Blockchain and megatrends: pathways to sustainable, inclusive and resilient food systems

C. Karkanias[1], A. Malamakis[1], L.M.S. Kingfisher[2], L.H.M. van de Burgwal[2], G.F. Banias[1]

[1]Institute for Bio-Economy and Agri-Technology, Centre for Research and Technology-Hellas, 57001 Thessaloniki, Greece
[2]Athena Institute, Faculty of Science, Vrije Universiteit, Amsterdam, 1081 HV, the Netherlands
Keywords: Blockchain, Food systems, Sustainability, Scenario analysis.
Presenting author email: c.karkanias@certh.gr

Introduction

The transformation of food systems is increasingly recognised as critical to addressing global challenges such as climate change, biodiversity loss, food insecurity, and socio-economic inequalities. Achieving sustainable, inclusive, and resilient food systems requires innovative approaches that combine technological solutions with social, economic, and governance reforms. Among emerging technologies, Blockchain Technology (BCT) has gained attention for its potential to increase trust, enhance traceability, and facilitate decentralised governance in food value chains (Upadhyay, 2020). However, the diffusion of blockchain in the agri-food sector remains partial and contested, shaped by diverging priorities, fragmented infrastructure, and institutional uncertainties. To understand how BCT can contribute to future sustainable food systems, an empirical foresight study was undertaken under the TRUSTyFOOD project. The study combined an analysis of global megatrends with participatory scenario development, involving a varied set of food system stakeholders across Europe (Manca et al, 2020). The main aim of the study was to investigate credible paths for blockchain adoption and to identify critical value-based stresses that could influence outcomes. The goal was to develop various futures that reflect challenging visions, risks, and opportunities fundamental in the food systems digital transformation.

Materials and methods

The methodological approach integrated two foresight components: a megatrends analysis and qualitative scenario building. First, the megatrends analysis synthesised key social, environmental, technological, and economic trends with potential to impact the agri-food sector (Vervoort et al, 2016). Primary sources included global foresight literature, policy documents from EU institutions, and academic studies. Trends were carefully chosen considering their relevance to the adoption, governance, and societal implications of BCT. Furthermore, a scenario development process was conducted using participatory visioning workshops with food system key actors. More specifically, three thematic workshops were organised, each focusing on an important dimension of food system transformation including climate change mitigation in agriculture; transparent and traceable supply chains; as well as sustainable, healthy, and inclusive food systems. Participants included farmers, food processors, regulators, consumer representatives, civil society organisations, researchers, and technology developers.

Each workshop followed a structured format. Participants were first invited to articulate their vision for a desirable food future around 2050. They then discussed the potential role of BCT in enabling this vision, including its applications, governance structures, and potential risks. In terms of the data, these were gathered through transcripts, notes, and digital whiteboards, while a thematic analysis identified critical values, drivers, and issues, which were used for the construction of three composite scenarios. Each of these scenarios was structured around leading values and types of blockchain use.

Results and discussion

The megatrends analysis identified ten interrelated trends with strong implications for food systems and BCT adoption. These included climate change and ecological degradation, population growth and urbanisation, global trade instability, consumer demands for transparency, digitalisation and datafication, the rise of decentralised trust mechanisms, and evolving regulatory landscapes. Together, these megatrends reflect a shifting context in which food systems are increasingly required to be not only productive and efficient but also transparent, just, and environmentally sustainable. Blockchain was identified as a potentially enabling infrastructure across several of these trends, particularly in relation to traceability, decentralised data management, and accountability mechanisms. The scenarios that were developed during the stakeholder workshops show varied yet plausible blockchain-enabled futures. In particular, the first scenario, titled Efficiency, Transparency and Resilience, envisions blockchain adoption driven by private sector actors seeking operational efficiency and market responsiveness. In this context, BCT is embedded primarily into business-to-business transactions to rationalise logistics, safeguard traceability, and meet consumer demand for green products. In general, technological innovation and economies of scale advance large agri-food corporations, who invest in blockchain solutions and shape the data ecosystems. While this scenario improves data transparency and carbon accounting, it also raises concerns regarding smallholders' exclusion, power centralisation, and potential greenwashing caused by poor data

quality control. The benefits of BCT are concentrated among well-capitalised actors, leading to a food system that is technologically advanced but socially uneven.

The second scenario, Compliance and Accountability, is centred around a policy-driven transformation in which governments adopt BCT to enforce environmental and social regulations. This scenario associates BCT adoption with policy instruments including EU Green Deal, Corporate Sustainability Reporting Directive (CSRD), and the EU Deforestation Regulation (EUDR). National authorities establish common standards and terminology, promoting interoperability of national and regional blockchain systems. BCT is used as a backend infrastructure to achieve data verification, regulatory compliance, as well as monitoring of sustainability indicators. In parallel, governments implement measures to support smallholder adoption through subsidies, education, and training. This scenario improves regulatory coherence and public trust, but also indicates potential risks related to surveillance, loss of autonomy, and increased administrative burdens, especially for resource-constrained actors. On the other hand, the third scenario, Ecologically Integrated and Place-Based, illustrates a bottom-up transformation led by local communities, small-scale producers, and cooperatives. In this case, BCT is adopted through participatory and decentralised initiatives alongside circular economy and food independence principles. Applications include participatory guarantee systems (PGS), local crowdfunding for sustainable farming, community-managed resource governance, and direct consumer involvement. Furthermore, BCT is also used for citizens empowerment and enhancing autonomy over data and decision-making. This scenario shows a strong alignment between environmental sustainability, social equity and advanced digital technologies. Yet, the localised and fragmented nature of technological innovation brings challenges in scalability, standardisation, and interoperability. Several communities lack the digital infrastructure, financial funds and/or technical support which is necessary to maintain such systems over time, and the risk of marginalisation remains if these models are not institutionally supported.

Across all three scenarios, two primary applications of blockchain emerged: transparency and traceability in supply chains, and accounting for environmental externalities such as carbon emissions. However, the purpose, governance, and beneficiaries of these applications vary substantially. While the first scenario sees markets as the primary agents of transformation, the second emphasises the regulatory state, and the third prioritises community-led initiatives. The scenarios also differ in terms of their treatment of values including decentralisation, equity, trust, and inclusiveness. All the selected scenarios underline that the outcomes of blockchain deployment in food systems are not predetermined. Blockchain can lead to vastly different impacts depending on how it is integrated within broader systems of governance, power, and participation.

Conclusions

Blockchain technology offers significant potential to contribute to the transformation of food systems by enabling new forms of transparency, accountability, and decentralised governance. Yet, realising this potential depends on navigating complex value tensions, mitigating exclusion risks, and addressing implementation with broader societal goals. All three scenarios analysed in the study provide insights in how BCT could evolve in the food sector under different configurations of policy, and innovation. This analysis stresses the importance of participatory governance, value-based design, and institutional support in supporting blockchain adoption towards equitable and sustainable outcomes. Policymakers, food system actors, and technologists must co-design frameworks that ensure data integrity, promote interoperability, and empower diverse actors, particularly those who are often marginalised in technological transitions. The foresight approach applied in this study demonstrates the value of participatory scenario development in clarifying the stakes of technological innovation in complex socio-technical systems. As food systems continue to digitalise, the need for anticipatory, inclusive, and reflexive governance will only grow. BCT, if implemented inclusively can be one of the enabling tools in this transformation supporting pathways that are not only efficient and transparent but also just, inclusive, and ecologically sound.

Acknowledgements

This study was implemented in the context of TRUSTyFOOD project that receives funding from the Horizon Europe framework program under the grant agreement number 101060534.

References

Manca, A. R., Benczur, P., & Giovannini, E. (2020). What are the megatrends that will shape the future? European Commission. JRC Foresight Report. EUR 29946 EN, Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/375209

Upadhyay, N., & Upadhyay, S. (2020). The role of blockchain technology in agriculture supply chain: A review. Journal of Cleaner Production, 279, 123456. https://doi.org/10.1016/j.jclepro.2020.123456

Vervoort, J. M., Béné, C., & Thornton, P. (2016). Foresight for food system transformation. Nature Food, 1, 1–3. https://doi.org/10.1038/s43016-019-0003-7

Whyte, J., Megatrends Assessment Tool: An exploratory workshop, Knutti, M. and Whyte, J. editor(s), Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/952999, JRC136