Advancing Sustainability with Blockchain-based Incentives and Institutions

Alex Smajgl [1,2,*]

Affiliations:

[1] Mekong Region Futures Institute (MERFI), Bangkok, Thailand

[2] Deakin University, School of Life and Environmental Sciences, Burwood – Melbourne Campus, Australia

*Correspondence to: Dr. Alex Smajgl, Mekong Region Futures Institute (MERFI), 399 Interchange 21 (32nd floor), Sukhumvit Rd, North Klongtoey, Wattana, Bangkok, 10110 Thailand; +61 411 571762; alex.smajgl@merfi.org

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Political science and economics define institutional arrangements as the set of formal and informal rules that guide and incentivise socio-economic activities [1–3]. These rules are typically combined with a specification of whom they apply to, under what circumstances and what penalty the breaking of the rule involves [2,4,5]. Institutional arrangements are therefore critical for pursuing sustainable natural resources management [3,6]. Anderies et al.[7] and Dietz et al.[8] identify the ability to monitor outcomes of user behaviour and efficient sanctioning to ensure rule compliance as critical design principles for natural resource sustainably institutions.

Technological progress evidently impacts on societies' ability to monitor behaviour and incentivise certain behaviour [3,8]. The introduction of blockchain technology or distributed ledger technology is increasingly perceived as the beginning of the fourth industrial revolution [9,10]. This research is focused on the potential of blockchain technology to provide new solutions for the sustainable management of natural resources.

Blockchain and distributed ledger technology

Blockchain technology – also increasingly referred to as distributed ledger technology [11] – involves three interlinked components. First, blockchains require a network of computers (nodes) that contribute processing resources. Each node participates with a unique public key and executes specific individual transactions with a private key [12]. Second, a ledger that records a continuously growing list of unalterable transactions resulting from the network-wide processing [13]. Third, a consensus algorithm (also known as a protocol) that defines how groups of nodes confirm transactions, which provides the essential security framework for the ledger [14]. This algorithm is the key element of the cryptographic proof necessary to verify data entering the network before adding them to the next encrypted data block.

Nakamoto [12] defines an innovative encryption for a ledger that establishes the digital currency Bitcoin, which provides a technical solution to a cryptographic challenge many investigated since [15]. The initial goal was to create a ledger system that protects buyers and seller by ensuring irreversibility and security of peer-to-peer transactions while preventing double-spending due to the cryptographic proof provided by multiple nodes [12]. The cryptographic innovation involves digital signatures (hash) and digital timestamps to encrypt transfers from one public address to another. Each user has a unique public address and a private key that allows the user to access the assets. The decentralised system implies that users don't need to know and trust each other, referred to as a trust-less network approach [14,16]. The initial design of Bitcoin triggered a substantial surge in the creation of non-state cryptocurrencies and other blockchain-based, decentralised services and markets. Decentralisation includes multiple benefits [10,17], including the improved security as central actors (e.g. bank) are increasingly exposed to hacks, independence from banks during financial crises, lower transaction costs, improved privacy of the internet, and improved power and control for costumers.

Another leap in the blockchain development is the design of blockchain based platforms, such as Ethereum, NEO, and EOS, which go beyond unconditional transactions and allow users to draft conditional transactions in form of smart contracts [10]. These second-generation blockchain approaches include a coding platform and a virtual machine to allow users to define so-called smart contracts and run bespoke decentralised applications. Numerous and varied blockchain based applications have been developed that are increasingly predicted to facilitate substantial ramifications for a wide range of socio-economic interactions [10,18,19]. Examples from this rapidly expanding field include the Golem project that creates a decentralised rental market for computing capacity [20]; the DeepBrain Chain project provides an AI computing platform; BAT, STEEM and AMP introduce monetary incentives for social network contributions. The Ontology, Civic and Hyperledger blockchain projects focus on specific protocols to enhance economic incentives, identity related or security focused processes respectively. Elastos aims to develop a new generation of Internet with advanced security protocols and integrated incentive mechanisms. All of these blockchain projects operate with their own "utility" tokens.

Improved sustainability through Blockchain based incentives and monitoring

Scholars predict that blockchain technology will transform many aspects of the prevailing socio-economic system, including various aspects of governance [9,18,21]. Blockchain technology provides mechanisms to alter the effectiveness of institutional arrangements concerned with the sustainable natural resource management. Advancing sustainability requires improved diagnostic capacity [2,4,22] as well as an evolutionary understanding of institutional dynamics [23–25]. Technology is an integral driver for institutional change and blockchain technology shifts boundary constraints for solutions developed in the fields of institutional economics, political science, and sustainability. Three dimensions are at the core of merging the technological innovation and the design of institutional arrangement:

- The ability to directly incentivise the behaviour of resource users.
- The utilisation of innovative monitoring capacity to establish an effective reward/penalty system and improve compliance.
- The mitigation of centralised power and related incentives that promote behaviour inconsistent with sustainable development objectives (coercion & corruption).

Various emerging blockchain projects aim to incentivise particular behaviour, for instance the provision of high quality content on social media or improved car driving behaviour. The principle mechanisms provide individuals or households with a payment for a desired behaviour. In the context of ecosystems unsustainable outcomes emerge due to a lack of effective incentives [26,27]. If, for instance prices for a particular cash crop increase, the pressure on remaining conservation forests and wetlands also increases. External costs are difficult to introduce to this calculation [28,29]. The conceptualisations provided in the next Section explain how blockchain technology accounts for the internalisation of externalities and, thereby, provide additional monetary incentives for individuals (e.g. land owners, car drivers, households) to employ sustainable strategies. Three examples that conceptualise blockchain-based mechanisms are described.

Monitoring is, as aforementioned, a critical aspect for institutional arrangements. Many institutional arrangements fail to achieve sustainable development objectives because of the lack of monitoring at the relevant scale [30]. Recent advances in remote sensing technologies combined with pattern recognition software to distinguish different forest types provide an effective monitoring mechanism of for example forest/canopy cover to audit the outcomes of actual forest related behaviour [31]. Such data and algorithms can be integrated in Blockchain designs to develop incentives based on actual observation.

The provision of economic incentives through centralised power structures without effective monitoring and enforcement has the tendency to involve coercion and corruption, which leads to unsustainable outcomes [32,33]. Scholars argue that the decentralisation of economic incentives can circumvent power related risks [34,35].

The effective combination of these three elements: incentives, monitoring and decentralisation, is a necessary prerequisite for blockchain mechanisms to contribute to the sustainable management of natural resources. Three conceptual examples for blockchain based mechanisms that propose substantial advancements in the design of sustainable institutional arrangements are described.

Blockchain solutions for sustainable natural resource management

Forest management

Deforestation is a key driver for the decline in global greenhouse gas mitigation potential[36,37]. Several global efforts have aimed at stabilising the extent of forests as carbon sinks or even reversing the trend in forest loss, including the UN/World Bank coordinated REDD and the

REDD+ programs [38]. Numerous observations and evaluations highlighted that REDD involves very high transaction costs, which is largely due to the centralised, multi-level governance mechanism [38,39].

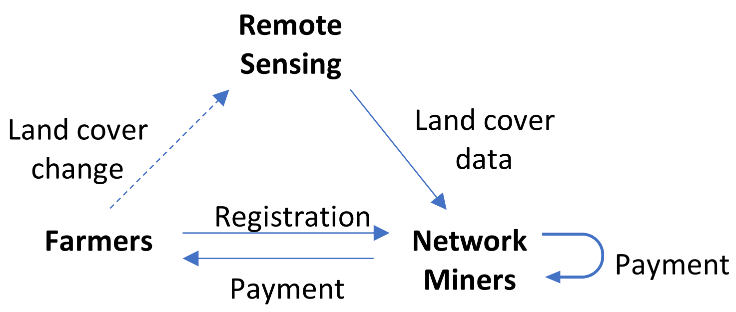

Figure 1: Conceptualisation of links in blockchain-based incentive mechanism for reforestation and avoided deforestation

Blockchain technology offers a decentralised bottom-up approach that would directly incentivise the behaviour of land managers. The proposed solution involves a payment token, which we refer to as the Global Forest Coin (GFC). Figure 1 visualises the conceptualisation of this incentive mechanism. In a first step, land managers would register their land. This step would require proof of ownership to avoid individuals establishing a claim for somebody else's land. Entries in the GFC database would be periodically monitored utilising remote sensing satellites (e.g. http://www.openforis.org). The monitoring step requires computation, which would be provided by a network of decentralised nodes (or 'miners') who would receive a reward for the processing in form of GFC. Farmers would receive their reward in form of GFC after their claim was validated through the independent blockchain approach and based on actual remote-sensing based monitoring data. The payment would be per ha for the previous period of one, three or six months, and could take into account the previous vegetation state as remote sensing data is continuously improving. Such a mechanism would generate regular income for the land owners and would improve forests' competitiveness against cash crops. During a reforestation phase, payments per ha might be higher than during a maintenance state when additional carbon sequestration declines. The mechanism could be modified to provide higher rewards for establishing mixed species than monoculture to improve biodiversity values. The land manager would be inclined to compare per ha returns from forests with other crops, which combined with non-pecuniary motivations could make the conservation of forests competitive.

The GFC decentralised token-based mechanism would allow Governments, International Organisations, and advocacy groups to increase the incentive by buying or mining GFC and increase the price. This would allow land owners to increase their income from forests and accelerate conservation incentives on the ground.

The conceptual blockchain based approach has some clear advantages as it minimises the risk for coercion and corruption and minimises transaction costs. However, the fact that the token would require a market for land owners to turn their earned GFC token rewards ns into fiat currency. Computationally, this step could be facilitated through the same software application as the initial step for registration or through one of the many. However, cryptocurrencies exchanges are subject to high volatility [17]. It is unlikely that risk-averse land owners will replace existing crops by forests if income prospects are highly uncertain. Equally, extremely high incentives could introduce substantial risks for food security and indirectly trigger a surge in food prices as food crops would start competing with high forest income. Third parties (Governments or international organisations) might provide the necessary interventions to stabilise GFC token prices to provide effective incentives for the desired land use change.

Deforestation could be targeted by regulatory instruments and require land owners to buy a certain amount of GFC tokens for a multi-year period and deposit them in a locked wallet. From a global perspective, this would increase the price and therefore the incentive to establish forests somewhere else, which would result in a stabilisation or even increase of global forest cover.

Groundwater management

Another environmental challenge is the sustainable management of groundwater aquifers. In comparison to forests, the system boundaries would not be global but rather regional in accordance to the geographical extent of the aquifer. Recently, Indian farmers faced increasing incentives to pump groundwater to irrigate crops and generate income as costs for pumps and energy (e.g. diesel and more recently solar) dropped substantially [40]. Environmental externalities, however, have rarely be accounted for and in many cases regulatory instruments had little to no effect [40].

Blockchain technology could provide improvements for monitoring and enforcement and introduce incentives for sustainable groundwater subtraction, similar to the forest example.

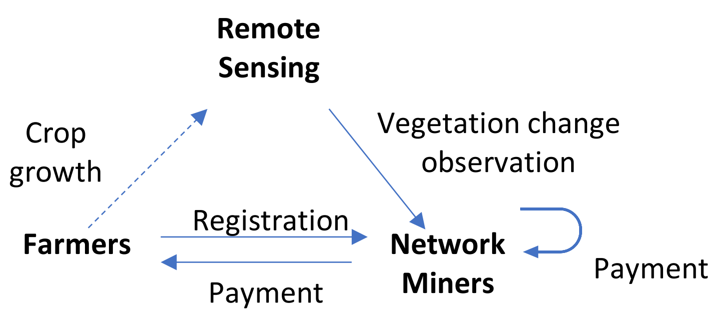

Figure 2: Conceptualisation of blockchain-based incentive mechanism for sustainable groundwater management

This blockchain-based mechanism would require the introduction of a token for a specific aquifer. Farmers adjacent to this aquifer would be offered to participate in this incentive scheme. After registration of individual farms through a software application and the validation of ownership through the network the farm would be listed for the relevant monitoring through remote sensing data. The combination with tools such as FAO's AquaCrop [41] provides essential high-resolution technology to track crop growth. Even easier would be a system that is based on actual well monitoring data (e.g. http://www.marvi.org.in/mywell-app). The network of miners would execute an algorithm that compares average crop growth, the actual rainfall and possible surface water subtraction to indicate if the farm used ground water or not. Depending on the crop planted the amount of water used could be estimated. This value would be compared with the level of sustainable groundwater use based on aquifer recharge for the past one or two years [42,43]. Farmers that use less groundwater than calculated for a sustainable amount per ha receive a number of tokens per megalitre. In the case of a drought the sustainable use level would decline and more tokens would be provided for lower or no use. In time of abundant water less tokens would be provided.

Governments could intervene and buy tokens which would increase the price. Governments could also decide to buy these tokens directly from farmers if the market mechanism is insufficient to manage a drought situation sustainably.

Greenhouse gas emissions trading

Economists advocated CO_2 emissions trading as a highly efficient instrument to curb greenhouse gas (GHG) emissions and was implemented in various parts of the world [44].

However, mitigation-focused instruments were only effective for large emitters as transaction costs for small emitters would have been too high. Blockchain technology offers a mechanism to incentivise small emitters. Similar to traditional emissions trading, such a decentralised mechanism requires an initial allocation of property rights, which can be allocated at no cost to the emitter (so-called grandfathering), can be auctioned, or sold for a fixed price [45].

A blockchain-based instrument approach would involve software application for individual registration and allocated a predetermined emission quota. Monitoring could utilise existing digital solutions installed in most newer cars that report on absolute and relative fuel consumption. Over the course of a certain period (e.g. 3, 6 or 12 months) the user would either receive tokens for emitting less (e.g. driving a car, heating the house, using fossil-fuel based electricity) or be required to buy tokens for emitting more than allocated. Network miners process the monitoring data for validation and to update a ledger for aforementioned credits or debits. Periodically the balance would be converted into reward tokens, for instance Avoided Emission Coins (AEC). This approach provides a clear incentive to reduce their fuel consumption. However, emitters that exceed their initial allocation require an additional enforcement mechanism, which could be implemented through the private sector or through the government. Petroleum companies could provide awards in form of lower fuel prices for those participating in this scheme, which would deliver to their CSR goals while amplifying the incentive for lower fuel consumption and mitigating parts of the costs for those exceeding their allocation. Governments could impose regulatory mechanisms to force car holders and households into such a scheme through incorporation into on road registration fees. Additionally, Governments could connect the AEC tokens to existing Emission Trading mechanisms, which would connect large emitters and the group small emitters and thereby find the most efficient mitigation potential.

Agricultural GHG emissions are highly problematic to be included as methane emissions depend on the feeding strategies for livestock (e.g. sheep and cattle) and NO_2 emissions arising from the management of crops (e.g. rice production [46]). Blockchain technology could easily implement a sales-based monitoring mechanism. However, this would neglect the relevance of the wide range of methane intensities for each ton of crop or livestock.

Discussion

Many scholars have investigated institutional mechanisms to contribute to the sustainable management of natural resources. Technological progress affects the effectiveness of institutional mechanisms, in particular by introducing improved monitoring or the incentivising of resource user's behaviour. Blockchain technology offers opportunities to craft instruments for sustainability-focused institutional arrangements. The combination of decentralised ledgers and state-of-the-art monitoring (e.g. remote sensing) allows circumventing centralised solutions, associated with high transaction costs and often failing to introduce effective incentives for the actual resource user [47]. This paper conceptualises three blockchain solutions that could improve sustainability for forest management, groundwater use, and the consumption of fossil fuels. These solutions demonstrate how the new era of token-economics could effectively change the behaviour of resource users. However, these technologies and the institutional arrangements they would be embedded in could have substantial side-effects. As for many other institutional arrangements, there is always a risk for resource users misusing the newly introduced economic incentives and lead to less sustainable outcomes. Previous assessments of economic instruments have demonstrated this effectively. Therefore, it is pertinent to test the institutional arrangements that would involve blockchain technology for example social simulation models, which allow for the modelling of individual behaviour [48,49].

In synthesis, blockchain technology offers new effective mechanisms for improving institutional arrangements for sustainable natural resource management and justifies increasing attention by the scientific community. Currently, blockchain developments are largely driven by private sector interests.

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