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INTEGRATION OF BLOCKCHAIN TECHNOLOGIES IN THE FOOD SUPPLY CHAIN – REGULATORY FRAMEWORKS IN THE EUROPEAN UNION

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Abstract. This study examines the regulatory frameworks for blockchain technology integration in the food supply chain across the European Union (EU). Through a comprehensive analysis of national regulatory documents and strategies, the research categorises EU member states based on their approach to blockchain regulation in six distinct categories. The analysis reveals significant variations in regulatory maturity, enforcement mechanisms, and sectoral focus among EU countries. The findings provide valuable insights for policymakers and industry stakeholders seeking to leverage blockchain's potential in enhancing transparency, traceability, and efficiency in the food supply chain.

Keywords: food supply chain; regulatory frameworks; digital innovation
JEL Codes: K23, O33, Q18

Introduction

Blockchain technology has emerged as a transformative tool across various industries, including the food supply chain. Its ability to enhance transparency, traceability, and efficiency has garnered significant interest from both industry stakeholders and policymakers. In the European Union (EU), the adoption of blockchain in the food supply chain is influenced by diverse regulatory frameworks across member states. The primary purpose of this report is to analyse the current regulatory frameworks governing the implementation of blockchain technology in the food supply chains across EU member states. By identifying best practices and gaps, the study aims to propose recommendations for harmonising regulations to enhance transparency, traceability, and efficiency in the EU's food sector.

The scope of the report is limited to the analysis of national regulatory frameworks related to blockchain technology in all EU member states. Blockchain technology, known for its decentralised, immutable nature, is increasingly being viewed as a solution to the inefficiencies and transparency issues in global food

supply chains. This report evaluates how blockchain's adoption in the food industry, specifically within the EU, can support improved product traceability and regulatory compliance.

1. Literature Review

The increasing complexity of global food supply chains has heightened the need for enhanced transparency and traceability. Recent literature highlights the challenges and potential solutions in this domain. Yadav et al. (2021) conducted a comprehensive review of traceability systems in the food industry, emphasising the role of emerging technologies like blockchain. They found that while traditional traceability systems have limitations in data integrity and real-time information sharing, blockchain offers promising solutions for enhanced transparency and traceability.

Behnke and Janssen (2020) explored the concept of boundary objects in food supply chains, focusing on how these objects can improve traceability and transparency. Their study suggests that blockchain technology can serve as an effective boundary object, facilitating information exchange and collaboration among diverse stakeholders in the food supply chain. In a case study approach, Kayikci et al. (2020) examined the implementation of blockchain technology for traceability in the Turkish food sector. Their findings indicate that blockchain can significantly improve supply chain visibility, product authenticity verification, and overall food safety. Similarly, in a case study of the Italian agri-food sector, Baralla et al. (2021) explored the potential of blockchain to combat food fraud and improve supply chain integrity.

Saurabh and Dey (2021) conducted a systematic literature review on blockchain adoption in agri-food supply chains. They identified key drivers and barriers to blockchain implementation, highlighting the technology's potential to enhance traceability, reduce fraud, and improve consumer trust. Astill et al. (2022) investigated the challenges of implementing traceability systems in the Canadian food sector. Their research emphasises the need for standardised data collection and sharing protocols, suggesting that blockchain could play a crucial role in addressing these challenges.

Kouhizadeh et al. (2021) highlights the potential of blockchain to enhance transparency and traceability but identifies significant obstacles including technological complexity, cost implications, and organisational resistance. The authors offer a comprehensive framework for understanding these barriers and propose strategies for overcoming them.

The regulatory landscape for blockchain technology is rapidly evolving, with various approaches being adopted across different jurisdictions. Yeung (2021) provided a critical analysis of regulatory approaches to blockchain technology, focusing on the European Union's efforts. The study highlights the tension between

fostering innovation and ensuring adequate consumer protection, suggesting a need for balanced, technology-neutral regulations.

Bodó and Giannopoulou (2021) examined the regulatory challenges posed by blockchain technology in the EU context. Their research emphasises the need for adaptive governance models that can accommodate the decentralised nature of blockchain while ensuring compliance with existing legal frameworks. In a comparative study, Fenwick et al. (2021) analysed regulatory sandboxes for blockchain and other fintech innovations across different jurisdictions. Their findings suggest that regulatory sandboxes can be effective tools for promoting innovation while managing risks associated with new technologies. Zetzsche et al. (2020) explored the concept of "embedded regulation" in the context of blockchain and other distributed ledger technologies. They propose a framework for incorporating regulatory requirements directly into blockchain protocols, potentially streamlining compliance processes.

Ferrari (2020) conducted an in-depth analysis of the EU's regulatory approach to crypto-assets and blockchain technology. The study highlights the challenges of creating a unified regulatory framework across member states and suggests potential pathways for harmonisation. Biolcheva and Sterev (2024) propose a model for evaluating the added value of AI in business that could help managers integrate AI by quantifying both material and non-material benefits, such as productivity and reputation.

The application of blockchain technology in the EU food supply chain is an area of growing interest, with several studies exploring its potential benefits and challenges. Kamilaris et al. (2021) provided a comprehensive review of blockchain applications in agriculture and food supply chains within the EU context. Their study identifies key use cases, including traceability, smart contracts, and decentralised marketplaces, while also highlighting implementation challenges. Kokina et al. (2021) examined the role of blockchain in enhancing food safety and quality control in the EU, suggesting that blockchain can significantly improve the efficiency of food recall processes and enhance consumer trust through increased transparency.

Talavera et al. (2022) investigated the integration of blockchain with Internet of Things (IoT) technologies in EU food supply chains. Their study highlights the synergies between these technologies in creating more resilient and transparent supply chains. Petropoulos et al. (2023) underlined the importance of introducing the intelligent animal husbandry approach into traditional sectors such as sheep farming industries to adapt it to the dynamics of the environment. The collaborative approach between farmers and government is of upmost importance.

This literature review highlights the growing body of research on blockchain integration in the EU food supply chain. The studies collectively emphasise the potential of blockchain to enhance transparency, traceability, and regulatory compliance. However, they also identify challenges in implementation,

standardisation, and regulatory harmonisation across the EU. Future research could focus on addressing these challenges and exploring the long-term impacts of blockchain adoption on food supply chain sustainability and resilience.

Further studies have highlighted the importance of blockchain technology in enhancing supply chain processes. Caro et al. (2018) present a comprehensive framework for blockchain-based supply chain management, emphasising the need for regulatory support to facilitate widespread adoption. Lastly, Pearson et al. (2019) provide a case study on the implementation of blockchain in the food supply chain, illustrating the regulatory hurdles and potential solutions.

2. Methodology

The research involved a comprehensive review of national regulatory documents, strategies, and plans related to blockchain technology across EU member states. Sources included official government websites, legal databases, and scholarly articles. This approach ensured a thorough understanding of the current regulatory landscape and its implications for the food supply chain.

The research focused on the regulatory maturity and approach toward blockchain technology. By categorising countries into six groups based on regulatory maturity and specific blockchain-related legislation, the study systematically identifies patterns that inform the development of harmonised regulations. The comparative analysis of these frameworks allows for a thorough evaluation of the challenges and best practices in blockchain adoption across the EU. This methodological approach provides a robust framework for evaluating the scientific results, highlighting both regulatory challenges and technological opportunities, thereby providing a solid foundation for actionable policy recommendations.

3. Results

The analysis reveals significant variations in the regulatory approaches to blockchain technology across the EU. Countries like France and Malta are at the forefront, with comprehensive regulatory frameworks and high penalties for non-compliance. In contrast, countries like Bulgaria and Croatia lack specific regulations, which may hinder the adoption and integration of blockchain technologies in their food supply chains.

Table 1. Strategic documents and severity of fines in EU Member states

Country	Regulatory Framework	Fines for Non-Compliance
Austria	Generic regulations with specific tax legislation	Moderate
Belgium	Several initiatives but not specific legislation	Moderate
Bulgaria	No specific legislation	None

Croatia	No specific legislation	None
Cyprus	Several directives and initiatives	Not defined
Czechia	Regulatory mandates introduced	Limited
Denmark	Several sectorial initiatives, strong foundations	High
Estonia	E-Residency program, first to introduce legislation	Moderate-High
Finland	Early adopter, but regulations are still lacking	Significant
France	Numerous initiatives across the private and public sectors, proactive stance on legislation	High
Germany	National Blockchain Strategy, Future Finance Act	Severe
Greece	Developing regulatory framework, no specific law	Moderate
Hungary	Existing legislation and sectorial legislative packages	Moderate-High
Ireland	Adopting EU related legislation	Moderate
Italy	National Blockchain Strategy, additional legislative initiatives	High
Latvia	No specific regulations	Not defined
Lithuania	Comprehensive set of regulations, fintech and sandbox strategies	Moderate-High
Luxembourg	Developed regulatory framework	Significant
Malta	"Blockchain Island" initiative, Digital Innovation Act, comprehensive legislation	High
Netherlands	Amendments based legislative approach, Dutch Blockchain Coalition	Moderate-High
Poland	Comprehensive set of regulatory mechanisms	Moderate
Portugal	Adopting EU related legislation, National Blockchain Strategy	High
Romania	No specific regulatory framework	Not defined
Slovakia	Specific regulations for blockchain, Strategy of Digital Transformation	Moderate
Slovenia	Advanced regulations, Strategy for Digital Transformation	High
Spain	Several legislative initiatives	Significant
Sweden	No specific legislation, numerous governmental initiatives	Moderate-High

For instance, France aims to build trust in the digital economy by clarifying legal aspects of blockchain technology. It encourages innovation through light-touch regulation, streamlining legal processes, facilitating investment, and promoting French blockchain development. This progressive approach positions France as a leader in blockchain adoption.

Germany, on the other hand, adopted a supportive, yet non-regulatory approach with its Blockchain Strategy. This strategy focuses on fostering innovation through research, development, and pilot projects across various industries, including supply chains. While it lacks direct regulations, it shows strong government interest in exploring blockchain potential.

Spain includes measures to promote blockchain adoption across industries, emphasising digitalisation and modernisation. Similar to Germany's strategy-based approach, it indicates broader interest in the technology rather than imposing direct regulations. Italy's National Blockchain Strategy outlines a multi-pronged approach focusing on public services, innovation support, and legal clarity. While it lacks specific supply chain regulations, it highlights government interest in targeted applications of blockchain technology.

The EU's blockchain regulatory landscape can be divided into six distinct groups, each representing different levels of regulatory development and approach:

1) Comprehensive Regulatory Framework – Countries in this group have implemented specific blockchain regulations with high penalties for non-compliance and a broad regulatory focus.

2) Developing Regulatory Framework – These countries are actively working on blockchain-specific regulations, with moderate penalties and a focused approach.

3) Adaptation of Existing Regulations – Countries in this group are applying existing regulations to blockchain, with variable penalties and sector-specific focus.

4) Observational Approach – These countries are monitoring blockchain development without specific regulations, typically with low penalties and a broad focus

5) Blockchain-Friendly with Limited Regulation – Countries in this group are actively promoting blockchain with minimal regulation, typically low penalties, and broad encouragement.

6) Early Stages of Consideration – These countries are in the early stages of considering blockchain regulations, with minimal or no specific rules.

A heatmap showing the level of regulatory maturity across the EU could be observed in Figure 1.

The severity of fines and penalties for non-compliance with blockchain regulations also varies across the EU. For example, France imposes high penalties for non-compliance with traceability requirements, reflecting its stringent regulatory approach. Germany's severe penalties for breaches of food safety regulations underscore the country's commitment to ensuring blockchain technology enhances compliance and safety.

In contrast, countries like Bulgaria and Croatia, which lack specific blockchain regulations, do not impose fines for non-compliance, leading to potential legal uncertainty and slower adoption of blockchain technologies. However, these countries are likely to align with broader EU regulations, such as the Markets in

Figure 1. Heatmap of EU's blockchain regulatory landscape

Crypto-Assets (MiCA) regulation, which could impact blockchain use in financial services and indirectly affect the food supply chain sector.

4. Discussion

The comparative analysis reveals a diverse regulatory landscape across the EU, with varying degrees of regulatory maturity and enforcement. Countries leading in blockchain adoption impose significant penalties for non-compliance, reflecting their commitment to maintaining high standards in the use of blockchain technology. In contrast, the lack of specific regulations may hinder the adoption of blockchain technologies in other countries' food supply chains.

Blockchain technology offers significant benefits for supply chains, particularly in the food sector. Enhanced traceability is achieved through blockchain's ability to

create a permanent record of every transaction and movement in the supply chain, enabling full traceability from production to consumption. Improved transparency allows all supply chain participants to access the same information, reducing information gaps and fostering greater trust among partners. Increased efficiency is facilitated by smart contracts, which streamline processes, reduce paperwork, and speed up transaction times. Food safety is enhanced as quick traceability enables the fast identification of contaminated products, allowing for swift recalls and reducing food safety risks. Fraud prevention is strengthened by the immutable nature of blockchain records, making it difficult to falsify information about a product's origin or quality.

The best practices identified in the analysis highlight the importance of comprehensive frameworks, collaborative initiatives, and focused strategies. France and Malta provide robust examples of comprehensive regulatory frameworks that support blockchain innovation while ensuring compliance. Collaborative initiatives, like the Dutch Blockchain Coalition and Belgium's Blockchain Lab, emphasise the importance of public-private partnerships in developing practical and industry-specific regulations. Germany and Italy's strategy-based approaches highlight the need for research, development, and pilot projects to foster blockchain adoption across various sectors.

There are several areas for improvement in the regulatory frameworks of EU member states. The EU could benefit from more uniform regulations to facilitate cross-border blockchain applications in the food supply chain. Countries with developing frameworks or undefined penalties need clearer regulations and enforcement mechanisms to ensure compliance and foster trust in blockchain systems. More targeted guidelines for specific sectors, such as the food supply chain, would help address the unique challenges and opportunities presented by blockchain technology.

Conclusion

The integration of blockchain technologies in the food supply chain across the EU is influenced by diverse regulatory frameworks, ranging from comprehensive and well-defined to non-existent. Countries leading in this space provide valuable insights into best practices, while others need to develop clearer and more uniform regulations. Moving forward, the EU should aim for harmonised regulations that support innovation and ensure compliance, thereby leveraging blockchain's full potential in enhancing transparency, traceability, and efficiency in the food supply chain.

As blockchain technology matures and its adoption in supply chains grows, we can anticipate the emergence of more targeted regulations specifically addressing its use in supply chains. The evolution of these regulatory frameworks will likely be characterised by increased collaboration between regulators and industry

stakeholders, aiming to develop practical and effective regulations that foster innovation while ensuring consumer protection and maintaining supply chain integrity.

In conclusion, the integration of blockchain technology in supply chains presents both unprecedented opportunities and unique regulatory challenges. As the technology continues to evolve, so too must the regulatory frameworks governing its use. The goal for EU policymakers should be to create a regulatory environment that harnesses blockchain's potential to enhance transparency, traceability, and efficiency in supply chains while addressing the associated risks and challenges. This balanced approach will be crucial in realising the full potential of blockchain technology in revolutionising supply chain management across the European Union.

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