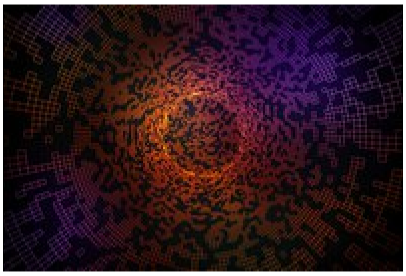
Drivers of change

Blockchain and the environment



An energy-intensive technology undermining climate change mitigation or a game changer for the governance of sustainability transitions?

Blockchain, a digital ledger technology, is widely known for its application to cryptocurrencies. Introduced in 2008 to serve as a public transaction ledger for Bitcoin, the technology has given rise to hundreds of cryptocurrencies (e.g. Ethereum, Ripple, NEO, Litecoin), as well as having **other emerging applications in diverse fields, including supply chains, digital content, patents, smart contracts, governance and e-voting** (EPRS, 2017).

Understanding the basics of blockchain technology is essential to assess its implications, which are potentially huge and transformative for society, the economy and the environment. The European Union Agency for Network and Information Security (ENISA) defines blockchain as:

> … a public ledger consisting of all transactions taking place across a peer-to-peer network. It is a data structure consisting of linked blocks of data … This decentralised technology enables the participants of a peer-to-peer network to make transactions without the need of a trusted central authority and at the same time relying on cryptography to ensure the integrity of transactions.
>
> (ENISA, 2019)

In contrast to the traditional ledgers used by banks and governments for centuries, which are centralised and inaccessible, **blockchain ledgers are decentralised and transparent** (EPRS, 2017). There is no central authority acting as the exclusive manager of the ledger, with sole responsibility for storage, updates and verification of transactions. On the contrary, **all participants of the blockchain network hold a copy of the ledger, and transactions — although encrypted — are visible to all.**

Although participants may not know each other, such a decentralised ledger system is viable because it is made trustworthy and secure by design. **Blockchain stores, shares and synchronises data as 'chains of blocks' using cryptographic techniques. Blocks represent recorded transactions, and each new block of transactions is linked to the previous ones, thus creating an ever growing chain** (Nakamoto, 2008). The creation of each new block must be approved by all network participants. This is achieved thanks to a predefined 'consensus mechanism' that sets the rules for the verification, validation and addition of transactions to the ledger (JRC, 2018). The most common approach is 'mining', which relies on the 'proof-of-work' mechanism. To add a block of transactions to a blockchain, participants compete to find a solution to a difficult mathematical problem based on a cryptographic algorithm (EPRS,2017). When a 'miner' finds the solution, and after verification from other participants, the block is added to the blockchain. All copies of the ledger are updated, making the new changes permanent.

Furthermore, **each block has a timestamp as well as a unique hash value referring to previous blocks.** The authenticity and integrity of transactions themselves are ensured by standard public-private key cryptography. With constant updates and validation made to the blockchain, as well as inspection of the complete history of transactions open (at least potentially) to everyone, unauthorised changes or tampering are almost impossible (JRC, 2018). **All these features make the ledger unique and immutable, ensuring trust among participants to operate their transactions.** In addition, these transactions can be executed automatically, without the need for human intervention, thanks to self-executing computer codes — named 'smart contracts' — that contain the terms of contracts and are stored in the blockchain.

'Permissionless' blockchains, of the sort just described, allow anyone to access, verify and add transitions. But it is also possible to set up a 'permissioned' blockchain where access to and the validation or addition of transactions are restricted to a more limited group of people (Kouhizadeh and Sarkis, 2018).

Overall implications (non-environmental)

Blockchain is currently a technology in an early phase of development, with many start-ups exploring potential applications. Obviously, cryptocurrencies remain the most mature and well-known application, offering the potential for transformative change in the international financial system. This warrants particular attention in view of the 'growing trend towards less trust in financial and governance institutions and greater social expectations of accountability and responsibility' (EPRS, 2017). The mainstreaming of cryptocurrencies could lead for instance to the emergence of a true global virtual currency, not controlled by any nation, or to several virtual currencies used by different communities on the basis on their shared values. For the time being, cryptocurrencies provide fertile spaces for experimentation in social innovation and new business models (EPRS, 2017). Beyond cryptocurrencies and the financial sector, the technology could potentially be extended over a wide range of other non-financial areas, including governance, commerce, healthcare, education and logistics (ENISA, 2019), although further research and innovation would be required.

One key advantage of blockchain technology is that it allows the ‘middleman’ to be removed from a wide array of transactions, which can lead to efficiency gains (EP, 2018a). The reduction of transaction costs, be they financial or administrative, can be particularly decisive for small businesses and start-ups, which often lack substantial financial capital and need to move fast. In addition, the use of smart contracts allows the automation of many processes (e.g. payment execution), thus further cutting down the cost and time of transactions (Kouhizadeh and Sarkis, 2018) and improving services by reducing bureaucracy (EP, 2018a). The application of blockchain technology in public administration can benefit users by allowing them to create records (e.g. land registries, birth certificates) without the unnecessary involvement of public officials (e.g. lawyers, notaries, government officials). Such a blockchain-based system has been tested in Estonia, where people have been allowed to use their ID cards to access a large variety of digital services (EPRS,2017).

The shift of control from a centralised authority to users within decentralised networks can foster potentially more participatory, transparent and decentralised governance systems and perhaps revive democracy as a result (EPRS, 2017). For example, the use of blockchain in electoral systems could transfer logging and verification tasks away from a central authority and distribute them among voters, who would hold a copy of the open voting record. Blockchain-enabled e-voting has already been used in internal elections within a political party in Denmark and shareholder votes in Estonia (EPRS,2017).

Other applications of blockchain are being developed for situations where it is necessary to know ownership histories. For example, blockchain can be used for digital content management by storing and authenticating ownership rights and licensing terms, enabling authors to know when and who is using their work and to be directly and immediately rewarded via smart contracts (JRC, 2018). This could help to protect copyright at a time when the internet has made piracy (especially of audiovisual material) common practice thanks to torrent applications and streaming.

However, blockchain technology also raises several security, privacy, data protection and accessibility concerns. First, the anonymity of users, the use of cryptocurrencies and the possibility for blockchain-enabled networks to operate across borders increase opportunities for illegal transactions and criminal activities, including money laundering and tax evasion (EP, 2018a). Institutional accountability and legal responsibility become increasingly diffuse, while identifying cryptography-literate perpetrators becomes more difficult. This makes it harder for national authorities to control these activities and enforce the law (EPRS, 2017).

Security breaches and malicious attacks can also occur, which can make users less keen to distribute sensitive information within the network. As the case of the cryptocurrency Verge demonstrates, smaller blockchains based on the ‘proof of work’ algorithm can be the victim of malicious attacks (such as a 51 % attack) from malevolent miners taking advantage of errors in the blockchain protocol to modify recorded transactions (Sedgwick, 2018). By using great computational power, miners can also compromise the decentralised character of the blockchain and exercise considerable power and control over the ‘mining’ process (Shawn, 2015).

Privacy and data protection concerns relate to the possibility of identifying individual users. The more personal data are stored on the blockchain, the easier it is to discover to whom they belong (EPRS, 2017). Recent research indicates that third-party web trackers can deanonymise users of cryptocurrencies by using the information provided by consumers on most shopping websites (Goldfeder et al., 2017). Another issue comes with the immutability of blockchain, as it may compromise the ‘right to be forgotten’, whereby users may, under certain circumstances, demand that their personal data be erased. Last, but not least, is the issue of accessibility and equity, as there is a risk that blockchain could increase the digital divide, either because of lack of access to blockchain-based services or lack of practical knowledge about how to use them (EPRS, 2017; ENISA, 2019).

Implications for the European environment

The most well-known implication of blockchain technology for the environment relates to its energy consumption and, therefore, its possible negative impact on climate. The current standard process of transaction verification, based on the proof-of-work algorithm, is ‘extremely energy hungry’ (de Vries, 2018), as it requires a huge amount of processing power, and, therefore, electricity, to run associated computer calculations. Wider use of blockchain technology could counteract climate change mitigation efforts, as electricity remains largely generated from fossil fuels worldwide. In 2016, generation from combustible fuels still accounted for 67.3 % of total world gross electricity production (IEA, 2019b).

The Bitcoin application is particularly illustrative. Compared with alternative payment methods, Bitcoin was claimed to be 20 000 times more energy intensive than Visa (Brosens, 2017). In 2019, according to some analysts, the energy consumed for each Bitcoin transaction had increased to 635 kWh, which is equal to the electricity that could power approximately 21 US households for 1 day (Digiconomist, 2019). Recent studies estimate Bitcoin’s electricity consumption to be between 20 and 80 TWh annually, or about 0.1-0.3 % of global electricity use (IEA, 2019a). For instance, the Cambridge Bitcoin Electricity Consumption Index (CBECI) cites a figure of 64 TWh per year (CBECI, 2019), which exceeds the annual electricity consumption of Switzerland or all electric vehicles in operation worldwide (58 TWh) in 2018. These estimates must be interpreted with caution, due to methodological issues, limited data availability and highly variable conditions across the industry (Koomey, 2019). Moreover, these figures are still much lower than other end-uses, such as cooling, which consumed 2 020 TWh of electricity in 2016 (IEA, 2019a).

Nevertheless, Bitcoin is only one cryptocurrency, which is only one application of blockchain. Finding a way to reduce the energy consumed for transaction verification will be essential. Swapping the orginal consensus mechanism, i.e. the proof-of-work algorithm, for other approaches (such as 'proof-of-stake', 'proof-of-authority' or 'proof-of-elapsed-time' algorithms) has already been suggested (Jones, 2017). Some cryptocurrencies and blockchain applications already rely on these alternatives. However, a thorough assessment of each mechanism and its energy impact and energy efficiency is still required (EP, 2018b). Switching to greener sources of energy and developing less energy-demanding computation are other options to be further explored (Jones, 2017). It would also be possible to reduce the energy consumption of Bitcoin by restructuring the way blockchain maintenance is incentivised (de Vries, 2019).

Like other emerging ICT-based technologies, blockchain also raises concerns about electronic waste (e-waste). Competing miners require more and more efficient mining hardware, leading to quick obsolescence, roughly every 1.5 years (de Vries, 2019). Since its creation, Bitcoin-mining hardware has already shifted from the use of central processing units to graphic processing units, field programmable gate arrays and application-specific integrated circuits. Rough estimates show that Bitcoin creates 135 g of e-waste per transaction, which is 30 000 g more than a Visa transaction (de Vries, 2019).

Notwithstanding the energy consumption and e-waste issues, blockchain technology can also support environmental protection. In particular, it can offer opportunities to make existing consumption and production processes more transparent, which could enhance their sustainability. A promising application relates to supply chain management in industries such as forestry, energy, food or mining. There are already standards and certification schemes to ensure sustainable and responsible supply chains, but existing processes remain costly and unreliable in many regions (EPRS, 2017). Blockchain can make information about the origin of a product, processes and the parties involved in related transactions and logistics visible, traceable and verifiable by all those in the supply chain (Kouhizadeh and Sarkis, 2018). As the information is secured and time-stamped, it cannot be altered or modified, which reduces the risks of fraud and errors (EPRS, 2017). This can support the application of sustainability criteria for the selection of suppliers, vendors, materials and products, as well as the design of more sustainable logistics networks and internal operations (Kouhizadeh and Sarkis, 2018).

Eventually, this would help consumers to make choices that do not undermine environmental protection — or human rights and working conditions — in countries across the supply chain (EC, 2019b). Experimentation is under way. For example, researchers have recently simulated the application of blockchain technology to electronically trace timber through its life cycle, combining an open source radio frequency identification system and a blockchain ledger to retain records in a secure and decentralised way (Figorilli et al., 2018). The Programme for the Endorsement of Forestry Certification, the world's largest forest certification system, has signalled its interest in blockchain (ITU, 2017).

Sustainability transitions

More generally, some internet and blockchain pioneers argue that blockchain-enabled initiatives, such as decentralised autonomous organisations (DAOs), could bring about new forms of governance arrangements that would challenge existing economic and power dynamics (EPRS, 2017). A DAO is an organisation that can run on its own, without the need for any central management, as the governance rules agreed by its members are programmed in smart contracts that are automatically enforced and executed through blockchains (EPRS, 2017). Based on the assumption that peer-to-peer and commons models of governance could manage resource use better than purely top-down governance approaches (for instance, building on Elinor Ostrom's work), some argue that DAOs could be a game-changer for sustainability (P2P Foundation, 2019). So far, however, DAOs remain largely at an experimental stage and in a regulatory grey zone (EPRS, 2017)

Other blockchain applications potentally beneficial to renewable energy diffusion, energy efficiency and the reduction of energy consumption are being explored. IBM and Energy-Blockchain Labs are experimenting with a blockchain-based green asset management platform for trading carbon assets in China in a more efficient way (IBM, 2017). Some envisage a blockchain-based peer-to-peer energy transaction platform that would enable efficient electrical energy transactions between prosumers and lead to economic and environmental benefits (Park et al., 2018). EnergiMine has developed a blockchain-based rewards system that uses digital tokens to incentivise consumers to save energy (Forbes, 2018). The issue remains whether these niche initiatives will scale up and whether their benefits are offset by blockchain's own energy consumption.

Implications for environmental policy in Europe

Blockchain technologies have attracted the interest of European public institutions. For example, the European Commission considers blockchain to be 'transformative for the decades to come' and it therefore 'aims at positioning Europe at the forefront of blockchain innovation and uptake' (EC, 2019a). The European Commission has recently co-initiated several initiatives to support the development, monitoring and standardisation of blockchain technologies, such as the European Blockchain Partnership (EC, 2019b) and the European Blockchain Observatory and Forum (EC, 2018), as well as extending funding and awards through the Horizon 2020 programme. The European Parliament Committee on Economic and Monetary Affairs concluded that the regulation of blockchain is not an immediate concern (ENISA, 2019). At present, however, the environmental and sustainability implications of blockchain remain insufficiently analysed. This is particularly true for energy consumption. More reliable data are needed on current and future blockchain energy consumption, which also requires more rigorous methodologies and alternative scenarios. Careful monitoring and sustainability assessments are required at global, European and local levels.

This brief belongs to a series of 'rapid assessments' on the implications of emerging trends for the environment and environmental policies in Europe. The identification of the topic results from a participatory horizon-scanning process run by experts from the Eionet National Reference Centres on Forward Looking Information and Services (NRC FLIS) during the period 2018-2019. The brief was drafted with support from the European Environment Agency (EEA) and the European Topic Centre on Waste Materials and the Green Economy (ETC WMGE). It is conceived as a living document that should be enriched through interactions with other knowledge communities and stakeholders, and evolve according to technological developments.

Type of signal: **Emerging trend**

Geographical scope: **Local, regional, national, European, global**

Origin of signal: **Technological**

Time horizon of expected significant impact: **Mid- to long-term**

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Main related EU policies

- 2030 Climate and energy framework
- Environment action programme to 2030
- Trade policy

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