Front. Comput. Sci.
DOI
Fazal Raheman: Blockchain sustainability: A reality check
RESEARCH ARTICLE

Economic & social sustainability of legacy blockchains for non-crypto use cases: A reality check

Fazal RAHEMAN (✉) [1]
1 Blockchain 5.0 Ltd, Kesklinna linnaosa, Ahtri tn 12, 10151, Tallinn, Estonia

Abstract Blockchain is predicted to be a $3+ trillion business by 2030, but it is still hasn't achieved commercial viability beyond its stupendous success in enabling a multi-trillion cryptocurrency industry. It's very high transaction cost and vulnerability to centralization limits its potential. As they say complacency is death of innovation and accurate diagnosis is the only way to cure a disease, we cannot afford to remain complacent anymore. As cryptocurrency thrives while blockchain struggles to find its place, we need to reach an accurate diagnosis of what's ailing. This paper looks at blockchain technology, its failed attempts at non-crypto use cases, and provides an overview of the criticism and much ignored shortcomings that need to be overcome for building the next generation blockchain. The realization of blockchain's full potential is impossible without an introspection and a deep dive into lessons learnt from the setbacks. Based on those lessons, five rules that define the next generation blockchain emerge. This paper articulates those rules clearly and presents measurable key performance indicators (KPIs) that blockchain researchers can use in building future decentralized solutions.

Keywords sustainable blockchain, future blockchain, economic sustainability, social sustainability, decentralization, consensus, Ethereum

Received Month dd, yyyy; accepted Month dd, yyyy

E-mail: drfazal@bc5.eu

1 Introduction

In 2021 cryptocurrency market cap hit $3 trillion [1], a feat no technology in the history has achieved within a short span of a dozen years that blockchain has existed. There is absolutely no doubt that blockchain is here to stay, no hesitation in concluding that blockchain's cryptocurrency use case is indeed commercially viable. Blockchain and cryptocurrency are inseparably linked. As much as a decentralized form of money simply cannot exist without the security provided to it by blockchain, a public blockchain cannot be created without giving people incentives to create it. Decentralized currency is that incentive.

Blockchain is a decentralized ledger technology that immutably links a growing list of publicly accessible records called blocks *in a chain*, *using cryptographic hashes that require consensus of majority of record validating peer nodes in a peer-to-peer public network incentivized with tokenized rewards for contributing their resources for validating the blocks.*

The following five essential elements make the definition of blockchain complete:

1. Decentralized ledger
2. Immutable chain of publicly accessible records
3. Cryptographic hashing
4. Consensus of peers for validating records
5. Incentivized public network

Humongous body of evidence has accumulated in peer reviewed literature suggesting blockchain's utility in almost all walks of life. But it has hardly made any inroad into any non-crypto use cases, raising a question whether it is at all economically sustainable in use cases beyond cryptocurrency. If a solution isn't commercially viable, there's no point studying its social and environmental sustainability. A sustainable blockchain use-case cannot be sustainable unless the blockchain itself is economically sustainable. Economic sustainability trumps social or environmental sustainability all the time. Any initiative, no matter how noble it is, if it isn't economically viable it is rendered moot. No one conducts an environment damaging activity unless there is economic benefit. It is indeed surprising that there is so much literature on blockchain and environmental sustainability and almost nothing on its economic sustainability. The economic and social sustainability question is reviewed de novo in this paper. We believe this is a maiden review of the economic and social sustainability of blockchain.

2 Understanding sustainability & its 3 barriers preparation and submission requirements

A lifestyle, a way of doing things, is sustainable if most of the world's population could continue it for a long time without major adverse consequences. It is a potential dynamic equilibrium of some type [2]. Hence it is most often defined as meeting the needs of the present without compromising the ability of future generations to meet theirs [3]. Sustainability means meeting our own needs without compromising the ability of future generations to meet their own needs [4]. In addition to natural resources, we also need social and economic resources. Sustainability is not just environmentalism, but also encompasses social equity and economic concerns. It is the way an economy operates in a sustainable manner, protecting social and environmental elements. This is clearly enshrined in United Nation's 17 Sustainable Development Goals (SDGs) for 2030 adopted by 193 countries as a "blueprint to achieve a better and more sustainable future for all" [5]. Sustainability is essentially what we want to happen indefinitely.

The 17 SDGs are integrated, recognizing the fact that action in one area will affect outcomes in others, and that development must balance economic, social and environmental sustainability. Countries have committed to prioritize progress for those who're furthest behind. The SDGs are designed to end poverty, hunger, AIDS, and discrimination against women and girls. Creativity, knowhow, technology and financial resources from all of society is necessary to achieve the sustainability in every context [6]. From that perspective are blockchains sustainable? An answer to that question will go a long way in building the next generation blockchain.

Currently blockchain's only use case that is commercially successful is cryptocurrency. Beyond cryptocurrency, blockchain's social and environmental sustainability is at best questionable. This is despite being aggressively pursued for all kinds economic, social and environmental use cases [7]. If a use case isn't commercially viable, the question of social and environmental sustainability will become a moot point. But ironically almost all sustainability literature on blockchain pertains to environmental sustainability without even considering whether it passes the economic and social sustainability barriers.

2.1 Economic Sustainability

Economic Sustainability is the first barrier that's more or less a showstopper for any new innovation to be adapted. If a solution isn't commercially viable it simply culminates in its natural death. There is no question of exploring its social and environmental dimensions because no one will pursue a socially or environmentally adverse activity unless there is some economic benefit or a financial advantage in the pursuit. Blockchain's cryptocurrency use case remains a hot pursuit because of the overwhelming success of the crypto industry in recent years, and therefore qualifies an investigation into social and environmental sustainability. But a review of the non-crypto use cases of blockchain tells us a completely different story that is hardly voiced in peer-reviewed literature, which often considers Ethereum synonymous with blockchain technology [8]. No matter what the use case, "Ethereum is the standard for smart contract" [9] that remains the foundation of any non-crypto use case. The cost of each transaction recorded on each node of the blockchain may not be of as much relevance when recording a token buy/sell transaction as long as there is a profit-making potential involved. But it is of huge relevance to a non-crypto use case when recording a smart contract transaction on blockchain as compared to saving it on a legacy database for almost no cost.

The notions of "transactions" and "costs" are the focus of the economic theory of transaction costs. The term transaction is used to describe the process of shifting a commodity or service unit, whereas transaction costs are the total amount of both monetary and non-monetary resources required to complete the transaction. The costs occur as a result of the combination of environmental uncertainty, limited rationality, expediency, and the asset-specific nature of the transfer.

A 2017 study by Rimba et al is the only study we found that compares the cost of recording data on Ethereum blockchain against a legacy database, finding that the blockchain cost was 360 times higher than the conventional cost [10]. They further estimated that the conventional Amazon servers have to store the data for a mind boggling 197 years to reach a break-even point to justify the blockchain transaction. Moreover, those estimates were when the Ethereum price was in 2 digits. Now, with the Ethereum price being in 4 digits, the cost will be astronomically prohibitive. While sustainable blockchain researchers mostly focus on blockchain's electricity consumption and its carbon footprint [11 and propose sustainability use cases [12] the humongous transaction cost, which makes it totally unsustainable, is hardly on anyone's radar screen. Even if the carbon footprint hurdle is overcome in future, the transaction cost is unsurmountable. When the upcoming shift from proof-of-work to proof-of-stake reduces carbon footprint of Ethereum, experts believe its transaction cost will not come down [13].

The high transaction cost of a blockchain smart contract is fairly comprehensible but often ignored by sustainability researchers. If we look at the number of nodes that each blockchain deploys to replicate and validate the transaction and receive a financial incentive in return. The number of nodes varies dynamically at any given point of time. The two most popular blockchains Bitcoin [14] and Ethereum[15] exceed 10,000 nodes, and almost all the leading blockchains boast of 1000+ nodes. However, blockchains like Steem, EOS, Tron, Cosmos deploying delegated proof of stake consensus protocol [16] may limit the nodes to around 21. This essentially means that when a transaction is recorded on a blockchain it is replicated thousands of times in most blockchains or at least 21 times in some. With each node receiving a financial incentive to participate in the network the transaction cost skyrockets to a level of absurdity that perhaps only an NFT auctioned at $100,000 may sustain a gas fee as high as $100+. A social or environmental activity such as renewable energy management or inclusivity enforcement action is economically impossible at a $28 transaction fee (**Fig. 1**).

Fig. 1 Historical ETH gas fee/transaction.
Data Source: www.statista.com/statistics/1221821/gas-price-ethereum/

Most environmental and social sustainability actions are low margin, low value transactions [17] and as such not economically viable using legacy blockchain's replicated ledger database. If a use case isn't commercially viable the questions of its social and environmental sustainability do not arise because it will not be economically sustainable.

2.2. Social Sustainability

Social good is something that benefits the largest number of people in the largest possible way, such as equality, inclusivity, clean air, clean water, healthcare, literacy, etc. The core of social sustainability of a blockchain lies in its inclusivity, equitability and transparency, all of which depends on the extent of decentralization it represents. Robustness and sustainability of any decentralized blockchain system depends on the strength of the consensus algorithm it deploys.

No matter how much decentralization is inherent in blockchain, human intervention will always work to centralize the power by one or the other means.

Consensus algorithm is at the heart of such a power play. Since Satoshi Nakamoto's first disclosure of the Proof-of-Work (PoW) consensus algorithm in his bitcoin blockchain white paper in 2008, several consensus protocols have been developed and deployed. But none can claim to be completely immune to a 51% attack. This is because:

Although blockchain, in theory, decentralizes power, it cannot completely stop human greed and craving for power from gaming the system. Pooling, syndication, cartelization are the names of the game [18].

A 51% attack on a blockchain network is when a single entity or organization or syndicate can control much of the hash rate, potentially causing a network disruption. In such a scenario, the attacker would have enough mining power to intentionally exclude or modify the ordering of transactions. They can send a transaction and then reverse it, making it appear as though they still had the coin they just spent. This vulnerability, known as double-spending, is the digital equivalent of a perfect counterfeit and the basic cryptographic hurdle the blockchain was built to overcome. A network vulnerable to double spending would quickly suffer a loss of confidence. 51% attackers can also prevent other miners from completing blocks, theoretically allowing them to monopolize the mining of new blocks and earn all the rewards. All cryptocurrencies that use distributed ledger blockchains are potentially vulnerable to 51% attacks [19], with bitcoin itself suffering one in 2014 [20]. While the debate on the most robust decentralized consensus algorithm goes on, the consensus protocol that sanitizes a blockchain from 51% attack alludes. There seems to be no consensus on the perfect consensus protocol.

Centralization, due to its simplicity, is a phenomenon that happens to any disciplined and organized system automatically [21]. Bitcoin core developers once decided to lower the transaction fees unilaterally without discussing with the community [22]. Similar centralized control also exists in Ethereum [23]. Core developers of blockchain have more decision-making power in the decision-making process and hence centralizing the governance of blockchain [24].

Currently 4 bitcoin mining pools and just 3 Ethereum pools control these networks [25] (**Fig. 2**).

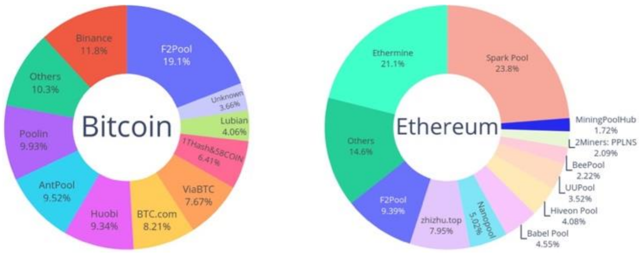

Fig. **2** Consensus centralization in Bitcoin & Ethereum. Image Source: Sai et al [25].

Given the existing mining concentration, decentralization seems to be impossible in blockchain. Theoretical discussions [26] and empirical evidence show that complete decentralization is an illusion [24]. Several dominant miners can account for validation of most transactions in bitcoin and Ethereum. Another report claims Ethereum is more centralized than bitcoin [27]. To alleviate the negative effects of collusions, Ethereum blockchain implemented new transaction fee mechanism in the London Fork in 2021, but it neither deters pooling, nor bribery [28].

2.2.1 Blockchain beats North Korea in centralization

It is clear that legacy blockchain ecosystem is far from being decentralized. According to Guo et al [29] "wealth in crypto land is more concentrated than in North Korea where the inequality Gini coefficient is 0.86. The Gini coefficient for bitcoin is an astonishing 0.88." Unfortunately, in contrast to the regulated centralized legacy systems, the increasing centralization of blockchain systems do not abide by any transparent regulations / legislations. This could, in turn, lead to severe consequences on the fate and reputation of blockchain ecosystems.

2.2.2 Emergent centralization: The decentralization paradox

Apart from inherent nature of blockchain participants to amass control and accumulate power by hook or by crook, the growth of a network may also naturally propel itself towards centralization in an expanding socio-technical system [30]. Such "emergent centralization" (**Fig. 3**) is predictably inevitable if left to manipulation by powerful peers.

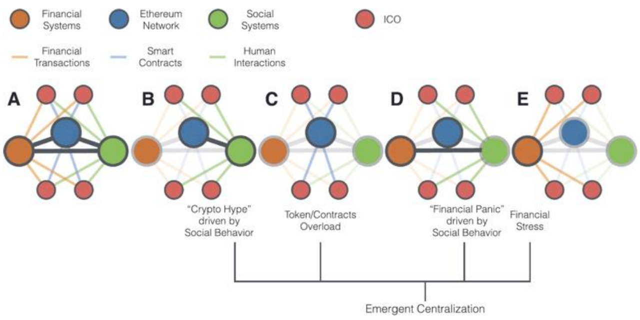

Fig. 3 Emergent centralization with scale up
Image Source: De Domenico & Baronchelli [30].

Marginal cost is the cost of producing one extra unit of a particular good, which in case of blockchain represents the cost expended by a consensus-producing actor to produce one additional unit of consensus on the network. Economies of scale reduces marginal costs encouraging fewer producers and larger scale production which is inherently in opposition to the goal of decentralization. Based on the capital costs, operating costs and opportunity costs, any system which aims to remain decentralized must aim to minimize the advantage of economies of scale when producing extra consensus or it will suffer from emergent centralization as it grows.

2.3 Environmental Sustainability

Ethereum is the most energy consuming blockchain after bitcoin. It eats up at least a quarter to one third energy as bitcoin does A typical Ethereum transaction gobbles as much power as an average U.S. household uses in almost a week leaving a carbon footprint larger than over 200,000 VISA transactions (**Fig. 4**).

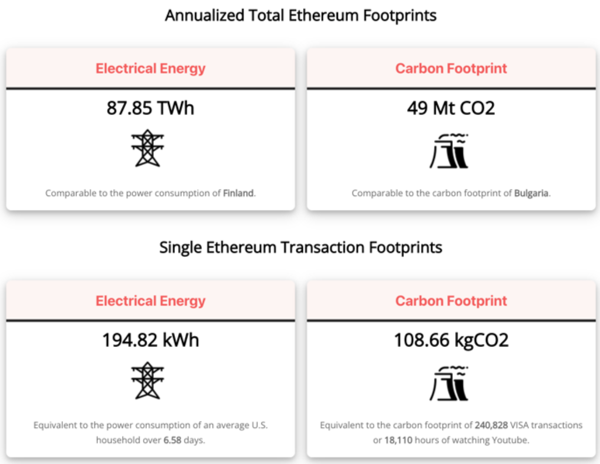

Fig. 4 Ethereum Carbon Footprint
Image Source: DIGICONOMIST.net [31]

On July 29th 2022, Ethereum consumed 87.85 TWh of energy comparable to the power consumption of Finland and left 49 Mt of CO2 as carbon footprint equivalent to Bulgaria [31]. Ethereum has plans to change its proof-of-work algorithm to an energy efficient proof-of-stake algorithm called Casper. This change would minimize energy consumption and will be implemented gradually according to the latest roadmap. For now, Ethereum is still running on proof-of-work completely. In its current state the entire Ethereum network consumes more electricity than a number of countries.

With that level of carbon footprint and super high transaction costs can sustainability professionals justify smart contract deployment in utilities or renewable energy development seeking a more efficient way of pricing and selling clean power? Or consumer products companies and retailers seeking a better way of validating supply-chain claims? And, can banks and insurance companies interested in verifying the provenance of minerals, commodities or raw materials, justify smart contracts?

The real problem is most entrepreneurs working on “social good,” “sustainability” are social entrepreneurs and not blockchain experts. Almost all of them use Ethereum blockchain as their network backbone for proof-of-concept totally ignoring its prohibitory transaction costs. Can any solution based on Ethereum be sustainable or do “social good?” Yet in the frenzy that blockchain has created, even most “blockchain for good” challenges have judged Ethereum based startups as winners. In 2020, European Commission’s European Innovation Counsel awarded 5 million Euros each to six winners of “blockchain for social good,” [32] who were Ethereum researchers deploying Ethereum for sustainability driven applications. Unfortunately, most current “social good” use cases piggyback on the most unsustainable blockchain. If a blockchain is not sustainable, it at least shouldn’t be an enemy of sustainability. That compels the critics to ask: will there at all be a blockchain for social good?

3 Why no production grade dApps yet?

Most blockchain research focusses on scalability and speed of transactions, which we believe are already within reach. The dynamics of real-world use cases go beyond scalability and speed and hinge around creating a surplus value from each transaction recorded on the blockchain, and done so in perfectly democratic manner, leaving no scope for human manipulation. Blockchain researchers have been so focused on scalability and speed issues that the transaction cost and decentralization dimensions of blockchain have mostly been ignored. While the former depends on the economics of each transaction and is a showstopper of sorts, the latter involves perfecting the blockchain's consensus mechanism, which are currently prone to pooling, syndication or some such centralization. A less than perfect consensus mechanism cannot be perfectly decentralized to prevent 51% attacks.

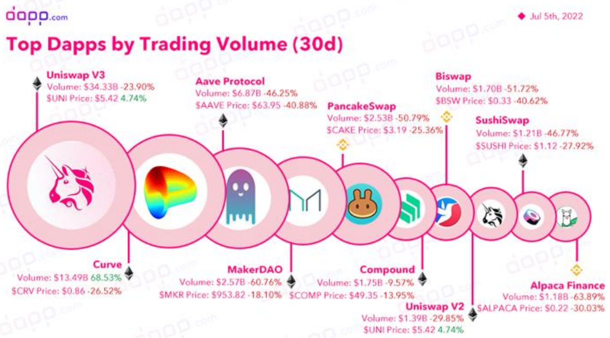

Fig. **5** Top 10 dApps in July 2022.
Image Source: Dapp.com [33].

In July 2022, Dapp.com reported data on top 10 dApps (**Fig.5**). All those dApps represent crypto use cases (either DEX or DeFi)[33] , and none of them service a non-crypto use case. The much-promised non-crypto use cases still remain confined to During a dozen years that blockchain has existed CB Insights reports 1,178 unicorn companies [34], but none of them is based on non-crypto use case of blockchain.

A joint study by the US Agency for International Development and Research and Learning (MERL) examined 43 blockchain projects and reported Zero % success rate (**Fig. 6**), and vendors did not call back when asked for evidence [35]. This finding was consistent with results reported by a subsequent study by British Blockchain Association [36]. Out of the 25 blockchain case studies that Arup published in 2019, the Bankex blockchain project WaterCoin was the only project that was estimated to reach TRL 7 the earliest, i.e.in 2020 [37]. But WaterCoin is now defunct and none amongst Arup's reported 25 blockchain projects have seen the light of the day. Recently IBM shut down its super ambitious blockchain project we.trade launched in 2019 in collaboration with 12 European banks[38]. Sources report that IBM has cut its blockchain team down to nothing [39].

Fig. **6** Image Source: Pixabay.

The principal reason that real world non-crypto blockchain use cases have failed is that it is not cost efficient to replicate transactions thousands of times or at least 21 times (in case of delegated proof of state blockchains), particularly when the transaction is a low value, low margin transaction and the blockchain is Ethereum. That is not to say that there cannot be blockchain use cases or economically sustainable blockchains in future. In fact, there is already a fairly successful non-crypto use case of blockchain operating since 2016 as a popular blockchain social network (BSN) platform- Steemit.com, that deploys Steem blockchain [40]. Steem blockchain transaction costs are extremely low and the transactions it records on blockchain has an intrinsic value far higher than the transaction costs, leaving some surplus value that can be redistributed among the participating peers. But Steem-powered BSN is an exception, albeit a poster child of hope that there are possibilities beyond umpteen failures.

4 Skepticism, Criticism and Rebuttal

A vast plethora of scholarly articles hail blockchain as a powerful technology. It may indeed be. But so is nuclear tech. Do you use nuclear energy to heat up your morning cup of coffee? Do you use a cannon to knock down a fly? Everybody indeed has been talking about blockchain for quite some time now, but will it really change everything? And are the potential applications really endless? (**Fig. 7**)

Fig. **7** Image Source: www.marketoonist.com

In the face of the big blockchain hype, its criticism has picked up momentum [41] and critics are calling it not only a crappy technology but a bad vision for the future [42]. Bruce Schneier, a renowned cryptographer and a public-interest technologist, whose Wired opinion [43] received industry-wide attention, asks a question & answers it:

"Do you need a public blockchain? The answer is almost certainly no."

The outspoken economist, Nouriel Roubini (A.K.A. "Dr. Doom" for predicting the last recession), called blockchain a "big lie", and *the most overhyped — and least useful — technology in human history* [44]. Furthermore, Dr Roubini claims bitcoin/Ethereum are more dictatorial and centralized than the rogue regime of North Korea.

If blockchain is a powerful technology, is it a solution looking for a problem? Majority businesses fail due to "No Market Need." Should we ask "Does blockchain work?" or "Does it work better than other technology solutions in the market?" What is the cost-benefit trade-off to switching to a new consensus-based technology solution?

Applying the transaction speeds and cost of Ethereum to all and sundry non-crypto applications that are being converted to dApps, the technology may indeed look crappy and useless. In fact, Ethereum should have no role in dApps of tomorrow. Ethereum does neither define the entire scope of the blockchain technology, nor it was designed to do anything more complex than ERC20 tokens, which it undoubtedly did exceedingly well. Ethereum sure is a revolutionary milestone in the history of blockchain and deserves the top spot in the hall of fame. But the critics have to realize two things:

1. ***Firstly, Blockchain defines Ethereum, Ethereum does not define Blockchain.***
2. ***Secondly, Ethereum is the very first iteration of a smart contract.***

All the flaws of the first ever iteration of a blockchain smart contract cannot be automatically shifted to all the subsequent smart contract iterations to come. In the history of innovation, there is no evidence of a technology, the first iteration of which, could perform all the magic that the technology was eventually capable of in its more advanced iterations. It is like expecting second generation computers of 1960s to do the AI and quantum resistance of fifth generation computers of future (**Fig 8**). AI and centralization resistance is still extraneous to legacy blockchains.

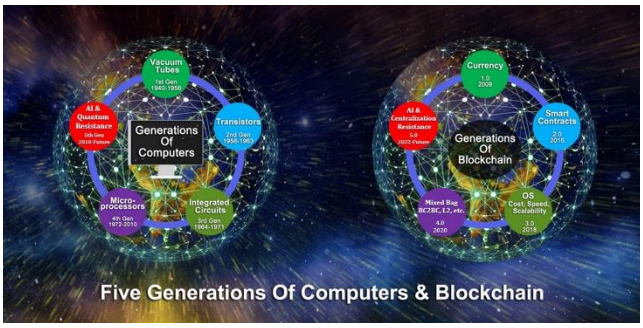

Fig.**8** Five generations of computers and blockchain

In our own quest for the optimal use cases for blockchain, we chose to first work on defining the problems, and then work on perfecting the imperfections in blockchain. We gave ourselves the following due diligence criteria before embarking on a blockchain project:

1. Whether tokenomics has a significant intrinsic role,
2. Whether decentralization adds additional value over conventional low-cost relational database,
3. Whether value of each transaction (new data entry) is more than the cost of recording it on the blockchain, and,
4. Whether there is incentive for peers to participate in the network.

In designing the next generation blockchain that is economically and socially sustainable and identifying appropriate blockchain use cases we identify the following rules or key performing indicators (KPIs):

1. The transaction that the blockchain records should have significant intrinsic or perceived value to justify the cost of recording the transaction on the blockchain.
2. The cryptocurrency tokens that the blockchain generates to reward peer participation should have adequate liquidity in crypto exchanges.
3. The ROI or yield on a staked cryptocurrency token should be higher than the highest interest rate available in any legacy bank.
4. The cost of recording a transaction on the blockchain should be as close as possible to the cost of a traditional database and should leave a surplus value after covering all costs including staking investors' profits. Such surplus value ratio should always exceed 3 (reward value/total transaction cost) to make it a commercially viable solution.
5. Centralization resistant consensus mechanism is crucial for a blockchain that is inclusive, equitable and non-discriminatory, and achieves a Gini Coefficient of at least 0.4 or lower.

The above metrics are essential to implementing real world use cases, which are currently impossible to achieve with most blockchains out there, but certainly possible to custom design one with sustainability in mind. At the 2018 World Economic Forum in Davos, 100% of the participants believed that even if the cryptocurrency bubble bursts, the token economy will prevail [45]. The fact remains that the increasing amount of data and number of transactions will require new innovative systems that are economically, socially and environmentally sustainable. It might very well be that blockchain isn't the right technology to revolutionize every use case conceived by the blockchain enthusiasts, but at least it will be a step in the right direction if the next generation blockchain development prioritizes economic and social sustainability of its tokenomics model in select use cases.

5 Modelling the next generation blockchain

Zero carbon footprint, very low or zero transaction costs and public transparency are the fundamental qualifiers for a sustainable blockchain. While the may be a few promising blockchains, Steem is perhaps the only sustainable blockchain to our knowledge that has passed a full TRL 9 production grade maturity for a non-crypto use case such as blockchain social network – Steemit.com.

Following are the three bare minimum requirements that a blockchain should pass to be considered as sustainable.

1. **Economically sustainable**: Transaction and data storage cost very low, or close to zero, or at least comparable to the cost of traditional relational databases. Economic sustainability is the absolute showstopper making social and environmental sustainability irrelevant.
2. **Socially sustainable**: Perfectly decentralized, equitable and inclusive and publicly transparent. This essentially means the blockchain's consensus mechanism is resistant to centralization.
3. **Environmentally sustainable**: Almost zero carbon footprint.

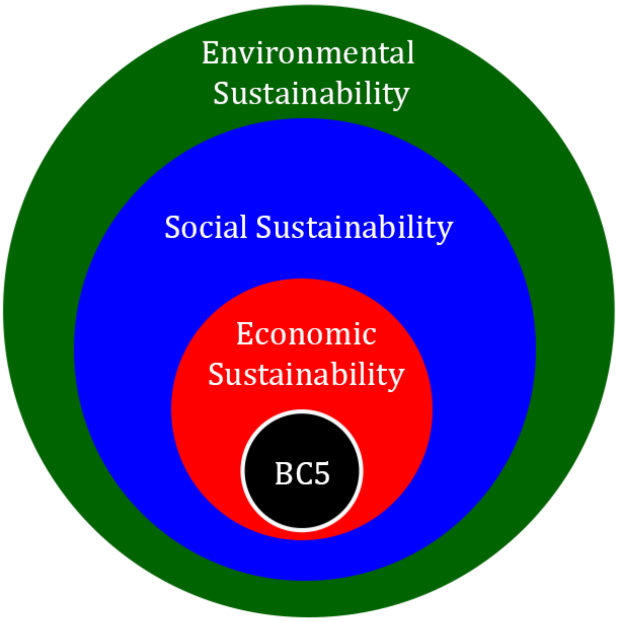

Fig. 9 Modelling the next generation sustainable blockchain

As stated earlier economical sustainability has hardly been on the radar screen of blockchain researchers. Nevertheless, once in a while report purporting to be studying the economic sustainability dimension of blockchain emerge. Surprisingly a study purporting to be evaluating feasibility of blockchain for economically sustainable wireless mesh networks [46], does not present any cost consequences of blockchain deployment in comparison to standard methods. Similarly, several papers report development of sustainable blockchain [47] claiming novel consensus mechanisms [48, 49]. However, without any empirical evidence that these blockchain projects will bring down the transaction costs and will be centralization resistant, it is difficult how well they will endure the demands of sustainability.

Just like TCP/IP, on which the internet was built, blockchain is a foundational technology that will require broad coordination which will take years before seeing any significant commercial traction. No wonder, despite years of hype, the blockchain industry hasn't seen any real-world use beyond its role in cryptocurrencies. The adoption of TCP/IP suggests blockchain will follow a fairly predictable path that will take years to mature. It's time we got started with planning the next generation blockchain that models around economic, social and environmental sustainability.

6 Conclusion and Future Outlook

Blockchain is predicted to be a $3+ trillion business by 2030 [50], but it still hasn't achieved commercial viability beyond its success in enabling a cryptocurrency industry. It's very high transaction cost and vulnerability to centralization limits its potential. As they say complacency is death of innovation and accurate diagnosis is the only way to cure a disease, we cannot afford to remain complacent anymore. As cryptocurrency thrives and blockchain struggles to find its place, we need to reach an accurate diagnosis of the ailing, which this paper strives to achieve.

Although UN Sustainable Development Goals (SDGs) cover a wide range of sustainability parameters, environment / climate change has almost become synonymous with sustainability. Perhaps that is the reason almost all research on blockchain sustainability pertains to environmental sustainability. First and foremost, any technology has to be economically sustainable, only then the question of environmental and social sustainability arises. It's time we looked for sustainable blockchains that first establish economic sustainability before validating its social and environmental sustainability.

Having discussed at stretch what the next generation blockchain should look like, it opportune to answer some of the tough questions posed by the critics:

Will blockchain really change everything?
Conservatively speaking, maybe not.

Are the potential blockchain applications really endless?
Certainly not, at least not in the near future.

Is it a big lie?
May be, if the blockchain critics as well as evangelists are expecting the current generation iterations of this tech to deliver the moon. Time will tell if future iterations of blockchain will deliver the magic.

Finally, the efforts made to write this article will be worth it if the critics who think blockchain is crappy, useless and a lie, may mellow down a little bit, and give the more advanced future iterations of this tech a chance with at least a select few specialized non-crypto use cases. It will also be gratifying if this comprehensive review spurs scholars into advancing blockchain research into the next generation.

Acknowledgements The author is grateful to Mr Tejas Bhagat for support in preparing this manuscript and disclose no conflict of interest.

References

[1] Horch Andrea, Schunck Christian H., and Ruff Christopher. "Adversary Tactics and Techniques specific to Cryptocurrency Scams." *Open Identity Summit 2022* (2022).

[2] Heal Geoffrey. "Reflections—defining and measuring sustainability." *Review of Environmental Economics and Policy* (2020).

[3] Tsalis Thomas A., et al. "New challenges for corporate sustainability reporting: United Nations' 2030 Agenda for sustainable development and the sustainable development goals." *Corporate Social Responsibility and Environmental Management* 27.4 (2020): 1617-1629.

[4] Emas Rachel. "The concept of sustainable development: definition and defining principles." *Brief for GSDR* 2015 (2015): 10-13140.

[5] United Nations. (2020). *About the Sustainable Development Goals*. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[6] Sachs Jeffrey , Schmidt-Traub,Guido , Kroll, Christian , Lafortune, Guillaume , Fuller, Grayson , Woelm & Finn, 2021. "Sustainable Development Report 2020," Cambridge Books, Cambridge University Press, number 9781108994651.

[7] Al-Megren Shiroq, et al. "Blockchain use cases in digital sectors: A review of the literature." *2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)*. IEEE, 2018.

[8] Li Wenzheng, and He Mingsheng. "Comparative Analysis of Bitcoin, Ethereum, and Libra." *2020 IEEE 11th International Conference on Software Engineering and Service Science (ICSESS)*. IEEE, 2020.

[9] Caldarelli Giulio. "Understanding the blockchain oracle problem: A call for action." *Information* 11.11 (2020): 509.

[10] Rimba Paul, et al. (2017). "Comparing blockchain and cloud services for business process execution." *2017 IEEE international conference on software architecture (ICSA)*. IEEE, 2017.

[11] Schinckus Christophe (2020). "The good, the bad and the ugly: An overview of the sustainability of blockchain technology." *Energy Research & Social Science* 69 (2020): 101614.

[12] Yahaya Adamu Sani, et al. "Blockchain based sustainable local energy trading considering home energy management and demurrage mechanism." *Sustainability* 12.8 (2020): 3385.

[13] Gogo Jeffrey. Transaction Fees on Ethereum 'Will not Come Down' After Merge, Says DeFi Researcher. Beincrypto.com July 13, 2022. Available at https://beincrypto.com/ethereum-transaction-fees-will-not-come-down-after-merge/

[14] Mandap Rudy. Bitcoin Lightning Network Jacks Up Nodes from 7,000 to 15,000. Coinquora.com March 3, 2022. Available at https://coinquora.com/bitcoin-lightning-network-jacks-up-nodes-from-7000-to-15000/

[15] https://ethernodes.org/history

[16] Jeong Seungwon Eugene. "Centralized decentralization: Does voting matter? simple economics of the dpos blockchain governance." *Simple Economics of the DPoS Blockchain Governance (April 21, 2020)* arXiv:2110.08673.

[17] Phookan Neeraj Kumar, Sarmah Bijoylaxmi, and Devi Toijam Sarika. "Exploring Determinants of Green Marketing Practices in Food Service Industry to Attain Environmental Sustainability: A Conceptual Analysis." *Proceedings of the 5th International Conference on Computers & Management Skills (ICCM 2019)| North Eastern Regional Institute of Science & Technology (NERIST), Nirjuli, Arunachal Pradesh, India*. 2020.

[18] AlgoShare (2019). No consensus on consensus. Medium.com, July 16, 2019. Available at https://medium.com/@AlgoShare/no-consensus-on-consensus-444686c2b45b

[19] Bambrough Billy. (2021). Bitcoin Fork Suffers 'Massive' 51% Attack In Attempt To 'Destroy' The Cryptocurrency, Sending Its Price Sharply Lower. Forbes, Aug 4 2021. Available at: https://www.forbes.com/sites/billybambrough/2021/08/04/bitcoin-fork-suffers-massive-51-attack-in-attempt-to-destroy-the-cryptocurrency-sending-its-price-sharply-lower/

[20] Hern Alex (2014). Bitcoin currency could have been destroyed by '51%' attack. The Gaurdian, July 15, 2014. Available at https://www.theguardian.com/technology/2014/jun/16/bitcoin-currency-destroyed-51-attack-ghash-io

[21] Beikverdi Alireza, and Song JooSeok. "Trend of centralization in Bitcoin's distributed network." *2015 IEEE/ACIS 16th international conference on software engineering, artificial intelligence, networking and parallel/distributed computing (SNPD)*. IEEE, 2015.

[22] Gervais A., Karame, G., Capkun, V. and Capkun, S., 2014. Is Bitcoin a Decentralized Currency?. IEEE Security & Privacy, 12(3), pp.54-60.

[23] Bai, Q., Zhang, C., Xu, Y., Chen, X., and Wang, Xin., 2020. Evolution of Eethereum: A Temporal Graph Perspective. [online].

[24] Sun, Xiaotong, Charalampos Stasinakis, and Georigios Sermpinis. "Decentralization illusion in DeFi: Evidence from MakerDAO." *arXiv preprint arXiv:2203.16612* (2022).

[25] Sai Ashish Rajendra, et al. "Taxonomy of centralization in public blockchain systems: A systematic literature review." *Information Processing & Management* 58.4 (2021): 102584.

[26] Abadi Joseph, & Brunnermeier Markus. *Blockchain economics*. No. w25407. National Bureau of Economic Research, 2018.

[27] Lin Qinwei, et al. "Measuring decentralization in bitcoin and ethereum using multiple metrics and granularities." *2021 IEEE 37th International Conference on Data Engineering Workshops (ICDEW)*. IEEE, 2021.

[28] Sun Xiaotong. "Bribes to Miners: Evidence from Ethereum." *arXiv preprint arXiv:2203.14601* (2022).

[29] Guo Mingyu, Wang Zhenghui, and Sakurai Yuko. "Gini index based initial coin offering mechanism." *Autonomous Agents and Multi-Agent Systems* 36.1 (2022): 1-20.

[30] De Domenico, Manlio, and Andrea Baronchelli. "The fragility of decentralised trustless socio-technical systems." *EPJ Data Science* 8.1 (2019): 1-6.

[31] DIGICONOMIST.net available at https://digiconomist.net/ethereum-energy-consumption

[32] Digibyte. The Commission's European Innovation Council awards €5 million to blockchain solutions for social innovations. European Commission, Europa.eu. June 30, 2020. Available at https://digital-strategy.ec.europa.eu/en/news/commissions-european-innovation-council-awards-eu5-million-blockchain-solutions-social-innovations

[33] Dapp.com. Top Dapps By Trading Volume. Only 1 Got A Positive Volume Increase. Medium.com, July 5, 2022. Available aat https://medium.com/dapp-com/top-dapps-by-trading-volume-jun-only-1-got-a-positive-volume-increase-3ac95317af10

[34] Tracker. The Complete List Of Unicorn Companies. CBInsight.com, July 2022. Available at https://www.cbinsights.com/research-unicorn-companies

[35] Orlowski Andrew. Blockchain study finds 0.00% success rate and vendors don't call back when asked for evidence. The Register, 2018. Nov. 30, 2018. Available at https://www.theregister.com/2018/11/30/blockchain_study_finds_0_per_cent_success_rate/

[36] Naqvi Naseem, and Hussain Mureed. "Evidence-based blockchain: findings from a global study of blockchain projects and start-up companies." *J. Br. Blockchain Assoc* 3.2 (2020): 16795.

[37] Gerber David et al. Blockchain technology timeline case studies in built environment. Arup.com, 2019. Available at https://www.arup.com/perspectives/publications/promotional-materials/section/blockchain-technology-timeline/

[38] Gooding Mathew. IBM-backed blockchain platform we.trade 'shutting down'. TECHMONITOR, June 5, 2022. Available

at https://techmonitor.ai/technology/emerging-technology/ibm-backed-blockchain-platform-we-trade-shutting-down

[39] Allison Ian. IBM Blockchain Is a Shell of Its Former Self After Revenue Misses, Job Cuts: Sources, Feb 1, 2021. Available at https://finance.yahoo.com/news/ibm-blockchain-shell-former-self-175818192.html

[40] Kim, Moon Soo, and Chung Jee Yong. "Sustainable growth and token economy design: The case of steemit." *Sustainability* 11.1 (2018): 167

[41] Song Jimmy. Why blockchain is not the answer. Medium, May 17, 2019. Available at https://jimmysong.medium.com/why-blockchain-is-not-the-answer-3b7d5f612d11

[42] Stinchcombe Kai. Blockchain is not only crappy technology but a bad vision for the future. Medium, April 5, 2018. Available at https://medium.com/@kaistinchcombe/decentralized-and-trustless-crypto-paradise-is-actually-a-medieval-hellhole-c1ca122efdec

[43] Schnier Bruce. There's No Good Reason to Trust Blockchain Technology. Wired, Feb 6, 2019. Available at https://www.wired.com/story/theres-no-good-reason-to-trust-blockchain-technology/

[44] Roubini Nouriel. The Big Blockchain Lie. Project Syndicate, Oct 15 2018. Available at

https://www.project-syndicate.org/commentary/blockchain-big-lie-by-nouriel-roubini-2018-10

[45] World Economic Forum (2018) Blockchain Beyond the Hype A Practical Framework for Business Leaders. Retrieved from: http://www3.weforum.org/docs/48423_Whether_Blockchain_WP.pdf

[46] Kabbinale Aniruddh Rao, et al. "Blockchain for economically sustainable wireless mesh networks." *Concurrency and Computation: Practice and Experience* 32.12 (2020): e5349.

[47] Mattila Vilma, et al. "Blockchain for environmentally sustainable economies: Case study of 5irechain. International Journal of Social Sciences and Management Review Volume: 05, Issue: 02 March-April 2022 ISSN 2582-0176. https://doi.org/10.37602/IJSSMR.2022.5204.

[48] Shoker Ali. "Sustainable blockchain through proof of exercise." *2017 IEEE 16th International Symposium on Network Computing and Applications (NCA)*. IEEE, 2017.

[49] Li Aiya, Wei Xianhua, and He Zhou. "Robust proof of stake: A new consensus protocol for sustainable blockchain systems." *Sustainability* 12.7 (2020): 2824.

[50] Chang, Yanling, Eleftherios Iakovou, and Weidong Shi. "Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities." *International Journal of Production Research* 58.7 (2020): 2082-2099.

Fazal Raheman, is a researcher and serial entrepreneur. He completed his MBBS and MD degrees from Government Medical College, Nagpur, Maharashtra, India. He spent his initial professional years working as biotechnology researcher in United States. In 1998 he shifted his focus to Information Technology inventing several technologies in diverse fields ranging from cybersecurity, cloud computing, healthcare, blockchain, IoT, etc. He has over 30+ patent application at various stages of patent prosecution. A complete list of patents can be viewed here: https://www.bc5.eu/DrFazal-Patents/. He is also the founder director of Blockchain 5.0 LTD, an Estonian start up specialized in developing products and services using technologies based on decentralized network architecture.