Briefing note

Delivering blockchain's potential for environmental sustainability

Miriam Denis Le Sève, Nathaniel Mason and Darius Nassiry

October 2018

Key messages

- Blockchain could help address environmental governance challenges by offering a secure and verifiable record of who exchanges what with whom and who has what at a given time.
- Blockchain can be used to reinforce entitlements to use a natural resource, substantiate claims of reduced environmental impact and incentivise environmentally sustainable actions.
- There are key challenges to be addressed if blockchain is to work in the environmental sector, which include a lack of access to digital infrastructure among poorer and often rural communities, who are the stewards of many natural resources and environmental services.
- To realise more of the potential benefits of blockchain for environmental sustainability:
  - governments in poorer countries will need to invest in innovation and digital infrastructure to ensure their citizens can engage with and shape the opportunities that blockchain can create
  - governments in wealthier countries will need to support these efforts, and encourage innovation in less energy intensive blockchain technology
  - firms will need to support innovators in low- and middle-income countries, and target and tailor blockchain solutions to environmental sustainability problems that the technology can really address.

Glossary

Blockchain	A digital list of records in which transactions are recorded in 'blocks' and linked using cryptography. When the blocks are filled with data, they are 'sealed' and added to the blockchain chronologically in a manner that is verifiable and cannot be altered without the consensus of a majority of participants.
Cryptocurrencies	Digital assets that use cryptography to control key processes including creation of additional units and transfer of assets. Decentralised control is achieved through distributed ledger technology. In this way, cryptocurrencies operate independently of central authorities, such as banks.
Distributed ledger technology (DLT)	An umbrella term used to describe technologies that allow information or records to be transferred and updated by network participants, and facilitate this in a trustworthy, secure and efficient way without necessarily being controlled and administrated by a central party that is known and trusted by every participant.
Internet of things (IoT)	A network of 'smart' devices (typically involving sensors) that can communicate over the internet, collecting and sharing data.
Permissioned blockchain	A closed platform, built to allow an organisation or network of organisations to exchange information and record transactions. Participating organisations manage permissioned blockchains; only preapproved entities can access and interact with them.
Permissionless blockchain	Decentralised and distributed platforms that have no central governance. No single entity or government can bring the network down and participants must be incentivised (through tokens) to run and trust the network – transparency is paramount.
Smart contract	A computer protocol intended to digitally facilitate, verify or enforce the negotiation or performance of a contract, without third parties.
Digital token	Fungible (that is, mutually exchangeable) and tradeable digital assets commonly based on blockchain – such as cryptocurrencies. In permissionless and some permissioned blockchains, tokens are offered as a reward, incentivising participants to contribute their resources (e.g. computing power and time) to core processes that underpin the functioning of the blockchain, such as validating transactions.

Introduction

By placing trust and authority in a decentralised network, rather than in a powerful central institution, blockchain – the technology underlying Bitcoin and a growing number of financial and non-financial use-cases – could reconfigure how we assign, protect and transfer many assets and services, including in the natural environment.

In the decade since blockchain was developed as the technology behind Bitcoin (Nakamoto, 2008), several pilots and a few larger-scale projects have sought to apply it to various global challenges – from voting and identity to health (Galen et al., 2018; Blockchain and UNDP, 2018; Pisa, 2018). In the environmental sustainability domain, a recent review identified over 65 existing initiatives, mainly at concept or pilot stage (Herweijer et al., 2018). While there is, as yet, little hard evidence on blockchain's ability to address environmental problems at scale, its enthusiastic uptake reflects broad potential at a conceptual level (Box 1).

In this briefing note, we explore the following questions:

- What kinds of environmental sustainability challenges might blockchain address?
- What are the considerations to harness blockchain as a positive force for environmental sustainability?
- What steps are needed to help achieve the potential?

The briefing recognises the scope of blockchain's disruptive potential, while also acknowledging key barriers to efficacy, uptake and scaling – and proposes, where possible, solutions to these challenges. We focus on environmental challenges, and blockchain considerations that are relevant to low- and middle-income countries while placing these in a global context.

This briefing note, which draws on interviews with experts, discussions from a consultative roundtable and a desk review (see Acknowledgements), is intended for a broad audience interested in development, environmental sustainability and technology. We address our main recommendations to governments of low- and middle-income countries that seek to harness blockchain, as well as providing additional recommendations for governments of wealthier countries and businesses and start-ups that may be developing blockchain applications.

Box 1 Why could blockchain matter for environmental sustainability?

The potential of blockchain to support environmental sustainability comes down to one key feature: its ability to provide a verifiable record of who exchanges what with whom – and therefore who has what at a given time. Many of the challenges for how we manage natural resources and maintain ecosystem services arise because of a lack of trust and confidence in the rules governing exchange and possession: will governments and other users respect entitlements to use a natural resource? Can companies' claims of reduced environmental impact be verified and trusted? Can environmentally sustainable actions be effectively incentivised?

Blockchain's ability to provide a verifiable and transparent record may make it well-placed to help answer such questions. By decentralising and digitising the adjudication of what is trustworthy, blockchain also has the potential to empower broader communities of stakeholders and improve the slow, costly intermediation associated with our current models of environmental governance.

But for this potential to be fulfilled, a number of conditions will have to be met. And, in this context, it should be noted that not all blockchains are public. 'Permissioned' blockchains – in contrast to public, permissionless networks – are designed to restrict access to only verified parties. This characteristic has important implications for the extent to which blockchains can disrupt existing power dynamics and potentially dis-intermediate powerful central entities, such as governments or dominant firms (Pisa, 2018).

Opportunities

Blockchain technology can address a range of environmental sustainability challenges. Building on Chapron's review (2017), we suggest that blockchain might support environmental sustainability through three key underlying mechanisms relating to **resource rights**, **product origins** and **behavioural incentives**. These mechanisms reflect three underlying challenges in relationships between people that have consequences for sustainable management of natural resources and the environment. Other papers provide more thorough surveys of existing examples (e.g. Herweijer et al., 2018), though few have been fully evaluated or scaled. Here, we highlight an illustrative selection relating to low- and middle-income countries:

- **Origins.** Where it is used to encode verifiable information about a product's origins, blockchain could give greater confidence to consumers and intermediary companies in supply chains about the environmental impacts of their purchasing decisions. An early example in this area was the work of Provenance, a UK-based start-up, to pilot a tuna-tracing system on a public blockchain. Similar initiatives have emerged in the timber trade – for example BVRio's system in Brazil makes use of blockchain technology to support the traceability of wood products from source to final buyer (Herweijer et al., 2018).
- **Incentives.** Blockchain could offer greater certainty to people that they will be rewarded for environmentally sustainable behaviour. For example, GainForest has developed a concept to incentivise farmers in the Amazon to preserve rainforest, offering potential climate change mitigation and biodiversity benefits. Remote sensing satellites verify the preservation of a patch of forest and blockchain facilities the payment of internationally crowdfunded financial rewards to farmers (Greene, 2018).
- **Rights.** Using blockchain to encode rights to use natural resources could increase a right-holder's confidence that their share can be defended against expropriation, and that overuse by others, or themselves, will be identifiable. In turn, this could discourage each right-holder from overusing the resource for short-term gain. Existing examples for this mechanism are rarer. The majority of pilots explore private property rights to land, and focus on the economic, rather than environmental, benefits – though some of these are in middle-income countries such as Ghana, Georgia and Brazil (Graglia and Mellon, 2018).[1] Common-pool resources – that is, natural resources that are owned and managed collectively by a community or society rather than by individuals – are potentially more complex, featuring rights for different types of use and nested levels of rules (Ostrom and Hess, 2007). However, blockchain is intuitively suited to decentralised or collective management of common pool resources, given the technology itself functions through distributed consensus rather than central control. A rare, though unsuccessful, example is an attempt to use blockchain to encode water rights in Australia (Box 2). It should be noted that markets for water rights are rare, globally, and require a high degree of institutional and technical capacity, even without introduction of technologies like blockchain.

Initiatives may work through more than one mechanism (Figure 1). For example, in the energy sector, which has been a major focus for blockchain development, the technology could unlock peer-to-peer trading in decentralised energy systems using small-scale renewables (Livingston et al. 2018). For example, Power Ledger uses a blockchain-based platform to let consumers buy and sell renewable energy directly

1 It is important to note that evidence for economic benefits from private land rights at household level is inconclusive (DFID, 2014). Additionally, where improved security of tenure increases investment in a fixed resource like land, it is not necessarily good for the environment – for example where it encourages use of artificial fertilisers to boost production. While some have hypothesised a link between land rights on blockchain and conservation benefits – such as reducing illegal forest clearance in the Amazon (Mendes, 2018; Kshetri 2018) – we did not identify applications to land rights that put this benefit front and centre, nor any that are attempting to rigorously test the hypothesis.

with one another (UNDP, 2018). Following success in Australia, the company launched a pilot project in Thailand in 2018 (BCPG, 2017). This speaks to both traceability (identifying the source of a kilowatt hour, including whether it is renewable or not) and incentives (encouraging households and businesses to install renewables to allow them to make money from excess generation capacity) (Basden and Cottrell, 2017).

Two other features of blockchain further extend its potential. First, as the basis for **smart contracts**, blockchain can accelerate and automate exchanges of information and value concerning natural resources and environmental sustainability. Smart contracts embed the contract terms in computer code, allowing negotiation or performance of the contract to be automatically facilitated, verified and/or enforced, without the need for intermediaries such as brokers and lawyers (for an example of this, see Box 2). External data feeds, termed 'oracles' in the context of smart contracts and blockchain, provide the information to trigger execution of the smart contract, unlocking the value only once certain conditions are met. For many environmental applications involving biophysical conditions, 'hardware oracles' are needed, principally sensors, as opposed to software oracles, which handle information that is already digitised.

Second, as a basis for **digital tokens** and **cryptocurrencies**, blockchain could create new systems of value and remuneration around natural resources and environmental services. To date, the main driver for purchase of cryptocurrencies such as Bitcoin has been speculation, whereby investors buy the digital coins or tokens in the hope that increasing demand against a fixed supply will yield increasing value (cryptocurrencies are designed so that only a finite number of units can ever be issued). This speculation element is visible in some token issuances for environmental projects – that is, it is a quick and largely unregulated way to raise capital for blockchain projects. But some blockchain-for-environment projects appear interested in establishing self-contained 'token economies', in which tokens can be used to buy and sell environmental services. The Sun Exchange, for example, uses cryptocurrencies to underpin its model of cross-border solar-energy financing. Investors can purchase solar panels in communities in schools, in countries including South Africa and Moldova. The schools

Figure 1 Select examples of how blockchain is currently being applied to environmental sustainability challenges

	Product origins	Behavioural incentives	Resource rights
	Assurance about environmental sustainability of production	Assurance about reward for environmentally sustainable practices	Assurance about who has what right to what share of a natural resource
Energy	Peer-to-peer trading in renewables		
		Renewables investment	
Forests	Sustainable supply chain traceability	Payment for ecosystem services	
Fisheries			
Water		Resource rights trading	

Source: authors

and communities then lease, and eventually purchase, the panels by paying a regular fee. Participants have the option to pay in a number of cryptocurrencies or their national currency (UNDP, 2018).

Challenges

For blockchain technologies to fulfil their potential and deliver their promised benefits for environmental sustainability, a number of challenges will need to be addressed. It is easy to draw parallels with the internet, another decentralising digital technology that has transformed human society in many ways but which, in the words of the inventor of the World Wide Web, has 'failed to deliver the positive, constructive society many of us had hoped for' (Siegele, 2018).

For blockchain, the challenges are both technical and political, and though significant, are not necessarily insurmountable. They are especially relevant to questions of environmental sustainability in low- and middle-income countries but are also relevant to attempts to use blockchain for socially valuable outcomes more generally.

A solution in search of a problem

Blockchain is not always the best tool for the job. For example, in tracing product origins, distributed and consensus-based verification systems may be unnecessary where most parties are known to each other; existing supply-chain management systems and centralised databases already largely suffice for such purposes (Alicke, 2017). Certainly, there are many supply chains in which the parties do not know each other – for example those for agricultural commodities sourcing from a web of out-growers in low- or middle-income countries. However, the larger the network, the greater the cost – that is, the computing power and energy required to verify transactions.

A heavy environmental footprint

The original mechanism to validate transactions – consensus protocol – in a blockchain network

Box 2 Civic Ledger's Water Ledger

Civic Ledger is a technology start-up working with the Australian government to digitise operations and services using blockchain and smart contacts.

In 2017, the company explored using blockchain to improve the transparency of trading of water rights. In principle, trading water rights allows for water to be allocated more efficiently: for instance, a farmer who manages to obtain the same value yield while using less water could sell their excess water allocations to another user.

Australia is a world leader in water trading. But water training is a complicated and opaque industry, with four state water registers and many brokers, exchanges and business rules. The four registers – which are the primary source of publicly available market information – are not interoperable and water trading information is slow to be updated.

With a grant from the Australian government, Civic Ledger developed a proof of concept for 'Water Ledger' – a blockchain-based platform allowing smart contracts to facilitate and monitor peer-to-peer water trading and automatically update state registries. The objective was to reduce friction and complexity in a water trade, allow farmers to make more informed decisions about trading their water and bring confidence and trust to the water markets.

As a proof of concept, much of the project was focused on increasing the awareness, understanding and acceptance of government partners about the use of blockchain. And while Civic Ledger is yet to take Water Ledger beyond this, the company is confident that state governments in Australia will consider the technology as an option not only for bringing transparency to water trading but also for addressing corruption, which continues to be a huge challenge for water management in the country (ABC, 2017).

Source: press reports and expert interviews.

is known as 'proof-of-work' and is energy intensive because it relies on multiple computers undertaking complex cryptographic calculations to reach consensus on updates to the ledger (Hasse et al., 2016). The total electricity consumption of the Bitcoin network, which uses the protocol, is now estimated to be more than that of the whole of Austria in 2015 (de Vries, 2018). Data on the source of energy used by the large data centres that now perform the majority of calculations is not known, but most are in China where 58% of installed generation capacity is coal-fired (IEA, 2017). The huge computational and energy demands of proof-of-work also inhibits the scalability of blockchain applications: the Bitcoin blockchain can currently support only 7 transactions per second, while the Visa network can support more than 50,000 (Hasse et al., 2016).

As important as the energy source, then, is finding ways to reduce the energy intensity of the system, which principally depends on developing alternative consensus protocols (Truby, 2018).[2] Blockchain's energy usage doesn't rule out a net positive contribution to environmental sustainability. However, the environmental utility needs to be evaluated in terms of the amount and type of energy the application uses, as well as opportunity costs (alternative ways to derive utility from the energy). Assessing the trade-offs is highly complex: in the near term it is likely that those considering blockchain for environmental purposes will need to use expert judgement rather than hard science to do so.

Permission equals power

Permissioned blockchains are increasingly the focus of development, rather than the permissionless variety (see Box 1). In supply chains, for example, a permissioned blockchain traceability system can offer participating companies privacy for commercially sensitive transaction information and improve efficiencies by reducing the number of parties and data involved. There are also various reasons for why permissioned blockchain may be preferable for resource rights: data volumes are kept to a more manageable level and anonymity offered by many public blockchains is not desirable for rights, which need to be linked to identifiable rights-holders. Another reason is that, for governments, the authority to adjust entitlements without the consensus of all participants is crucial (Graglia and Mellon, 2018).

Adjustments could be made as a pragmatic response to erroneous entries on the blockchain or, for natural resources such as water, in response to natural variation in stocks and flows from season to season and year to year. However, it is also possible that an authority that retains power over a permissioned blockchain may not act benignly – for example where an authoritarian regime decides to expropriate citizens' property or entitlements to natural resources. Even the perception that this might happen could undermine confidence in blockchain solutions: in a recent survey more than a quarter of households in Tanzania and Indonesia felt it was both possible and probable that they could lose their tenure over non-residential land – used mainly for smallholder farming – in the next five years (Gallup, 2017). Of course, any technology used to store data can be manipulated or overridden by an entity with sufficient power. Yet it shows that blockchain's ability to overcome entrenched power dynamics depends on the intent of existing power-holders, the quality of governance more generally and the type of blockchain adopted (permissioned vs. permissionless, in the first instance). This also provides an argument for public, permissionless blockchains – especially for applications involving governance of environmental commons.

Genus, not ecosystem

Blockchain depends on other technologies to reach its full potential. As such, blockchain is one genus, in a much broader digital ecosystem, interdependent with others such as artificial intelligence and the internet of things. For example, blockchain and smart contracts cannot facilitate trustworthy, automated markets for renewable energy in a decentralised network, without an 'oracle' – in this case, smart meters to collect, process and transmit data on production, consumption and storage in

2 For a review of current and proposed alternative consensus protocols, see Wang et al. (2018).

real time (Livingston et al., 2018). This points to the need for physical infrastructure to generate data in the first place – and this requires significant investment in monitoring for the relevant natural resource systems.

Garbage in means garbage out

A consequence of the need to encode physical resources and assets as digital records is that the trustworthiness of data depends as much on the security of that process as the blockchain onto which data is encoded. Blockchain's immutability makes the need for accurate inputs even more important. As noted, digitisation can be automated using the internet of things or remote sensing, as in the case of forest conservation by satellite, mentioned in the previous section on opportunities. However, while human data-entry is open to manipulation and error, automated digitisation may be vulnerable to hacking.

There are further challenges in natural resource systems, where key parameters can be difficult to define, trace and measure: standardising data collection across multiple and geographically dispersed actors is challenging (a common hurdle for global supply chains); and reaching consensus on the validity of existing registries may be difficult. The last issue is particularly relevant to resource rights in low- and middle-income countries, where claims may overlap, and customary and collective forms of tenure may exist alongside – and sometimes in contradiction with – formal, private property rights (Ostrom and Hess, 2010).

An uneven playing-field

To be empowered by blockchain technologies, participants need a minimum level of digital access – starting with fast and reliable internet connection. In 2016, 82% of people in high-income countries had internet access compared to only 14% in low-income countries (World Bank, 2018). If smallholder farmers in a supply chain are to participate as empowered agents in blockchain solutions and receive incentives, such as payment for ecosystem services, via blockchain-enabled platforms, internet access will be essential. So, too, will a degree of digital literacy to ensure all participants in a peer-to-peer network have a grasp on key concepts (even if efforts are underway to create simple user interfaces) (Gatteschi et al., 2017). Policy-makers and blockchain developers must integrate technical understanding with sociological and political aspects. For example, German development agency GIZ has established a Blockchain Lab, which matches blockchain start-ups with legal, managerial and financial experts, supporting solutions of relevance to the Sustainable Development Goals in developing countries (GIZ, 2018).

Conclusions and recommendations

Use-cases of blockchain for environmental sustainability and natural resources management are rapidly evolving. In our assessment, we identify potential but also a significant set of preconditions, several of which could be harder to achieve in low- and middle-income countries. Numerous stakeholders will need to work together if we are to make the most of blockchain for environmental sustainability – and minimise its downsides and risks. There is good reason for cooperation: the actions we propose would strengthen the chances of success for blockchain applications to support a wider set of socially valuable outcomes, not only those relating to the environment.

Governments of low- and middle-income countries should:

- **invest in the digital infrastructure and literacy that enables participation in blockchain solutions**, including bandwidth, internet enabled hardware (e.g. internet-of-things devices) and digital education. For environmental sustainability applications, governments should pay particular attention to including rural and coastal communities, who are often stewards of natural resources such as timber, fish and water.
- **establish local innovation labs with capability in blockchain and related technologies** to improve ownership of and relevance for blockchain solutions for their citizens. Such labs should nurture the skills required for blockchain and other technologies to support a digital economy, including coding,

cryptography and data science. The labs should also facilitate partnerships with specialists in relevant policy fields to orient blockchain solutions to environmental problems facing local communities, as well as to develop appropriate policy to govern blockchain projects active in their country, region or city.

Governments of donor and industrialised countries should:

- **incentivise blockchain innovators to reduce the environmental footprint of the technology.** Although the main blockchain-related preoccupation for regulators is fiduciary risk associated with cryptocurrencies, the environmental footprint of blockchain systems also requires attention. Governments can use various fiscal levers, including levies on transactions relying on polluting blockchain technologies, to encourage a shift to renewable power and innovation in less energy-intensive consensus protocols (Truby, 2018).
- **support the efforts of poorer countries to capitalise on blockchain technology.** Aid programmes can invest in digital infrastructure and technical assistance to support policy-makers and citizens to better utilise the technology and orient it to their needs. Policy and regulation has a role to play too, given firms that are pioneering applications are concentrated in rich countries, and this can also have global reach – for example through international natural resource supply chains.

Start-ups and larger firms deploying blockchain for environmental sustainability challenges should:

- **ensure that all candidate applications:**
  - are developed with subject specialists to ensure they address a defined and relevant problem for environmental sustainability based on robust natural and social science;
  - are fit for purpose in terms of design and implementation, paying particular attention to the question of permissioned vs. permissionless systems and the risks of inaccurately digitising natural resources and entitlements onto blockchain; and
  - assess and disclose the potential environmental benefits, against the environmental footprint of the proposed blockchain solution.
- **support innovators and regulators in low- and middle-income countries by sharing and building skills** – for example through partnerships with local technology organisations and policy-makers.

References

ABC (2017) 'Murray-Darling Basin: NSW's most senior water bureaucrat resigns over corruption allegations'. Australian Broadcasting Corporation, 15 September (www.abc.net.au/news/2017-09-15/murray-darling-basin-nsw-top-water-bureaucrat-resigns/8951258)

Alicke, K. (2017) 'Blockchain for supply chain – a must or a maybe?' Disruption Hub, 7 February (https://disruptionhub.com/blockchain-supply-chain-must-maybe)

Basden, J. and Cottrell, M. (2017) 'How utilities are using blockchain to modernize the grid'. Harvard Business Review, 23 March (https://hbr.org/2017/03/how-utilities-are-using-blockchain-to-modernize-the-grid)

BCPG (2017) 'First in South East Asia: BCPG and Power Ledger to bring distributed renewable energy trading to Thailand'. Press Release, BCPG, 18 December (http://bcpg.listedcompany.com/newsroom/20171218-bcpg-news1-en.pdf)

Blockchain and UNDP – United Nations Development Programme (2017) *The future is decentralized: blockchains, distributed ledgers, & the future of sustainable development*. White Paper. Blockchain and UNDP (www.blockchain.com/whitepaper/index.html)

Chapron, G. (2017) 'The environment needs cryptogovernance' *Nature* 545(7655) (www.nature.com/news/the-environment-needs-cryptogovernance-1.22023)

DFID – UK Department for International Development (2014) *Secure property rights and development: economic growth and household welfare*. DFID Property Rights Evidence Paper. London: DFID (www.gov.uk/government/publications/secure-property-rights-and-development-economic-growth-and-household-welfare)

Galen, D., Brand, N., Bourcherle, L., Davis, R., Do, N., El-Baz, B., Kimura, I., Wharton, K. and Lee, J. (2018) *Blockchain for social impact: moving beyond the hype*. Stanford Graduate School of Business Center for Social Innovation and RippleWorks (www.gsb.stanford.edu/sites/gsb/files/publication-pdf/study-blockchain-impact-moving-beyond-hype.pdf)

Gallup (2017) Global Property Rights Index (PRIndex): 2016 testing of a new survey module on perceptions of land tenure security in nine countries. Washington DC: Gallup Inc. (http://s3.amazonaws.com/prindex/publications/2/PRIndex_2016_Analytic_Report_FINAL.pdf?1512752596)

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C. and Santamaría, V. (2018) 'Blockchain and smart contracts for insurance: is the technology mature enough?' *Future Internet* 10(2): 20 (www.mdpi.com/1999-5903/10/2/20/html)

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (2018) *GIZ Blockchain Lab: how can we leverage the disruptive potential of distributed ledger technologies for the Sustainable Development Goals?* Eschborn, Germany: GIZ (www.giz.de/en/downloads/Factsheet_Blockchain%20Lab.pdf)

Graglia, J.M. and Mellon, C. (2018) 'Blockchain and property in 2018: at the end of the beginning' *Innovations: Technology, Governance, Globalization* 12(1–2): 90–116 (www.mitpressjournals.org/doi/pdf/10.1162/inov_a_00270)

Greene, S. (2018) 'Can blockchain unblock climate finance?' Blog, International Institute for Environment and Development, 21 May (www.iied.org/can-blockchain-unblock-climate-finance)

Hasse, F., von Perfall, A., Hillebrand, T., Smole, E., Lay, L. and Charlet, M. (2016) *Blockchain – an opportunity for energy producers and consumers*. London: PricewaterhouseCoopers Global Power & Utilities (www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf)

Herweijer, C., Combes, B., Swanborough, J. and Davies, M. (2018) *Building block(chain)s for a better planet.* London: PricewaterhouseCoopers (www.pwc.com/gx/en/sustainability/assets/blockchain-for-a-better-planet.pdf)
IEA – Institute of Economic Affairs (2017) 'World Energy Outlook 2018: China'. Website, International Energy Agency, 14 November (www.iea.org/weo/china/#section-7)
Kshetri, N. (2018) 'Blockchain-based property registries may help lift poor people out of poverty'. The Conversation, 29 June (https://theconversation.com/blockchain-based-property-registries-may-help-lift-poor-people-out-of-poverty-98796)
Livingston, D., Sivaram, V., Freeman, M. and Fiege, M. (2018) *Applying blockchain technology to electric power systems*. Washington DC: Council of Foreign Relations (https://cfrd8-files.cfr.org/sites/default/files/report_pdf/Discussion_Paper_Livingston_et_al_Blockchain_OR_0.pdf)
Mendes, K. (2018) 'Can blockchain save the Amazon in corruption-mired Brazil?' Reuters, 25 January (www.reuters.com/article/us-brazil-property-blockchain/can-blockchain-save-the-amazon-in-corruption-mired-brazil-idUSKBN1FE113)
Nakamoto, S. (2008) *Bitcoin: a peer-to-peer electronic cash system* (https://bitcoin.org/bitcoin.pdf)
Ostrom, E. and Hess, C. (2010) 'Private and common property rights' *Property Law and Economics* 5: 53 (https://surface.syr.edu/cgi/viewcontent.cgi?article=1024&context=sul)
Pisa, M. (2018) 'Reassessing Expectations for Blockchain and Development' *Innovations: Technology, Governance, Globalization* 12(1–2): 80–88 (www.mitpressjournals.org/doi/pdf/10.1162/inov_a_00269)
Provenance (2018) 'From shore to plate: tracking tuna on the blockchain. Provenance'. Report. London: Provenance (www.provenance.org/tracking-tuna-on-the-blockchain#overview)
Siegele, L. (2018) 'How to fix what has gone wrong with the internet'. Economist, 28 June (www.economist.com/special-report/2018/06/28/how-to-fix-what-has-gone-wrong-with-the-internet)
Truby, J. (2018) 'Decarbonizing Bitcoin: law and policy choices for reducing the energy consumption of blockchain technologies and digital currencies' *Energy Research & Social Science* 44: 399–410 (www.sciencedirect.com/science/article/pii/S2214629618301750#!)
UNDP – United Nations Development Programme (2017) 'UNDP, solar currency exchange to power up Moldovan University'. Press Release, UNDP, 7 May (www.undp.org/content/undp/en/home/news-centre/news/2018/UNDP-solar-currency-exchange-to-power-up-Moldovan-university.html)
UNDP (2018) *The future is decentralised: blockchains, distributed ledgers and the future of sustainable development*. New York: UNDP (www.undp.org/content/dam/undp/library/innovation/The-Future-is-Decentralised.pdf)
de Vries, A. (2018) 'Bitcoin's growing energy problem' *Joule* 2(5): 801–805 (www.cell.com/action/showPdf?pii=S2542-4351%2818%2930177-6)
Wang, W., Hoang, D.T., Xiong, Z., Niyato, D., Wang, P., Hu, P. and Wen, Y. (2018) 'A survey on consensus mechanisms and mining management in blockchain networks'. Submitted to *IEEE Communications Surveys & Tutorials* (https://arxiv.org/abs/1805.02707v1)
World Bank (2018) 'Individuals using the internet.' World Bank Data (https://data.worldbank.org)

Acknowledgements

We particularly thank the following experts for reviewing the paper: Shelagh Whitley, Head of ODI's Climate and Energy Programme, Feja Lesniewska, Research Associate, PETRAS IOT Research Hub, and Nabil Abou-Rahme, Global Practice Leader, Data Science, Mott MacDonald. All errors and omissions are the authors' responsibility.

We also thank those our expert interviewees and our roundtable participants:

Individuals consulted

Andrew Kodis	Olea Edge Analytics, Chief Executive Officer (CEO)
Anna Poberezhna	Smart4Tech, CEO
Callie Stinson	World Economic Forum, Agenda Contributor
Katrina Donaghy	Civic Ledger, CEO
Nicolas Cary	Blockchain, CEO
Riggs Eckelberry	OriginClear, CEO
Salome Eggler	GIZ Blockchain Lab, Blockchain Governance Expert
Scott McKenzie	DLT Capital, Legal Adviser; UBC, PhD Candidate

Roundtable participants

Jessi Baker	Provenance, CEO
Anina Henggeler	Provenance, Research Lead
Anna Poberezhna	Smart4Tech, CEO
Antonio Astone	DNVGL, Sustainability and Water.
Doll Avant	Aquagenuity, CEO
Dr Cathy Mulligan	Imperial College Centre for Cryptocurrency Research and Engineering, Research Fellow
Dr Feja Lesniewska	PETRAS IOT Research Hub, UCL, Research Associate
Fraser Brown	ACT Foundation, Founder
Jahda Swanborough	World Economic Forum, Global Leadership Fellow, Environmental Initiatives
Mary Davies	PWC, Associate Consultant – Sustainability and Climate Change
Scott McKenzie	DLT Capital, Legal Adviser; UBC, PhD Candidate
Shelagh Whitely	ODI, Head of Climate and Energy Programme
Zach Bayham-Herd	University of Edinburgh, PhD Student

Evidence.
Ideas.
Change.

ODI
203 Blackfriars Road
London SE1 8NJ

+44 (0)20 7922 0300
info@odi.org

odi.org
odi.org/facebook
odi.org/twitter

ODI is an independent, global think tank, working for a sustainable and peaceful world in which every person thrives. We harness the power of evidence and ideas through research and partnership to confront challenges, develop solutions, and create change.