World Economic Forum

Guidelines for Improving Blockchain's Environmental, Social and Economic Impact

INSIGHT REPORT

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Images: Getty Images

Contents

Foreword

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Climate change is one of the most pressing challenges facing the world today. Extreme weather events, biodiversity loss, infrastructure degradation and other negative impacts on the environment and society will increase if humanity does not take effective action. Addressing this challenge requires a combination of mitigation measures, such as reducing greenhouse gas emissions, and adaptation measures, for example, preparing for and adapting to the already inevitable impacts. It is crucial that individuals, businesses and governments all take action to address climate change to create a more sustainable future. The blockchain industry is no exception, and this report aims to help effective decision-making in the industry.

Blockchain technology has the potential to both contribute to the problem of climate change and help address it. On the one hand, the energy consumption of Bitcoin and Ethereum mining has been a significant concern, with the proliferation of large-scale mining operations that consume a substantial amount of energy, some of which is generated from fossil fuels. On the other hand, blockchain is becoming an essential part of developing a carbon-neutral energy grid and has made it economically viable to invest in, develop and build renewable energy power generation. There are several examples of meaningful climate action by the blockchain industry that create decentralized energy markets, or transparent tracking of carbon emissions associated with various activities, enabling companies and individuals to account more accurately for their carbon footprint and take steps to reduce it.

As environmental, social and economic regulation is improved, it is crucial that blockchain companies can provide proper reporting on their impacts. We hope this report contributes to this vital discussion.

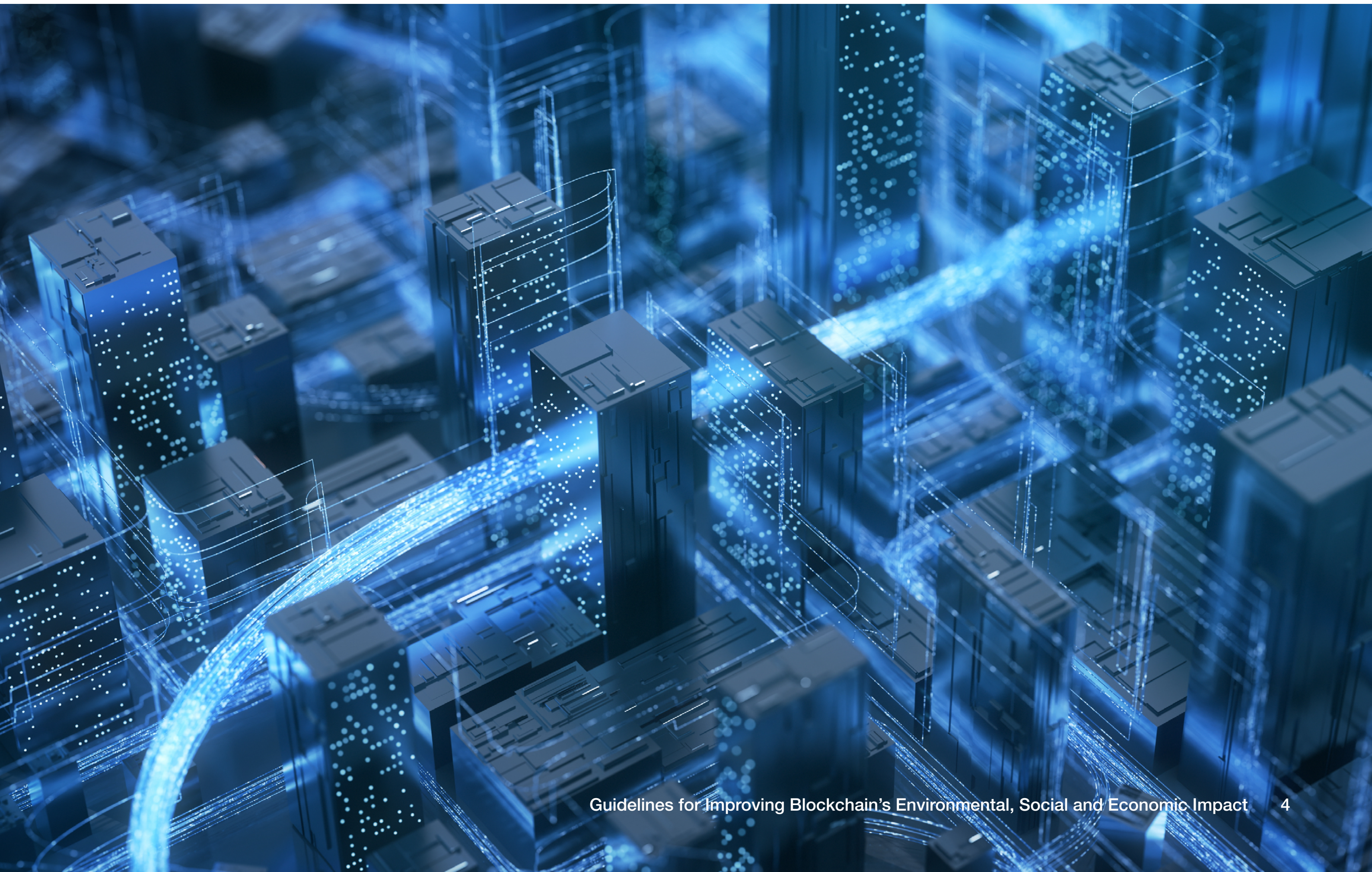
Executive summary

The world's energy system is in dire crisis, and developing the capacity to deliver net zero over the next decade may be the most important transition that humanity has ever needed to make. Blockchain technology could potentially improve the energy sector by enabling more efficient and secure transactions, as well as promoting other industries' decentralization and encouraging the use of renewable energy sources. However, to avoid unintended negative consequences, it is important to address issues such as high energy consumption and the potential concentration of control in the use of blockchain for energy. Additionally, careful consideration should be given to the governance and regulation of blockchain in the energy sector to ensure its responsible use.

Blockchain has the potential to revolutionize the energy sector by enabling the creation of decentralized, efficient and secure systems for managing energy production, distribution and consumption. Through smart contracts, blockchain can facilitate peer-to-peer trading of energy, making it easier for individuals and businesses to generate and sell renewable energy to their neighbours. This can lead to the more efficient use of renewable energy sources and reduce reliance on centralized energy providers. Additionally, blockchain can support the integration of emerging technologies such as electric vehicles and smart batteries for energy storage, providing more flexible and resilient energy systems.

In order to deliver on these possibilities, however, the energy impact of blockchain itself must be correctly accounted for, ensuring that more environmental harm is not caused by the creation of solutions than is saved by them. The blockchain community has done some excellent work that clarifies how to measure the energy consumption of different solutions; however, much remains to be done to ensure that companies, solutions and protocols in this space are ready for the emerging regulation.

The overall objectives of this report are, therefore: (1) to outline guiding principles and provide an overview of the current state of play related to the environmental impact of certain blockchain technologies; (2) to outline a potential approach for a unified impact assessment that balances economic, environmental and social perspectives so that blockchain companies and solutions are ready for the upcoming regulation, rather than lagging behind it; and (3) to illustrate examples of where and how blockchain has been effectively applied to both demand and supply issues of investment in energy and blockchain, moving towards net-zero solutions.



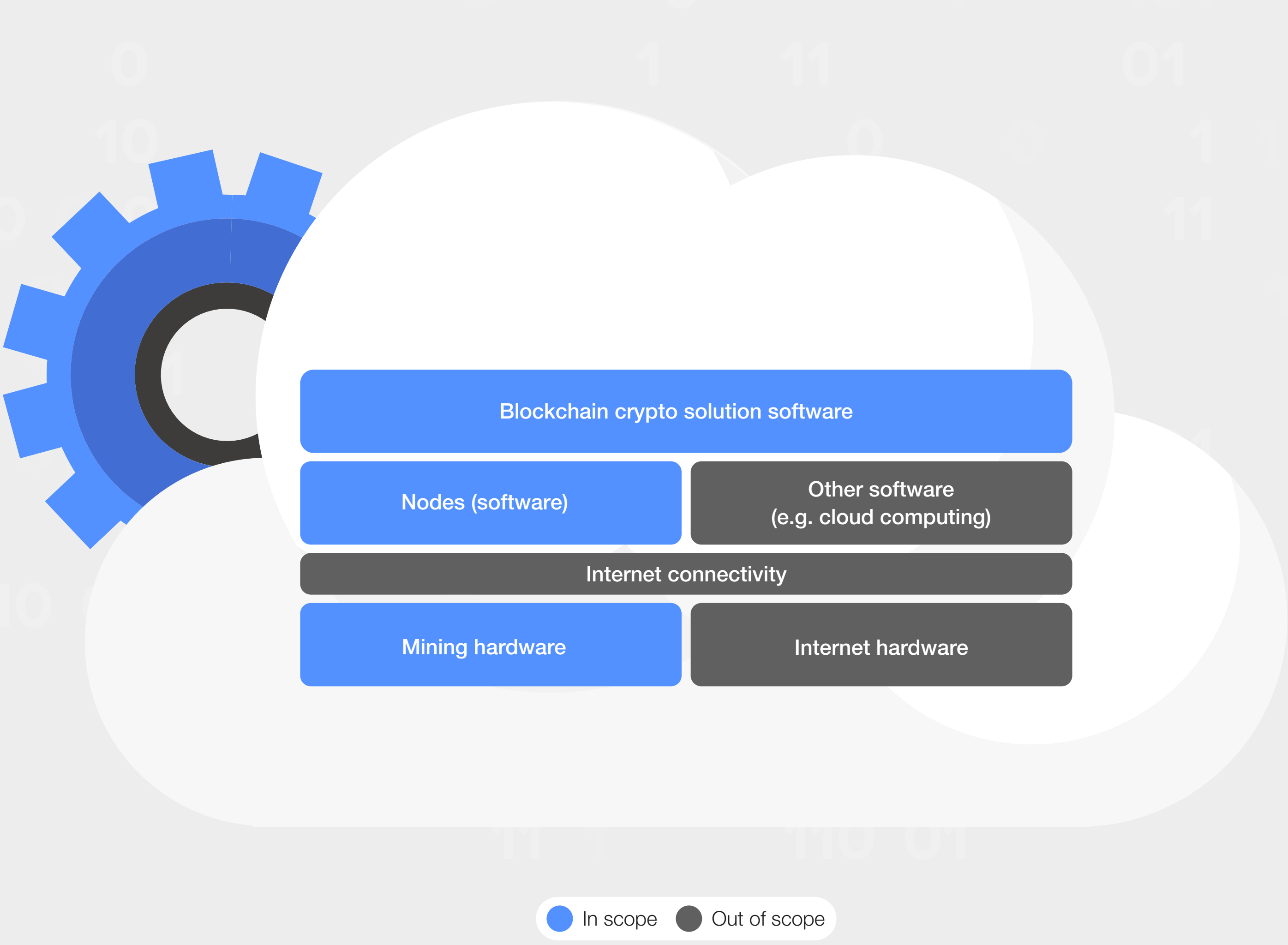
1 Scope of this report

The scope of the environmental impact of blockchain solutions is a complex and broad topic.

For the purposes of this report, the focus is on the mining, blockchain software and solutions that sit on top of the blockchain. It does not cover the energy consumption of internet hardware, internet connectivity or cloud computing.

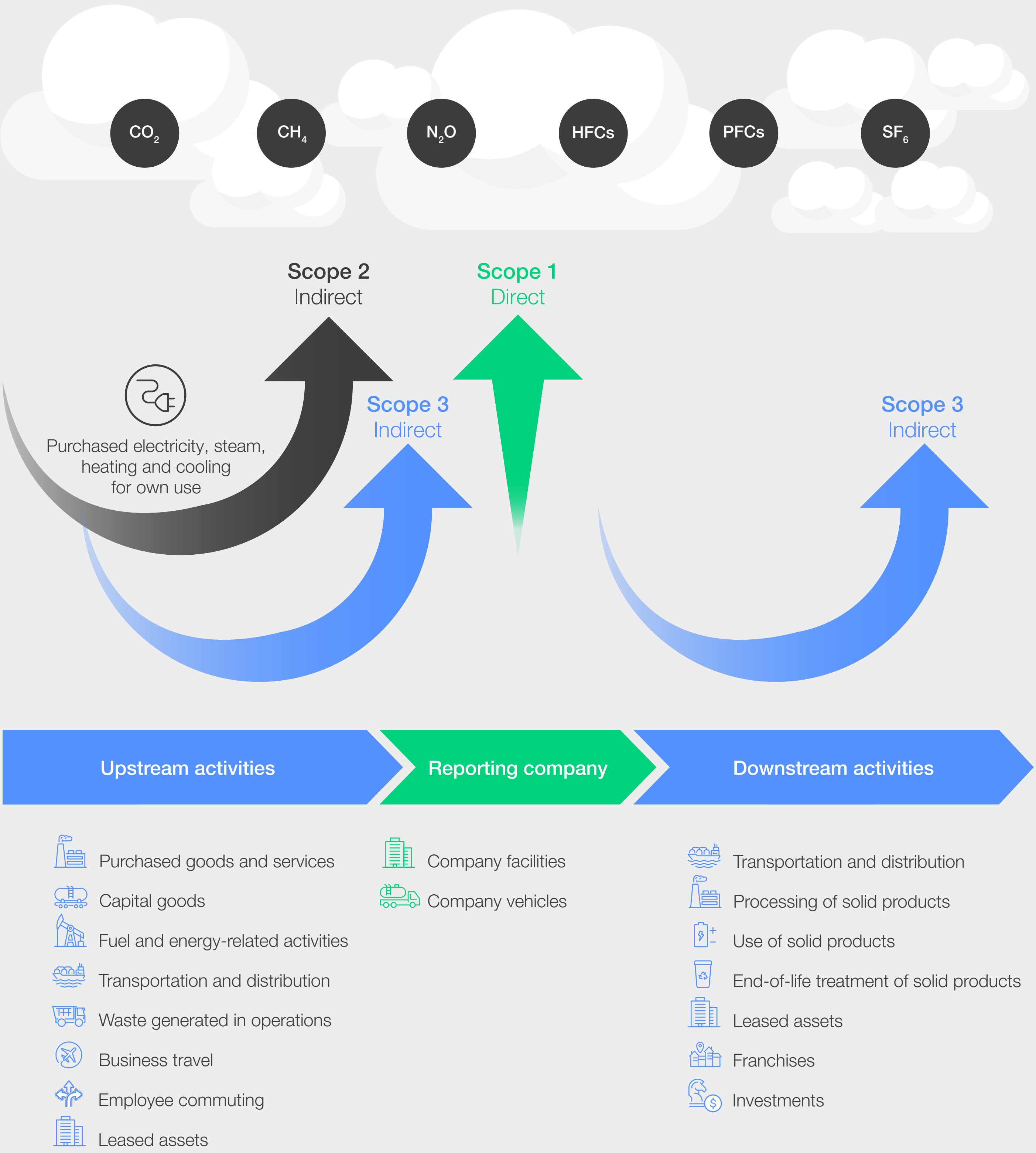
In this report, the term “blockchain” includes all blockchains, cryptocurrencies and digital forms of money.

FIGURE 1 **Environmental impact of blockchain: scope of this report**



Source: World Economic Forum

FIGURE 2 | Greenhouse gases: direct, indirect and tertiary impacts



Source: US Environmental Protection Agency

2 Why is this report being produced?

Recent criticisms of the energy consumption of blockchain networks have led to some positive developments in transparency and the modelling of different protocols. But more should be done.

The focus on blockchain sustainability impacts comes amid increasing pressure for the world to respond to climate change. Beyond just illustrating how much energy blockchain consumes, however, the broader blockchain industry is also subject to the effects of the broader push for practical sustainability reporting globally across all sectors.

Governments and regulators globally are actively considering or preparing new requirements for environmental, social and governance (ESG)-related disclosures by corporate and other entities. While many nations have required some level of reporting for many years, a relatively new feature of most of the future mandatory disclosures is that they will be provided within the context of regulated reporting such as 10-Ks or other such annual reports.

These requirements are intended to alert investors to any specific risks or opportunities. Depending on the jurisdiction, entities may be expected to describe their proposed actions to mitigate or eliminate such risks. A significant and relatively new development in some mandates is that companies will need to report financial statement effects of their related risks and opportunities, not simply metrics such as energy consumption or workforce diversity. This will also affect blockchain projects and solutions.

Reporting environmental and other social impact issues within the context of regulated financial filing has historically been voluntary. Entities are typically sent surveys by e.g. the Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB). This information is not standardized between organizations. Reporting entities can voluntarily disclose the information provided in surveys but are often under no obligation to quantify the effects on their financials. In addition, the landscape of activities is broad and multiple standards have been proposed for reporting. This landscape can be split into two main groups:

1. **Financial materiality** (the International Sustainability Standards Board [ISSB], International Financial Reporting Standards [IFRS], etc.): a measure of the relative financial importance of a factor among a company's considerations

2. **Impact materiality** (GRI, etc.): the external impacts an organization's activities have, including effects on communities and the environment

In addition, on 16 November 2022, the European Financial Reporting Advisory Group (EFRAG) approved[1] the updated versions of the European Sustainability Reporting Standards (ESRS). These are part of Europe's Corporate Sustainability Reporting Directive (CSRD), which had been adopted a week earlier. This led to a third group of reporting standards, namely:

3. **Financial materiality + impact materiality**: requires all large companies and all listed companies (except listed micro-enterprises) to disclose information on their risks and opportunities arising from social and environmental issues, and on the impacts of their activities on people and the environment

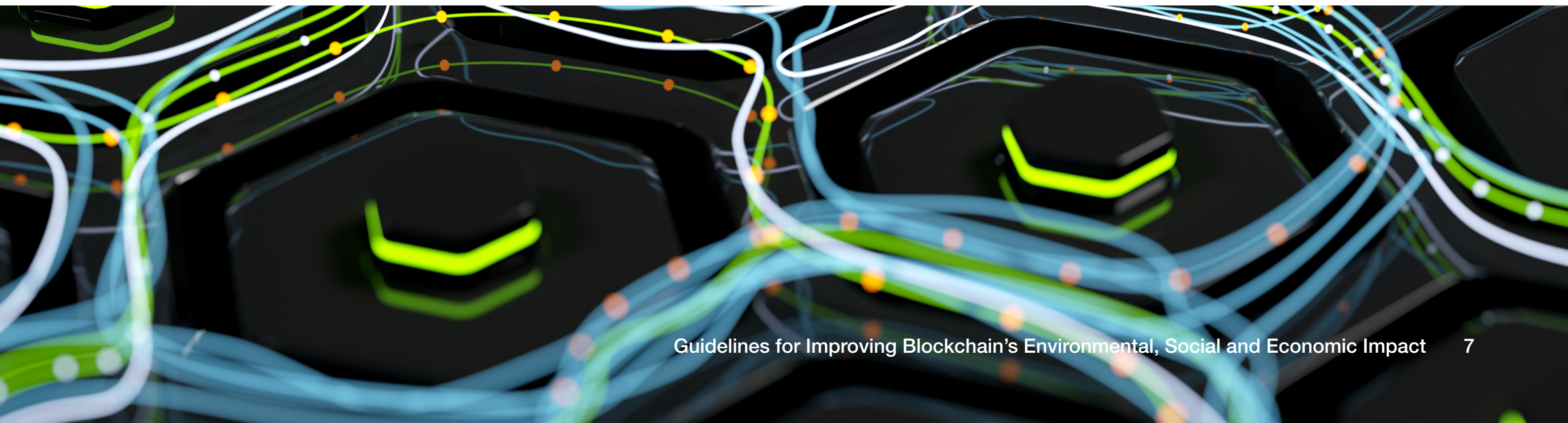
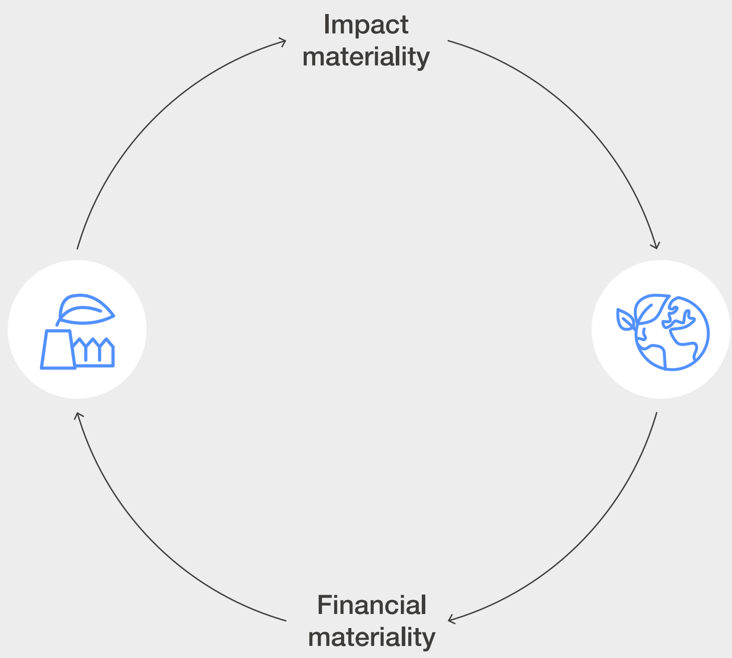


FIGURE 3 | **Relationship of impact materiality and financial materiality**



Source: World Economic Forum

The standards outline requirements for detailed corporate reporting on environmental and/or social impact. The CSRD is expected to enter into force for reporting in 2024, with the first submissions due in 2025. The directive aims to strengthen sustainability reporting requirements under the existing Non-Financial Reporting Directive (NFRD) to improve corporate accountability and the quality, consistency and comparability of information disclosed.

CASE STUDY 1: APG USE CASE

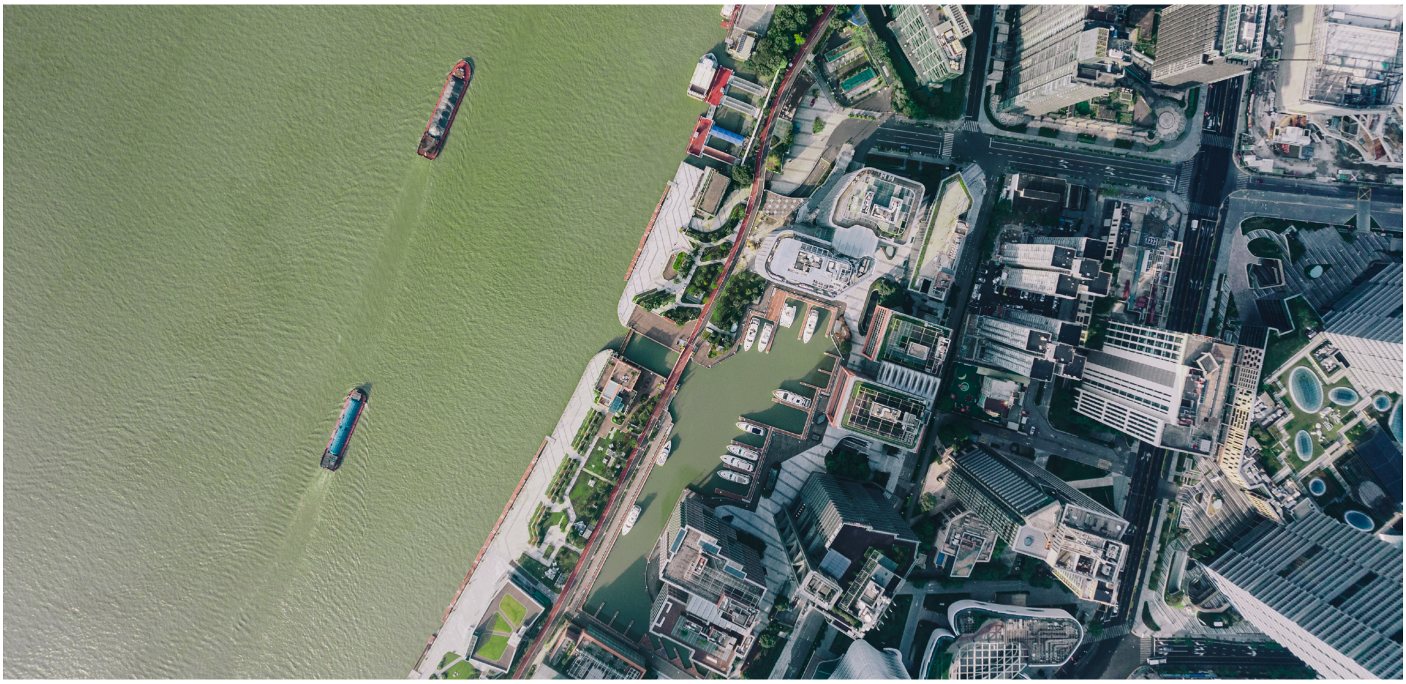
Use cases that demonstrate how blockchain can solve environmental, social and/or economic challenges

Name of project	Founding organizations	Description
APG FlexHub	(APG) Austrian Power Grid and Energy Web Foundation	This proof of concept established that a decentralized platform could enable customer-sited energy assets (e.g. battery storage systems) to offer their flexibility in a frequency market, be activated when called on, deliver flexibility when activated and be compensated for any flexibility provided.

The CSRD aims to enhance sustainability data's comparability, relevance and reliability by revising the NFRD[2] and the Accounting Directive.[3] It is designed to provide valuable information to investors, capital providers, civil society actors, business partners and other stakeholders by specifying which companies must report on what topics, where and when. The directive requires companies operating within the European Union and of a specific size to report sustainability information for the first time, which will be specified through the ESRS. The ESRS standards are designed to illustrate the impact of companies on sustainability matters, referred to as impact materiality, as well as the effects of sustainability on the development, performance and position of companies, known as financial materiality.

The blockchain industry must therefore be ready to address and provide comparable measurements to comply with these upcoming standards. The industry needs to ensure that effective energy consumption measurements are available and comparable to one another in order to properly report against these new directives. While many blockchain solutions are decentralized, many entities building and running decentralized applications (dApps), launching blockchains or participating in mining are incorporated as conventional companies. It is, therefore, important that the blockchain industry has a solution ready for these regulatory issues.

This report aims to provide a brief overview of the major areas of reporting, coalesce some initial thoughts for the industry from a range of experts, and outline concepts that enable cryptocurrency companies and solution providers to explain the social, economic and environmental impacts of their products and services in the space.



2.1 Rationale for blockchain interventions

Within the framing of the new reporting standards, it is important to note the rationale for blockchain interventions. Blockchain and associated solutions can provide a unique and innovative means for humanity to reduce its impact on the environment – as long as it is done in an appropriate manner. This often requires balancing the social/economic good with the negative environmental impact caused by the scale of energy consumption. Notwithstanding the need for such careful balancing, the decentralization that blockchain offers can produce environmentally positive effects through:

- **Supply chain transparency:** By enabling the transparent tracking of products and materials in supply chains, blockchain can help reduce the environmental damage caused by illegal or unsustainable practices, such as deforestation, overfishing or hazardous waste disposal.

- **Energy efficiency:** Blockchain-based systems can enable the efficient management of energy grids, smart buildings and renewable energy systems, optimizing energy consumption and reducing waste.

- **Waste management:** Blockchain can help track and manage waste streams, making it easier to monitor recycling, disposal and recovery efforts.

- **Conservation:** Blockchain can facilitate the creation of decentralized, community-based conservation initiatives, allowing stakeholders to pool resources and coordinate conservation efforts.

- **More efficient use of local energy and resources:** By empowering local communities to use energy and other natural resources more effectively, decentralization can reduce humans' impact on Earth. Decentralization can enable stronger local economies that have less environmental impact, while ensuring the benefits of globalization are not lost.

2.2 Who is this report for?

TABLE 1 Suggested users of this report

Audience	Description	Suggested use
Users of blockchain technology	– Companies or individuals – Those who are using this technology to support a business or other use case – Those who are interfacing with the technology solely as an (crypto) investor	– Decision-making regarding the use of blockchain-based vs. non-Web3 solutions – Selecting between different blockchain technology providers – Internal ESG accounting (e.g. Scope 3 emissions) – ESG/emissions mitigation activities
Providers of blockchain technology	– dApp developers – Node operators, including miners – Developers of adjacent hardware or software (e.g. wallets, mining hardware) – Organizations (e.g. foundations) that build/deploy/coordinate governance for specific blockchains – Organizations providing goods/services to providers of blockchain technology	– Internal ESG accounting (e.g. Scope 3 emissions) – ESG/emissions mitigation activities
Regulators, researchers and journalists	– Regulators wishing to understand the implications of blockchains for ESG	– Providing an overview of the environmental impacts of blockchain solutions – Illustrating how to balance the environmental, social and economic outcomes – Demonstrating how blockchain can assist in the transition towards a sustainable energy system

3 Blockchain energy initiatives to date

There is significant variability between blockchains in their carbon footprint and energy intensity.

There is no single methodology for quantifying the carbon footprint of a blockchain, given that blockchains use different algorithms, have different hardware requirements and different methods for processing and settling transactions. Table 2 illustrates the carbon footprint of several major emergent blockchains. While each of these is a proof of stake (PoS) chain and can be several orders of magnitude more energy efficient than the proof of work (PoW) consensus process, they are different implementations of the PoS algorithm, each of which requires a different methodology in calculating carbon footprint.

TABLE 2 **Carbon footprint of emergent blockchains**

Blockchain	Proof of stake implementation	Estimated annual carbon footprint
Solana	Proof of history,[4] Layer 1	3,412 tCO_2[5]
Polygon PoS	Sidechain[6]	55 tCO_2[7]
Cosmos	Blockchain of blockchains[8]	24.83 tCO_2[9]
NEAR	Sharded proof of stake, Layer 1[10]	174 tCO_2[11]
Stellar	Proof of agreement (PoA)	94,098 kg CO_2/yr[12]

Note: tCO_2 = metric tons of CO_2.

3.1 Variability in energy impact of blockchains

The word "blockchain" is often used as a generic term to refer to all types of blockchain solutions – there are, however, significant differences between blockchains and the solutions implemented on top of them. Key to addressing the energy impact of blockchain solutions is the ability to clearly delineate these differences so that assessments of environmental impact can be compared to one another. This section highlights some of the main issues related to the variation in energy impact of different blockchains.

Technology stack

The cryptocurrency ecosystem is broadly made up of three distinct layers, as defined by the Crypto Climate Accord (CCA):

– **Miners/validators (layer 1):** the base layer of the technology stack. This refers to the underlying blockchain protocol and the infrastructure that supports it. It includes the network of nodes that runs the blockchain software, the consensus mechanism that is used to add new blocks to the blockchain and the cryptographic algorithms that are used to secure the network.

– **Intermediaries such as wallets, exchanges and custodians (layer 2):** protocols and technologies that are built on top of the base layer and add further functionality to the blockchain. Examples of layer 2 solutions include payment channels (e.g. Lightning Network), which allow users to transact directly between one another without the need to record each transaction on the base layer, and sidechains, which are separate blockchain networks pegged to the main blockchain that can be used to move assets between the two blockchains.

– **Holders of cryptocurrency/investors/dApps (layer 3):** applications and services that are built on top of the blockchain. These are the end user-facing products and services that make use of the blockchain, such as decentralized finance (DeFi) applications, prediction markets and other dApps.

Each layer provides a different set of capabilities, and they can be combined and integrated in various ways to create powerful and flexible blockchain solutions.

CASE STUDY 2: TOOLKIT FOR 24/7 CARBON-FREE ENERGY

Use cases that demonstrate how blockchain can solve environmental, social and/or economic challenges

Name of project	Founding organizations	Description
Toolkit for 24/7 carbon-free energy	Shell, SB Energy, Elia, Energy Web Foundation	To address the growing demand for highly detailed tracking of renewable energy generation and consumption, Energy Web (EW) collaborated with Elia, SB Energy and Shell to create a software toolkit capable of monitoring and matching renewable electricity production and usage on a 24/7 basis. This is the first set of open-source software development kit (SDK) from EW, which will be incorporated into the existing EW Origin SDK and a new component named Green Proofs. The primary focus of this SDK is to achieve real-time transparency of energy consumption and generation, which is a vital initial step towards achieving significant decarbonization. The SDK includes features such as organization onboarding, data collection for energy generation and consumption, energy provenance tracking, preference-based matching and reporting.

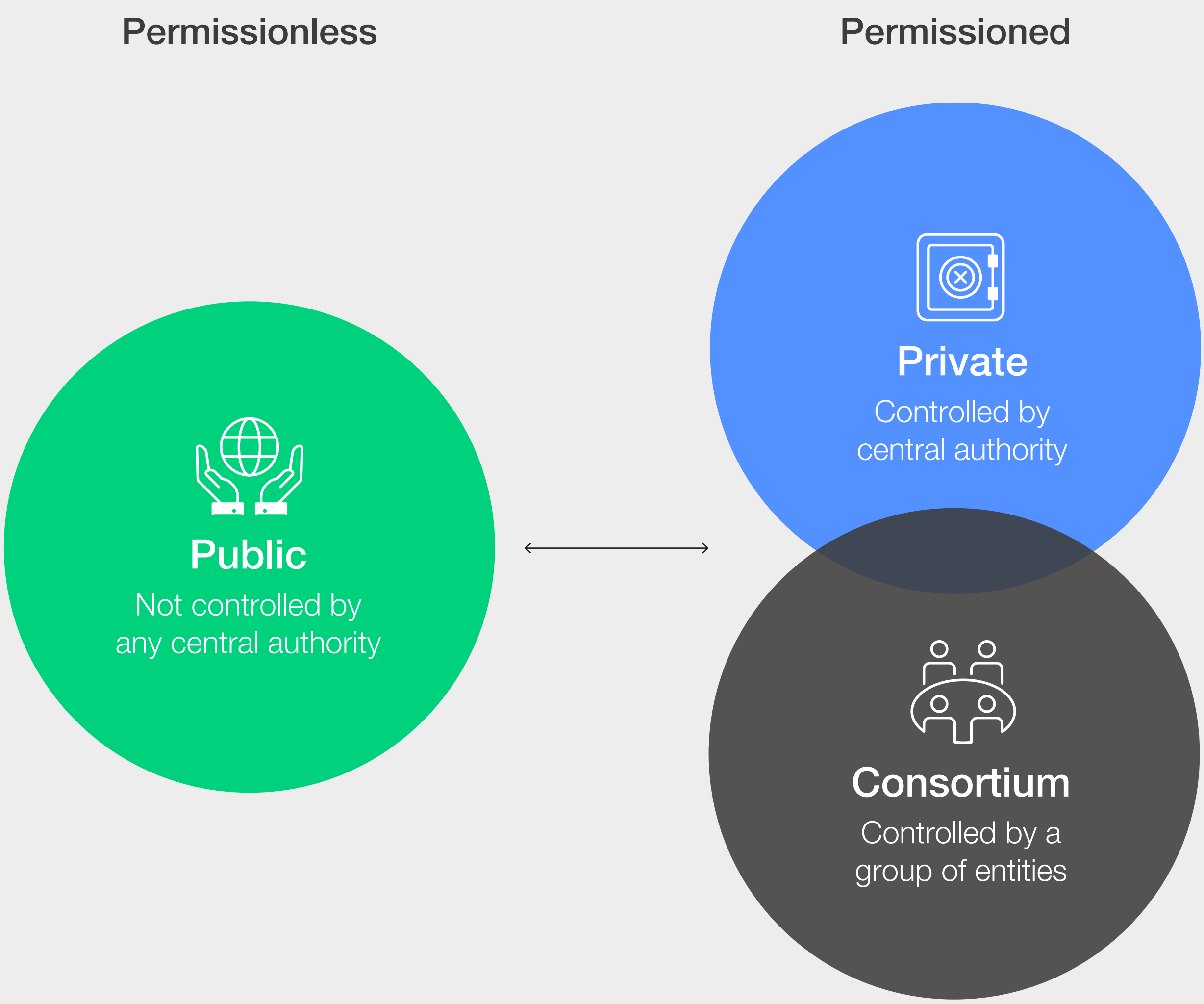
Permissioned vs. permissionless

Whether a solution uses a permissioned or permissionless network can have a big impact on its energy consumption. In a permissionless blockchain network, anyone is allowed to join and participate without the need for prior approval. This means that anyone can download and run the software that powers the network, and they can start creating and verifying transactions without any restrictions. Examples of permissionless blockchain networks include Bitcoin and Ethereum.

In a permissioned blockchain network, on the other hand, participation is restricted and requires approval from a central authority. In these networks, only certain pre-approved participants are allowed to join and participate. This means that only approved participants are able to create and verify transactions, and the central authority has the ability to control who is allowed to join the network. Examples of permissioned blockchain networks include some private and consortium blockchain networks.

Normally, technology selection is optimized for either security or performance in terms of speed or throughput. The selection of a permissioned or permissionless network can also have energy impacts, however. In general, permissioned networks require less computational power to ensure the security of the network and therefore they consume less energy. However, this is balanced against the loss of decentralization in the network.

FIGURE 4 **Controls in permissioned and permissionless blockchain networks**



Source: Cambridge Centre for Alternative Finance

Consensus mechanisms

Consensus mechanisms also have a big impact on the energy consumption of blockchain solutions. They form the backbone of blockchain networks and ensure that all participants agree on the current state of the network and the legitimacy of newly added blocks of transactions. There are several types of consensus mechanism, each with its own unique features and characteristics. Some of the most prominent include proof of work (PoW), proof of stake (PoS) and delegated proof of stake (DPoS).

PoW is the original consensus mechanism used by Bitcoin. In a PoW system, participants compete against each other in a race to provide a solution to a computationally intensive problem (a so-called hash puzzle) that cannot be solved by logic but only by brute force – or in other words, by trial and error. The first participant to solve the hash puzzle adds the next block to the blockchain and is rewarded with a certain amount of the network's native token.

PoS, on the other hand, is a more recent consensus mechanism that is based on the idea that doing "work" is substituted by putting up a "stake". In a PoS system, participants are selected to add new blocks to the blockchain based on the amount of cryptocurrency pledged as collateral. The exact design, however, strongly depends on the protocol. This may mean that the more native tokens a participant has pledged, the greater the chance of being selected to add a new block and earn a reward.

DPoS is a variant of PoS that allows participants to delegate their voting power to other users on the network. This means that instead of selecting block producers directly, participants can vote for other users to act on their behalf and add new blocks to the blockchain. This can make the process of reaching consensus more efficient and scalable.

Controversy surrounding PoW

During 2022, Ethereum moved from PoW to PoS,[13] which is often hailed as a major moment in reducing the climate impact of blockchain technologies. The move to PoS, however, illustrates the need to understand the overall impact of design choices in technical networks – because the move to PoS creates other effects. Most notably, there are security implications for the solutions that use it, including:

- **Reduced risk of 51% attacks:** PoS reduces the risk of 51% attacks, as it requires attackers to control a majority of the network's stake, which is more expensive and difficult than controlling a majority of the network's computational power, as required in proof of work (PoW).

- **Increased centralization risk:** PoS introduces a new form of centralization risk, however, as large holders of Ethereum can gain more influence over the network's consensus mechanism. This risk can be mitigated by implementing measures to prevent large holders from colluding or controlling the network.

- **Staking pool risks:** Staking pools allow smaller holders to participate in staking by pooling their stake with others, but they also introduce new risks, such as centralization, hacking and fraud, and have implications in terms of securities laws.

- **Smart contract risks:** PoS introduces new risks associated with the use of smart contracts, as they are responsible for managing staked funds and distributing rewards. Vulnerabilities or bugs in smart contracts can result in a loss of funds or other security breaches.

To address these security implications, Ethereum developers are implementing a range of measures, such as sharding, decentralized staking and more robust smart contract auditing and testing. This, however, highlights the necessity of balancing social impact (in this case, security), economic impact and environmental impact before making any final design decisions.

There is, therefore, still significant work to be done in reducing the climate impact of several blockchain technologies – particularly Bitcoin. Some blockchains are significantly more energy-efficient than others, but because of the variability in methodologies, it is difficult to paint a single picture of carbon footprints across blockchains. More importantly, in order to effectively develop the market for real-world blockchain solutions, methods are required that ensure a robust measurement of the claims made by blockchain protocols and solution developers. Through the robust – and comparable – measurement of claims across environmental, social and economic branches, the industry will be better able to meet the increasing demands for reporting, both directly and as blockchain technologies are integrated into enterprise systems.

TABLE 3 | **Energy consumption by consensus algorithms**

Selecting a consensus algorithm depends on your use case, which includes factors such as the choice of blockchain implementation (public or permissioned), blockchain provider, number of nodes in the network, processing time required for block commit, etc.

Understanding the consensus algorithm is important both from an application usage perspective and in terms of energy use. Some systems also employ a hybrid approach to use multiple algorithms based on their requirements.

There are many other consensus algorithms, such as proof of activity, proof of capability or other proprietary consensus algorithms that are better optimized versions of the earlier consensus algorithms, and new algorithms will evolve in the shift towards a smarter decentralized connected world.

Consensus algorithm	Proof of work	Proof of activity	Proof of burn	Proof of capability	Proof of elapsed time	Proof of authority	Proof of stake	Practical byzantine fault tolerance	Proof of history
Energy consumption	High	Medium–high	Low–medium	Low–medium	Low	Low	Low	Low	Low

Source: Accenture

Geography

The “carbon intensity” of the transactions running on blockchains will vary depending on the primary energy mix that generates the electricity used. This varies according to geographical location. Some countries may be largely reliant on fossil fuels as their primary energy source and it is important to know where the energy is being used. Among large emerging economies, China, India and South Africa use very limited amounts of low-carbon sources. At the other end of the scale, Iceland, Sweden, Norway, France, Switzerland and El Salvador obtain large amounts of their energy from low-carbon sources such as renewables or nuclear power. The geographic location of mining – and, to a lesser extent, layer 2 and layer 3 implementations, as well – could have a large impact on carbon emissions, while not actually affecting energy consumption per se.

Summary table of existing methods and initiatives

Measuring the electricity consumption of blockchain networks is a crucial aspect in evaluating the environmental impact of these technologies. The feasibility of obtaining accurate estimates for electricity consumption, however, differs between permissionless and permissioned blockchain networks.

Public permissionless blockchain networks such as Bitcoin are decentralized, meaning there is no central authority managing the network. This decentralization poses a significant challenge because it allows for anonymous participation, which makes it difficult to track the individuals or organizations operating nodes on the network.

Furthermore, the electricity consumption of nodes is not uniform, as the spectrum of deployed devices can range from powerful dedicated servers to less powerful devices such as laptops or mobile phones, further complicating the task of accurately measuring electricity consumption.

On the other hand, permissioned blockchain networks are controlled by a central entity or entities, with known and identifiable participants. This allows for better tracking and monitoring of the network’s energy consumption, as providing information in that respect can be made mandatory. The table below illustrates some of the main methods proposed across the blockchain space for measuring energy consumption.

TABLE 4 | **Methods of measuring blockchain energy consumption**

Author	Date of publication	Title	Architecture	Consensus mechanism	Blockchain network	Annualized estimate in GWh
Cambridge Centre for Alternative Finance (CCAF)	Live	Cambridge Bitcoin Electricity Consumption Index	Layer 1	Proof of work	Bitcoin	86,580.0[a]
Crypto Carbon Ratings Institute	Live	CCRI Crypto Sustainability Indices	Layer 1	Proof of work	Bitcoin	86,580.0[b]
		CCRI Crypto Sustainability Indices	Layer 1	Proof of stake	Ethereum	2.7[a]
Digiconomist	Live	Bitcoin Energy Consumption Index	Layer 1	Proof of work	Bitcoin	113,420.0[a]
		Ethereum Energy Consumption Index	Layer 1	Proof of stake	Ethereum	10.0[a]
Alex de Vries, Ulrich Gallersdörfer, Lena Klaaßen and Christian Stoll	February 2022	Revisiting Bitcoin's Carbon Footprint	Layer 1	Proof of work	Bitcoin	117,296.4
CoinShares	January 2022	The Bitcoin Mining Network: Energy and Carbon Impact	Layer 1	Proof of work	Bitcoin	89,000.0
Xiaoyang Shi, Hang Xiao, Weifeng Liu, Xi Chen, Klaus S. Lackner, Vitalik Buterin and Thomas F. Stocker	December 2021	Confronting the Carbon-Footprint Challenge of Blockchain	Layer 1	Proof of stake	Ethereum	311.9
Moritz Platt, Johannes Sedlmeir, Daniel Platt, Jiahua Xu, Paolo Tasca, Nikhil Vadgama and Juan Ignacio Ibañez	September 2021	Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work	Layer 1	Proof of stake	Ethereum	974.7

Philipp Sandner, Constantin Lichti, Cedric Heidt, Robert Richter and Benjamin Schaub	August 2021	The Carbon Emissions of Bitcoin from an Investor Perspective	Layer 1	Proof of work	Bitcoin	90,860.0
Susanne Köhler and Massimo Pizzol	November 2019	Life Cycle Assessment of Bitcoin Mining	Layer 1	Proof of work	Bitcoin	31,290.0
Christian Stoll, Lena Klaaßen and Ulrich Gallersdorfer	June 2019	The Carbon Footprint of Bitcoin	Layer 1	Proof of work	Bitcoin	48,500.0
Michel Zade, Jonas Myklebost, Peter Tzscheutschler and Ulrich Wagner	March 2019	Is Bitcoin the Only Problem? A Scenario Model for the Power Demand of Blockchains	Layer 1	Proof of work	Bitcoin	33,743.5
Max J. Krause and Thabet Tolaymat	November 2018	Quantification of Energy and Carbon Costs for Mining Cryptocurrencies	Layer 1	Proof of work	Bitcoin	30,143.2
Hass McCook	August 2018	The Cost and Sustainability of Bitcoin	Layer 1	Proof of work	Bitcoin	105,000.0
Alex de Vries	May 2018	Bitcoin's Growing Energy Problem	Layer 1	Proof of work	Bitcoin	from 22,338.0 to 67,189.2
Harald Vranken	October 2017	Sustainability of Bitcoin and Blockchains	Layer 1	Proof of work	Bitcoin	from 876.0 to 4,380.0
Marc Bevand	February 2017	Electricity Consumption of Bitcoin: A Market-Based and Technical Analysis	Layer 1	Proof of work	Bitcoin	from 4,120.0 to 4,730.0
Karl J. O'Dwyer and David Malone	September 2014	Bitcoin Mining and its Energy Footprint	Layer 1	Proof of work	Bitcoin	from 876.0 to 87,600.0

Notes: a. As of 3 December 2022. b. CCAF estimate functions as basis.

3.2 How blockchain can support innovation in the energy sector

Impact on energy system decarbonization

Countries or states with the highest penetration of renewables, such as Germany, Australia or California, are at the forefront of experiencing the effects of the increased use of renewables. Supply shortages caused by the variability of renewables have in the past been filled by fossil fuel backup capacity, but increasingly lower-carbon solutions on the "demand side" have been sought – such as batteries "behind the meter" and building efficiency. Currently, it is possible on grids to reduce energy usage in periods of high renewable penetration and potentially save little to no carbon, while increasing load-balancing challenges from renewable energy sources such as wind and solar.

CASE STUDY 3: GREEN PROOFS FOR BITCOIN

How blockchain can reduce the environmental, social and/or economic negative impact

Name of project	Founding organizations	Description
Green Proofs for Bitcoin	Energy Web Foundation	Green Proofs for Bitcoin is a transparency initiative supporting alignment between bitcoin mining and global decarbonization efforts. Using the Green Proofs for Bitcoin validation platform, miners can apply for and share sustainable mining certifications. Miners can then selectively disclose their certifications and/or underlying sustainability data with crypto market participants and business counterparties.

Innovation in the blockchain sector can provide inspiration for other sectors of the economy; one example is in the use of waste heat. Heat, produced as a by-product of blockchain mining through computational efforts, has so far been largely disregarded, but there is a growing interest in finding ways to use it as sustainable energy for other purposes. Because Bitcoin miners operate at maximum capacity every day of the year, they present a distinct opportunity to offer district energy systems a dependable and eco-friendly heat baseload.

Many mining companies are now investigating various methods of recovering and repurposing waste heat. For example, in 2021, North Vancouver[14] became the first city in the world to use Bitcoin mining for district-specific utility heating through using waste heat recovery to power local buildings. Lonsdale Energy Corporation collaborated with Canadian cleantech company MintGreen and converted heat electricity from Bitcoin mining to help heat residential and commercial buildings. The goal is to support the city's ambitious greenhouse gas (GHG) reduction targets.

Digital boilers developed by MintGreen can recover more than 96% of the electricity consumed during Bitcoin mining as heat energy,[15] which can then be used to sustainably heat communities and support industrial processes. Through its collaboration with North Vancouver, the company can prevent 20,000 metric tons of GHG per megawatt from entering the atmosphere. The recaptured energy will be used to heat approximately 100 residential and commercial buildings that house a population of approximately 155,000.

CASE STUDY 4: BLOCKCHAIN DECARBONIZATION

Use cases that demonstrate how blockchain can solve environmental, social and/or economic challenges

Name of project	Founding organizations	Description
Blockchain Decarbonization	Ripple, XRP Foundation, Energy Web Foundation	The first phase of deployment involves using energy attribute certificates (EACs) from renewable energy sources to reduce the carbon footprint of electricity consumption in the blockchain. Through Energy Web's open-source application EW Zero, individuals, businesses or entire blockchain ecosystems can transition to using verified zero-carbon electricity.

4 Creating comprehensive impact analyses

Fully evaluating the impact of blockchain projects requires not only considering the environmental effects but also weighing the social and economic benefits that these solutions can bring.

To achieve a full analysis, it is crucial to take a unified approach when assessing the impact – one that balances the project's environmental, social and economic effects.[16] This will enable projects to measure more successfully for the upcoming reporting standards referred to in Section 2. The following sections provide a high-level view of how to create a well-balanced and comprehensive assessment.

A comprehensive analysis includes environmental, social and economic impact – engineered to help companies, policy-makers and citizens make better decisions about how to implement and report on blockchain and cryptocurrency services and applications across the broad spectrum of activities that general purpose technologies (GPT) cover. These insights are critical to effective market development as policy-makers are increasingly directing significant attention towards blockchain and cryptocurrency markets.

CASE STUDY 5: I-REC MARKETPLACE

Use cases that demonstrate how blockchain can solve environmental, social and/or economic challenges

Name of project	Founding organizations	Description
I-REC Marketplace	Mercados Eléctricos, Energy Web Foundation	Mercados Eléctricos and EW cooperated to build a pilot digital marketplace for renewable energy certificates (RECs) in El Salvador to implement an assessment of its business viability as well as the technical feasibility of a blockchain-based regional I-REC marketplace. Given that El Salvador did not have an I-REC market in the initial stages of the I-REC pilot (2019), Mercados Eléctricos also took the lead in putting together the I-REC standard in the country. There are plans to add up to 200 devices in El Salvador to this I-REC pilot platform in the future.

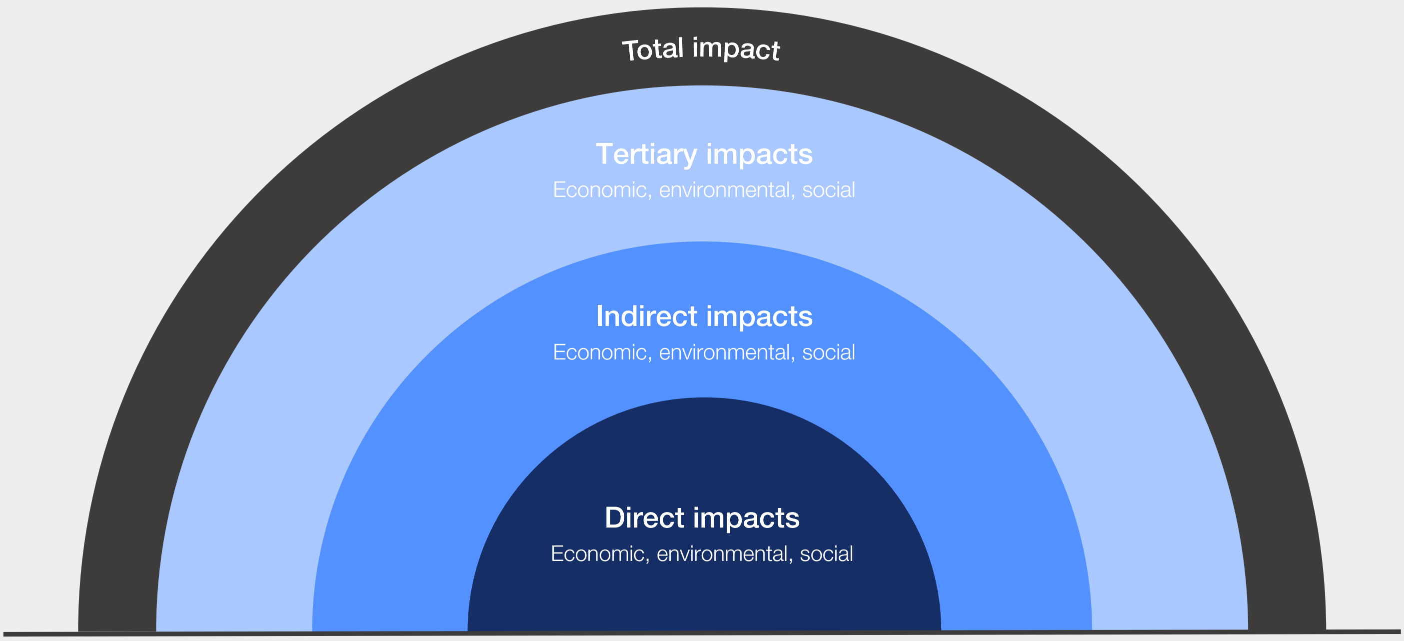
CASE STUDY 6: SRCFUL

How blockchain can reduce the environmental, social and/or economic negative impact

Name of project	Founding organizations	Description
Srcful	Srcful	Srcful is a virtual power plant that uses blockchain technology to create a decentralized community for shaping the future of energy. Srcful is working towards establishing a smart, decentralized grid using distributed energy resources (DERs), blockchain technology and the Internet of Things (IoT). To accomplish this goal, Srcful offers a way for individuals to earn tokens by constructing and connecting their own solar panels or batteries through the use of the Srcful Energy Gateway. This device is compatible with major inverter brands and provides a digital identity for DERs, enabling them to transact and verify their energy data on the blockchain. By linking various solar panel and battery systems, Srcful intends to enable micro-producers to participate in previously restricted ecosystems and monetize their contributions through ancillary services.

It is necessary to assess a solution across three different dimensions in order to perform a comprehensive impact analysis. First, as discussed, the solution needs to be assessed from the environmental, social and economic perspectives. Second, an assessment is needed of each of these from three separate angles – the direct, indirect and tertiary impacts. This is illustrated in Figure 5.

FIGURE 5 **Comprehensive impact analysis: three dimensions**



Source: Adapted from Mulligan, Catherine and Kelly, Fin. "Digital Entrepreneurship: Ensuring True Compliance with Sustainable Development Goals (SDGs)," 2021 IEEE International Conference on Technology and Entrepreneurship (ICTE), Kaunas, Lithuania, 2021, pp. 1–7: https://www.researchgate.net/publication/355761107_Digital_Entrepreneurship_Ensuring_True_Compliance_with_Sustainable_Development_Goals_SDG

Direct impacts: The direct impact of a solution or project encompasses its immediate – or direct – effects. This may include: 1) economic factors such as revenue and payments; 2) social factors such as incentives for carbon reduction; and 3) environmental factors such as reduced CO_2 emissions from implementing a solution or increased water usage. These types of impact are normally the easiest to measure. It is important to capture both the positive and negative impacts to make the correct optimization decisions.

Indirect impacts: Indirect effects are the consequences or impacts that result from solutions. These effects are not immediate or direct but occur over time and along various pathways. Indirect effects can be positive or negative and may affect different aspects, such as economic, social or environmental factors. In the context of economics, indirect effects can refer to the impacts of the money spent by local industries on other local industries, which can have a cascading effect on the entire supply chain. From a social perspective, these may include improved uptake of healthy lifestyles by using a particular dApp. From an environmental perspective, it may refer to a broader change in an area; for instance, using waste heat to heat local districts. To do this effectively, selecting the correct boundary for the system in question is critical so that the analysis is practical.

CASE STUDY 7: GAINFOREST.APP

How blockchain can reduce the environmental, social and/or economic negative impact

Name of project	Founding organizations	Description
Gainforest.app	Gainforest	Gainforest is a decentralized fund that uses artificial intelligence to measure and reward sustainable nature stewardship. AI plays a critical role in effectively estimating the value of nature and helps to accelerate the conservation and sustainable use of natural resources. Currently, Gainforest is among the last 15 teams in the semi-finals competing for the $10M XPRIZE Rainforest to develop innovative monitoring technology. Gainforest also leverages impact NFTs. The donations received for conservation projects are turned into a non-fungible and dynamic impact certificate (NFTrees™). This certificate captures live data (conservation photography, drone data, satellite imagery, wildlife cams and more) from the conservation area and keeps track of donors' impact over time.

CASE STUDY 8: ZERO HERO REC

How blockchain can reduce the environmental, social and/or economic negative impact

Name of project	Founding organizations	Description
Zero Hero REC	Zumo	Zumo leverages open-source industry data to forecast and calculate crypto electricity consumption, and then uses renewable energy certificates (RECs) to procure renewable energy and ensure that blockchain and crypto activities are powered by renewables. In 2022, Zumo successfully concluded its Zero Hero pilot project, which involved purchasing RECs to offset the electricity consumption of bitcoin acquired via the Zumo app. During the pilot phase, Zero Hero REC purchases covered bitcoin worth £1.5 million and compensated a total of 850 megawatt-hours (MWh) of electricity. This report provides information on the Zero Hero results, methodologies used and practical implications for digital asset solutions providers: *Decarbonising Crypto: Towards Practical Solutions*.

Tertiary impacts: Tertiary impacts refer to the effects that extend beyond a solution's immediate or indirect impacts. Such impacts may include changes in consumer behaviour, market competition and ripple effects on related industries and services. For instance, the establishment of a new manufacturing plant can create jobs and boost the local economy while leading to increased demand for housing and services in the area, which indirectly affects those industries. When viewed from a social perspective, tertiary impacts may have both positive and negative aspects. For example, reduced privacy resulting from data collection may have ethical implications, while improved healthcare services may be viewed positively. Similarly, when it comes to the environmental effects, tertiary impacts must consider the supply chain impacts of using technology. For instance, what are the environmental implications of an entity outsourcing all of its data storage to third parties where it has no control over energy usage and consumption? Finally, digital solutions' tertiary ecological impacts require consideration of the overall product life cycle, including how it will be recycled and disposed of.

CASE STUDY 9: CARBONARA

How blockchain can reduce the environmental, social and/or economic negative impact

Name of project	Founding organizations	Description
Carbonara	Unibright and Zühlke Engineering	Unibright and Zühlke Engineering have teamed up to launch Carbonara, a dedicated side project that includes Unibright developers, Zühlke engineers and third-party participants, including team members from eth.events (Ethereum), to explore blockchain energy consumption. The project has three main objectives: to generate knowledge about blockchain energy usage, to encourage the blockchain industry to be more energy-conscious and sustainable, and to motivate individuals to contribute to CO_2 compensation initiatives.

The comprehensive assessment guidelines presented in this report are designed to:

1. **Facilitate market creation** by ensuring that a robust measurement of the environmental impact of blockchain and cryptocurrencies is made available as a series of guidelines.

2. **Provide a business justification** for the effective measurement of the environmental, social and economic impact.

3. **Create an effective dialogue** between policy-makers and other stakeholders on the impact blockchain and cryptocurrencies can have on related initiatives across a range of areas for private enterprise, start-ups and society more broadly.

The insights generated by the frameworks can help in four ways:

1. **Assist companies in preparing for new reporting standards:** The frameworks outline an initial set of methods to allow blockchain and cryptocurrency companies to generate comparable datasets for new reporting requirements.

2. **Better position for wider adoption and exploitation:** The evidence assembled when populating the framework can help articulate the benefits to investors and service users and generate the interest needed to scale up and realize the initiative's full potential.

3. **Tighten the scope and specification:** Working through the framework should help refine the nature of the initiative to ensure everyone is clear about what it is trying to achieve, as well as making the details on how it needs to be delivered to best achieve its objectives more concise.

4. **Improve value:** Once the complete comparison of costs and benefits has been made, the framework can provide a helpful guide to highlight alternative approaches or refinements that offer a greater return on investment or deliver services at a lower cost.

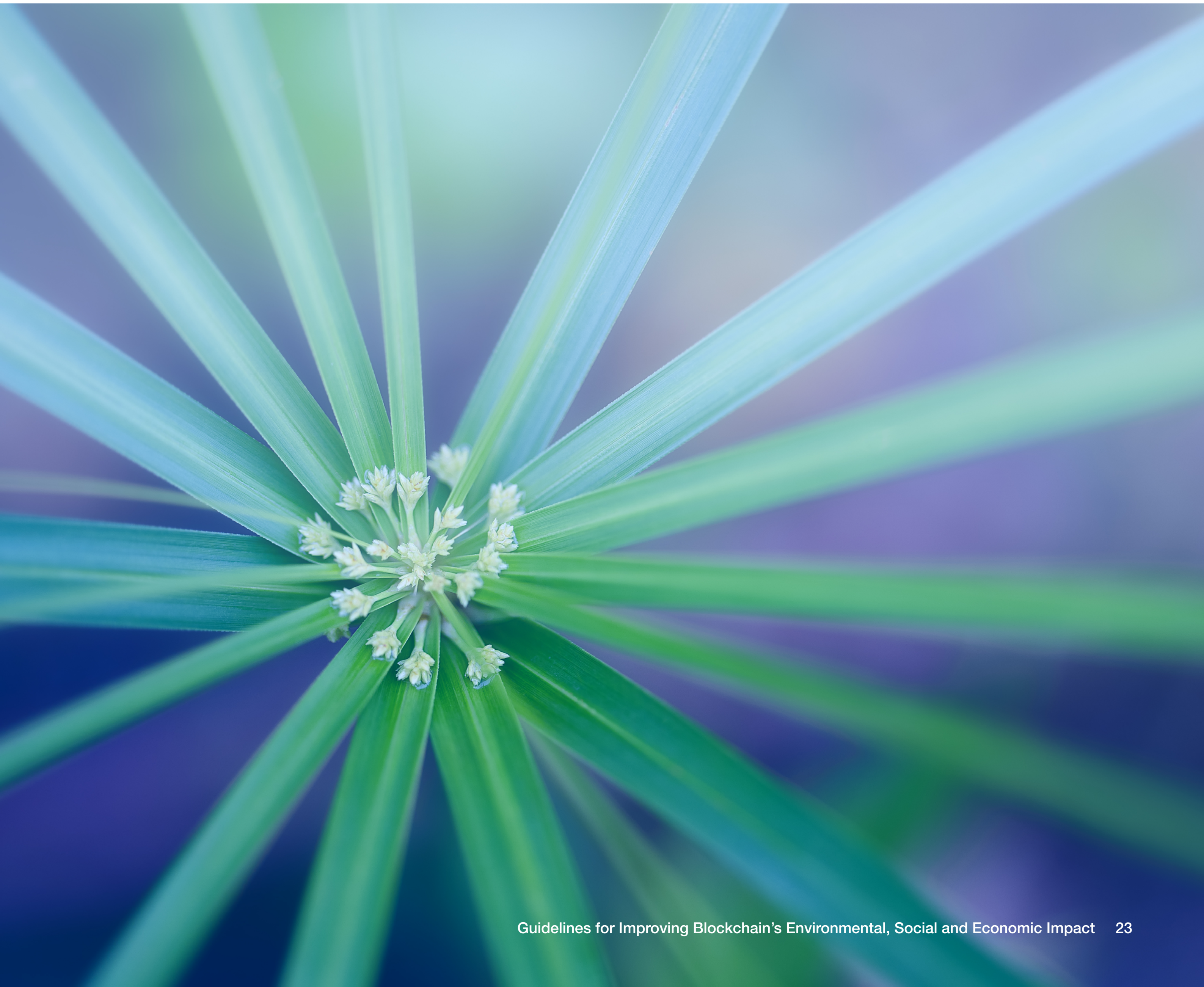
The tools outlined here are best used as a preparatory exercise to identify the challenges and opportunities at the onset of a blockchain project and then again at the end of the deployment to assess the results obtained, consider whether the standard has been met and identify further room for improvement. The environmental, social and economic impact frameworks comprising the unified impact assessment portfolio will yield maximum value to blockchain projects when used with the toolkit provided here.

The environmental, social and economic impact frameworks should be designed modularly so they can be used in isolation or alongside one another. At the onset of the assessments, therefore, the intervention type, aims, scope, scale and reach of the blockchain intervention need to be defined only once, but rigorously. The unified impact assessment impact frameworks are comprehensive in that they consider several factors throughout a project; for instance, the efficiency (cost-saving) and effectiveness (behaviour-changing) outcomes; pragmatic top-down and bottom-up approaches that address the scale, potential interlinkages between systems and the benefits spread among them; actualized (ex-post) versus possible future (ex-ante) impacts.

For all impact frameworks, it is advisable to construct a baseline; this will be a data-collection activity to establish the current state of affairs. For instance, to make an initial assessment regarding the degree of measurable economic impact that a given project will achieve, it is necessary to conduct a high-level evaluation to assess the impact accurately.

TABLE 5 **Environmental, social and economic impact frameworks**

Environmental impact	Social impact	Economic impact
Type (descriptor)	Type (descriptor)	Type (descriptor)
Aims, scope, scale and reach	Aims, scope, scale and reach	Aims, scope, scale and reach
Mapping impact	Pathways to impact	Implementation costs
Impact calculation	Alignment with SDGs	Efficiency improvements



5 Conclusion

The blockchain community has made progress in measuring its energy consumption, but more work needs to be done to prepare for upcoming regulation.

Using blockchain in the energy sector has the potential to revolutionize the industry by creating efficient and secure systems for managing energy production, distribution and consumption. The use of blockchain can enable peer-to-peer trading of renewable energy and support the integration of emerging technologies such as electric vehicles and smart batteries for energy storage, leading to more flexible and resilient energy systems. However, the energy impact of blockchain must be correctly accounted for to ensure that the creation of solutions does not cause environmental harm. The blockchain community has made progress in measuring its energy consumption, but more work needs to be done to prepare for upcoming regulation. This report summarizes the blockchain community's vision for measuring energy consumption across varied projects and has made suggestions for the future development of this space for the blockchain community through:

1. Providing guiding principles and toolkits for companies, regulators and start-ups to leverage the potential of blockchain to reach net-zero goals
2. Outlining potential approaches to a unified impact assessment that considers environmental, social and economic perspectives, to prepare blockchain companies and solutions for upcoming regulation
3. Illustrating effective applications of blockchain for both demand and supply issues in energy and investment, towards achieving full net-zero solutions

To achieve these objectives, the report has emphasized the importance of correctly accounting for the energy impact of blockchain and ensuring that the development of solutions does not cause more harm to the environment.

Glossary

10-K: A 10-K is a comprehensive report filed annually by a publicly traded company about its financial performance. The report is required by the US Securities and Exchange Commission (SEC) in the United States or the appropriate regulatory authority in other countries.

51% attack: This is an attack on a cryptocurrency blockchain by a group of miners who control more than 50% of the network's mining hash rate (the total computing power used for mining). The hash rate is determined by how many guesses are made per second. The overall hash rate helps determine the security and mining difficulty of a blockchain network. Owning 51% of the nodes on the network gives the controlling parties the power to alter the blockchain.

Carbon offsetting: Carbon offsets are credits representing the removal of 1 metric ton of carbon dioxide from the atmosphere. These offsets are obtainable through activities such as planting trees or carbon capture and legally offset the amount of carbon that a polluting entity has emitted. Once obtained, carbon offsets can be sold to other parties as authorized by the Kyoto Protocol.

Corporate Sustainability Reporting Directive (CSRD): The CSRD is a new piece of European Union legislation that requires all large companies to publish regular reports on their environmental and social impact activities. The reports help investors, consumers, policy-makers and other stakeholders evaluate large companies' non-financial performance.

Crypto Climate Accord (CCA): Launched in April 2021, the CCA is an open-source environmental initiative formed by organizations from the cryptocurrency, blockchain, technology and energy sectors that share a collective ambition to pursue environmental sustainability within the digital asset space.

Cryptocurrency mining: Cryptocurrency mining is the competitive process that verifies and adds new transactions to the blockchain for a cryptocurrency that uses the proof of work (PoW) method. The miner that wins the competition is rewarded with some amount of the currency and/or transaction fees.

Decentralized application (DApp): A DApp is an application that can operate autonomously, typically through the use of smart contracts, and can run on a decentralized computing, blockchain or other distributed ledger system. Like traditional applications, DApps provide some function or utility to their users.

Decentralized finance (DeFi): DeFi comprises financial products and services that are accessible to anyone with an internet connection. DeFi operates without the involvement of banks or any other third-party firms.

Decentralized staking: There are primarily two types of decentralized staking. The first involves staking to become a validator, which results in rewards as per the protocol's description. The second form involves delegating one's cryptocurrency to specific validators through staking applications or pools. With this method, the individual still owns their crypto assets but is not responsible for running a node to secure the network.

Electronic Subcontracting Reporting System (eSRS): eSRS is a web-based government-wide subcontracting system that allows electronic submission, management (acceptance, revision, rejection), reports and analyses of subcontracting data in a real-time paperless environment.

Environmental, social and governance (ESG): ESG stands for environmental, social and governance. These three elements are called pillars in ESG frameworks and represent the three main topic areas on which companies are expected to report. The goal of ESG is to capture all of the non-financial risks and opportunities inherent in a company's day-to-day activities.

European Financial Reporting Advisory Group (EFRAG): The EFRAG is a private association established in 2001 with the encouragement of the European Commission to serve the public interest by developing and promoting European views in the field of financial reporting and ensuring these views are properly considered in the International Accounting Standards Board (IASB) standard-setting process and in related international debates.

General purpose technology (GPT): General-purpose technologies are technologies that can affect an entire economy. GPTs have the potential to drastically alter societies through their impact on pre-existing economic and social structures. The archetypal examples of GPTs are the steam engine, electricity and information technology.

Global Reporting Initiative (GRI): The GRI is an international independent standards organization that helps businesses, governments and other entities understand and communicate their impacts on issues such as climate change, human rights and corruption.

Greenhouse gases (GHGs): GHGs are gases in the Earth's atmosphere that trap heat. During the day, the sun shines through the atmosphere, warming the Earth's surface. At night, the Earth's surface cools, releasing heat back into the air.

IFRS Foundation: The IFRS Foundation is a not-for-profit, public-interest organization established to develop high-quality comprehensible, enforceable and globally accepted accounting and sustainability disclosure standards – the IFRS Standards – and to promote and facilitate adoption of the standards.

International Sustainability Standards Board (ISSB): The ISSB is responsible for developing International Financial Reporting Standards (IFRS) Sustainability Disclosure Standards, to provide a truly global baseline of sustainability disclosures to further inform economic and investment decisions.

Node operators: Node operators run a blockchain's software, certifying transactions as they are entered into the chain by writing new blocks and broadcasting them to the network. They process blocks based on transactions that follow the blockchain's protocol rules.

Non-Financial Reporting Directive (NFRD): The NFRD was adopted by the European Union in 2014 to bring more transparency to the social and environmental performance of large companies. The directive sets out specific criteria on which type of companies should disclose non-financial information and the guidelines they should follow.

Scope 1 emissions: Scope 1 comprises emissions from sources that an organization owns or controls directly – for example, emissions from burning fuel in a company's fleet of vehicles (assuming they are not electrically powered).

Scope 2 emissions: Scope 2 emissions are those a company causes indirectly when the energy it purchases and uses is produced – for example, the emissions from the generation of the electricity that powers an electric fleet of vehicles would fall into this category.

Scope 3 emissions: Scope 3 emissions are those not produced by the company itself, or that result from activities arising from assets owned or controlled by it – rather it refers to emissions for which it is indirectly responsible up and down its value chain. An example of this is when a company buys, uses or disposes of products from suppliers.

Sharding: Sharding is a process that divides the whole network of a blockchain organization into several smaller networks, referred to as "shards". Because it contains data that is unique to it, one shard stands out as unique and independent of the others.

Sustainability Accounting Standards Board (SASB): The Sustainability Accounting Standards Board is an independent non-profit whose mission is to develop and disseminate sustainability accounting standards that help public corporations disclose material, decision-useful information to investors.

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Endnotes

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