cases where exogenous contractual agreements do not exist or are difficult to build, the guarantees must be endogenous and formulated as economic incentives to pay with endogenous tokens.

The type of token that best suits both the incentive mechanisms and any other tokenisation objectives of the project must be thereafter chosen.

Additionally, the tokens must be designed in order to fulfil any other roles that they will serve within the scheme. It should be considered whether the tokens must provide another additional service, such as serving as payment-, utility-asset-, equity- or voting tokens.

When designing the token type, it is also worth considering whether the chosen type is appropriate for the implementation of the payment design principles. So for example, if payments are meant to be collective and retrievable, the token type should allow for such types of payments to be coded.

Finally, considerations related to the redeemability of tokens should also be taken into account.

Consensus mechanism

Consensus mechanisms are a coordination rule to unify the versions of the canonical common ledger in a network. A consensus mechanism is necessary to ensure that the various distributed versions of the common ledger reach a consensual state. All network participants may have individual versions of the transaction status, but an accepted global status is necessary for the blockchain to serve its coordination purpose. A protocol is thus necessary for participants to agree on a global status and update their ledgers accordingly.

Choosing an appropriate consensus mechanism for the specific needs and capabilities of the scheme is important. Selecting such a mechanism essentially involves choosing a criteriaon by which a unique valid ledger version is chosen from two or more different conflicting ones. All participants must adopt this criterion when choosing and accepting the canonical version of the common ledger.

As an example, the *Longest Chain Rule* or Nakamoto consensus, dictates a coordination protocol by asking all validating nodes to define the valid chain of transactions based on one simple static principle: assume as canonical the chain of blocks that accumulates the largest amount of validation work (the longest chain of blocks accumulates the most amount of work). If two or more versions of the ledger emerge as possible candidates to the canonical version, participants choose only the one that has grown faster and accumulates more validation work. Other candidate versions are neglected. Such finalization components present strategies for resolving divergences in the blockchain. They promote that all nodes eventually follow one authoritative unique ledger despite constant short-term disagreements.

Oracle system

Blockchain records may reference internal, endogenous information (such as a native token), or external, exogenous information foreign to the system (such as the weather). The integration of exogenous real-life information into the digital realm of blockchains requires the usage of oracles, which are gateways that bridge the gap between the blockchain and external real life information on assets, events, problems, etc.

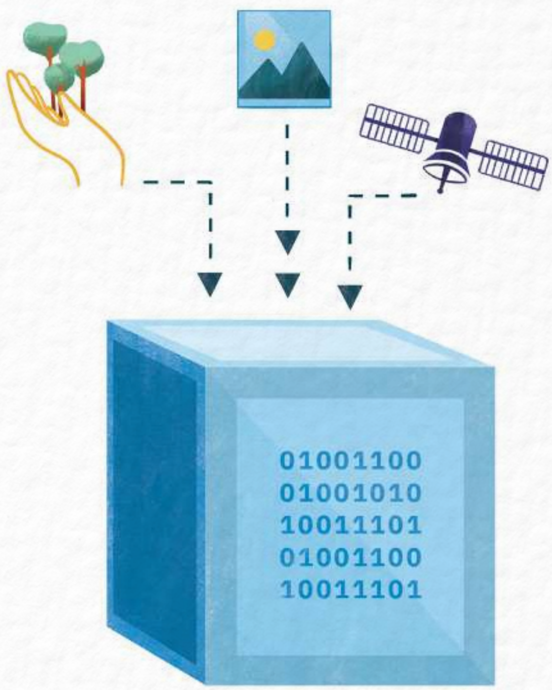
All types of oracles share the ability to: collect data from an off-chain source; transfer this data to the blockchain through a signed transaction; and make data available to smart contracts (Beniiche 2020).

PES schemes involve the use of exogenous data on the state of natural resources and environmental services. One must thus adapt the oracle system according to the characteristics and needs of their respective schemes. In this sense, it is important to first take into account the type of exogenous data that is sought to be perceived and digitized, and the availability of existing oracle solutions that can be used for this type of exogenous data.

It is also important to carefully analyse which existing technologies can be leveraged to serve as real-life information gateways.

When choosing the oracle system, it is also worth considering the expected reception that the oracle system might have among stakeholders. The acceptance (or rejection) towards a mechanism that collects information on not only the environmental resource, but also on the environmental services they provide, might partially determine the chances of successfully gathering, transmitting and using information in smart contracts. It is thus important to take into account the perceptions of ES providers, ES buyers, intermediaries and other stakeholders towards the oracle system.

So, for example, while an oracle system based on the usage of satellite photos for monitoring forest cover, or the use of GPS devices to indicate the position of fishing boats might be perceived as impersonal or objective, the use of cameras to monitor the activities of an ES provider or the usage of human-based oracle systems where co-participants report on the compliance of others might be perceived as a stark intrusion.



User interfaces

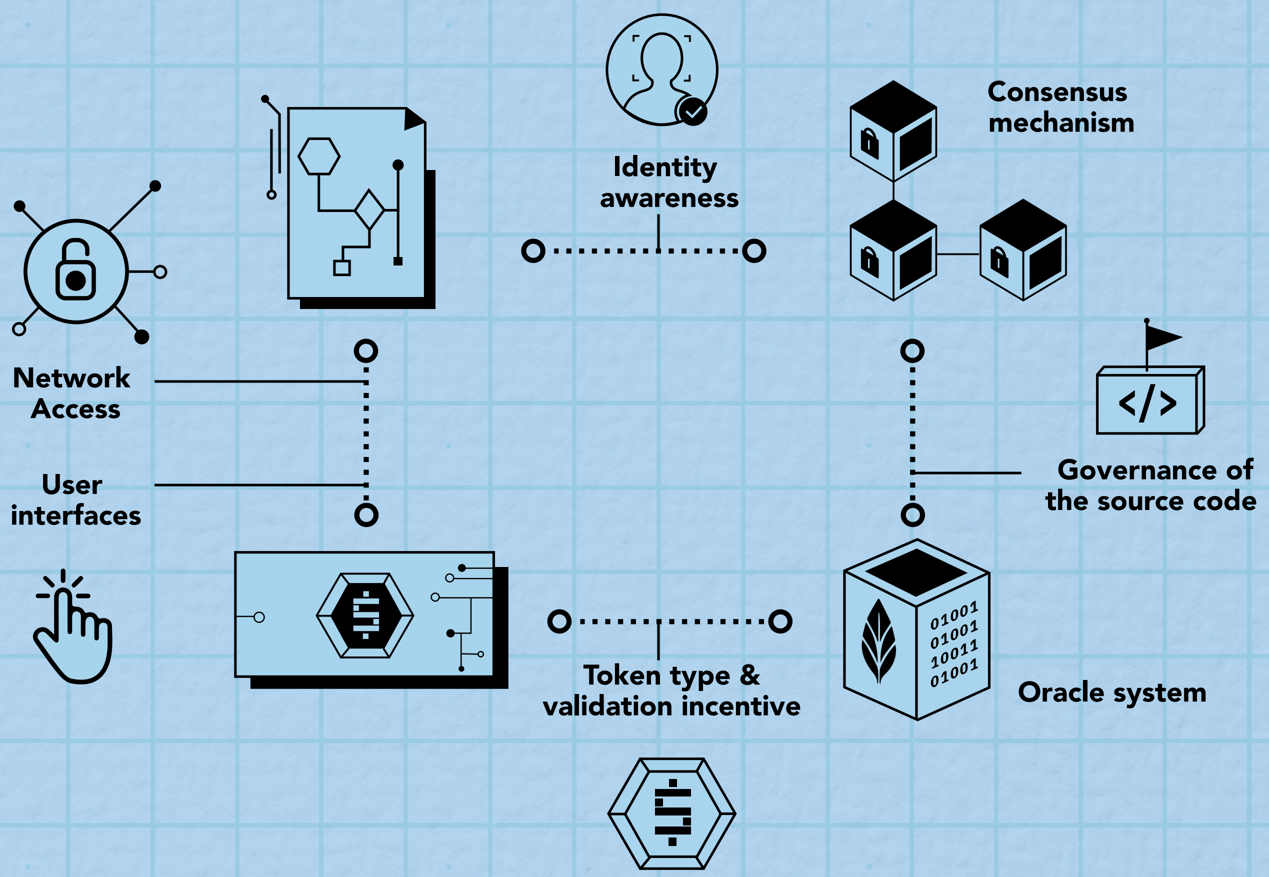
A final consideration is related to the design of the user interfaces which allow participants to interact with the back-end DLTs.

It is important to make sure that the applications are constructed in accordance to the capabilities and knowledge of the users. Many stakeholders might not be familiar with blockchains and some might not be familiar with the use of digital technologies (for example some indigenous communities in developing countries).

Adapting the user interfaces to the needs of their audience is important to make sure that participants can take advantage of the various opportunities and tools that emanate from blockchain implementation.

The user interface must be constructed in accordance with the technical endowment of participants. If participants have little technical know-how, the application through which they interact with the network must be simple, intuitive and user friendly.

Considerations for architectural design



User interfaces

Choose interfaces that facilitate and simplify usage

General consideration

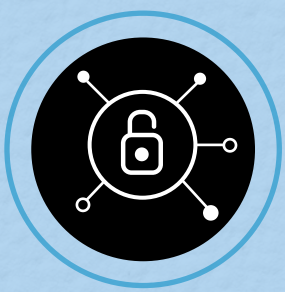
- Availability and costs of developing the interfaces.
- Make the applications in accordance to the capabilities and knowledge of the users.

Oracle system

Decide the type of oracle system that will be used

General consideration

- Implications on enforcement.
- Technological availability of oracle solutions.
- Type of exogenous data.
- Monitoring needs of the scheme.



Network Access

- Decide the degree of access that participants may have.
- For each design option decide whether it shall be open, closed (restricted), or semi-open.
- Decide who has the right to grant or deny access.

Authorization to viewtransactions

- Wish/need for transparency.
- Accountability of stakeholders.
- Privacy concerns.
- Data protection concerns.
- Scheme credibility.

Authorization to propose transactions

- Pursued degree of decentralization.
- Pursued reach of the scheme.

Authorization to validate transactions

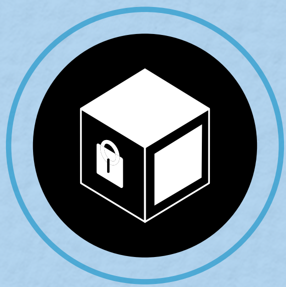
- Pursued degree of decentralization.
- Implications for the consensusmechanism.

Identity awareness

Decide whether identities of participants shall be known, or whether they can be anonymous, or even pseudonymous.

General consideration

- “Right to be forgotten”.
- Legal requirements on identities.
- Implications for the Sybil-control mechanism and consensus mechanism.
- Transparency and trust associated to known/ unknown identities.
- Existence of offline contractual agreements between participants.
- Environmental concerns associated to Sybil-control mechanisms.
- Monitoring needs of the scheme.



Consensus mechanism

Choose whether it is resource based or non-resource based.

General consideration

- Identity awareness of participants.
- Environmental concerns.

Governance of the source code

Decide whether the governance of the network protocol falls in the hands of an intermediary, or determine how it is distributed among stakeholders

General consideration

- Perceived legitimacy of respective governance structure.
- Transparency associated to each gov. structure.
- Traditional governance structures.
- Capability and will of participants to participate in the network governance.
- Relationship between PES stakeholders.

Token type & validation incentive

Choose whether the motivation for contributing to securing the network is monetary or based on offline contractual agreements.

General consideration

- Availability of offline contractual agreements
- Legislation on tokens for the project areas
- Payment-, utility-, asset, equity-, or voting token. Possibility to tokenize the environmental resources or the environmental service
- Options for increasing liquidity of payment tokens.

06.

Final thoughts

Blockchains offer valuable tools for iimproving PES schemes.The utilization of blockchains can potentially enable PES schemes to achieve outcomes that outperform those of schemes that do not take advantage of distributed digital technologies.

By matching the needs of PES schemes with the tools emanating from this new digital and institutional technology, this study helps understand how blockchains can improve the the design and management of PES schemes.

This study shows how blockchains can play an important role in revitalizing PES schemes, helping them achieve better environmental and social outcomes and stimulating their creation. This is particularly important in today's context, in which the urgency to achieve environmental sustainability implies using all available levers, particularly those that revalue environmental services.

People and organizations interested in the creation of PES schemes and educated in the use of this technology will have a broader palette of options for implementing successful PES schemes and managing them effectively. Not considering the usage of this technology can thus mean that PES schemes do not realize their full potential and PES outcomes might not reach optimal results in the light of the available tools.

Those individuals and organizations that better understand the changes brought about by the appearance of blockchain technologies will be better prepared to assume the new roles associated to managing blockchain-supported PES schemes.

Intermediary roles in PES schemes may change in the presence of blockchains. While classic PES intermediation roles typically include being scheme designer, providing technical support, financial intermediation, monitoring or lobbying, intermediaries that facilitate the appearance of blockchain-supported PES schemes might partially see their roles and contribution change to being, for example, protocol administrators, app creators, gatekeepers, token issuers, record producers, or others.

The lack of study cases and empirical evidence on blockchain implementation for PES represented an important limitation for this study. This limitation implied that there were no possibilities to confront the research with reallife evidence. Being an exploratory study, this investigation would have profited from empirical evidence to sustain or contradict the ideas that came up during the research phases.

Furthermore, the rapid evolution of blockchain technologies also means that the information related to the technology might be quickly outdated. Projects and companies are driving research and shaping the technological landscape of blockchains and DLSTs at high speed. New tools and networks appear on a weekly basis. The speed of development represents a limitation in analysing and understanding the innovative tools emanating from blockchain utilization. Despite the timelessness of some implementation benefits, this is and will continue to be a recurrent issue for research in DLTs for as long as research and development occurs at high speed.

Finally, it seems important to once again highlight that the possible social implications of blockchain implementation are still unknown. Whether technological implementation brings desirable social outcomes or not will depend on the context on which they operate and on the manner on which the technology can be adapted to the needs of the scheme. The first examples of PES schemes based on distributed ledger technologies will allow us to better understand the implications of technology adoption and the hidden consequences it entails.

Altogether, given the high potential that these technologies show in contributing to the improvement of EPS schemes, this study invites to continue conducting research on blockchains for PES. The opportunities arising from the use of distributed ledger technologies could revolutionize the way PES schemes are structured in the near future.

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