

Blockchain, Energy Concerns and Sustainability: Examining the Future of a Circular Economy

Gorazd Justinek*

This editorial examines the intersection of sustainable development, the circular economy, and blockchain technology, assessing how blockchain might enhance circular economy models and support sustainability goals despite ongoing questions about energy efficiency. This work is part of a broader research project led by Professor Jernej Letnar Čerňič at New University's Faculty of Governmental and European Studies, titled *Corporate Accountability, Human Rights, and Climate Change*.

Blockchain, a decentralized digital ledger, has progressed from its origins in cryptocurrencies such as Bitcoin to applications in transparency, traceability, and data integrity across industries. A key question arises: can blockchain foster circular economy principles by enabling closed-loop supply chains, transparent resource flows, and sustainable business models?

With the pressing issues of climate change, resource depletion, and unsustainable consumption, industries are increasingly focused on sustainability and circular economy principles. The circular economy framework aims to eliminate waste, maintain the value of products and materials, and regenerate natural systems for prolonged usage. Concurrently, blockchain technology is emerging as a transformative force, offering decentralized, transparent, and immutable record-keeping that could complement circular economy objectives.

Unlike the traditional linear economy, characterized by a »take, make, dispose« model, the circular economy emphasizes resource optimization through repair, reuse, recycling, and remanufacturing, aiming to establish regenerative systems. Blockchain tech-

*The author acknowledges the financial support from the Slovenian Research and Innovation Agency (project "Corporate accountability, human rights, and climate change: Towards coherent and just Slovenian and international legal order", ID JP-50171").

nology, on the other hand, is a decentralized ledger system that enables secure, immutable transaction recording through a peer-to-peer network. Each transaction is verified by consensus algorithms. Blockchain's elimination of intermediaries enhances efficiency and cost reduction.

One of the most significant challenges to implementing circular economy models is achieving comprehensive traceability and transparency of materials throughout their lifecycle. Blockchain offers a solution by enabling the tracking of origin, usage, and end-of-life processing of products, facilitating the monitoring of resource flows. Through blockchain, information can be made available in real-time to all stakeholders, reducing inefficiencies and minimizing fraudulent activities. Moreover, blockchain enables smart contracts—self-executing agreements with terms directly embedded in code. Within the circular economy, smart contracts could automate processes such as leasing, sharing, and product returns for recycling, thereby reducing administrative burdens and ensuring compliance with circular practices.

While blockchain presents numerous opportunities, it also faces technical challenges, particularly regarding scalability and energy consumption. Additionally, blockchain's decentralized nature raises regulatory issues; in the context of circular economy models, questions of liability, data privacy, and the jurisdictional scope of smart contracts must be addressed. Nevertheless, blockchain holds the potential to significantly contribute to the achievement of the United Nations Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production, climate action, and partnerships for sustainable development.

Blockchain technology relies on consensus mechanisms to verify transactions without the need for central authority. The most widely used consensus mechanism, Proof of Work (PoW), requires participants (miners) to solve complex computational problems, a highly energy-intensive process. For example, Bitcoin's blockchain network reportedly consumes more electricity than some countries, mainly due to its PoW mechanism. However, blockchain systems are evolving, with newer consensus mechanisms like Proof of Stake (PoS) requiring significantly less energy. PoS allows validators who »stake« their cryptocurrency holdings

to confirm transactions, thereby avoiding the energy-intensive computations of PoW.

The energy demands of PoW-based blockchains have raised concerns regarding carbon emissions, as mining activities often rely on fossil fuels. Bitcoin mining, for instance, has been widely criticized for its carbon footprint and potential exacerbation of climate change. According to some estimates, the carbon emissions associated with Bitcoin's annual energy consumption rival those of entire nations, primarily because mining is often concentrated in regions with inexpensive, non-renewable energy.

Beyond carbon emissions, blockchain's environmental impact includes the electronic waste generated by high-performance mining hardware. The rapid obsolescence of specialized mining devices contributes to an increasing electronic waste burden, further complicating the environmental cost of blockchain networks.

Despite these challenges, blockchain technology offers substantial benefits that may justify its application, particularly with advancements in sustainability. In supply chain management, for example, blockchain can enhance traceability, reduce fraud, and increase transparency. In the financial sector, it could reduce transaction costs and improve service access in underbanked regions. Additionally, blockchain has applications in energy trading and management. Blockchain-enabled microgrids, for instance, allow consumers to buy and sell renewable energy directly, facilitating a shift toward decentralized, low-carbon energy markets.

The central challenge is balancing blockchain technology's advantages with its environmental impact. Continued innovation in energy-efficient consensus mechanisms and exploration of renewable energy sources are essential for blockchain to evolve into a more sustainable technology.

The convergence of blockchain and circular economy models presents promising opportunities for developing sustainable, efficient business practices. Blockchain's potential to provide transparency, traceability, and automated processes through smart contracts aligns closely with the core principles of the circular economy. While integration challenges persist, the potential benefits of environmental sustainability and resource efficiency underscore the value of pursuing these technologies.