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Blockchain Traceability for Sustainability Communication in Food Supply Chains: An Architectural Framework, Design Pathway and Considerations

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Abstract: The increasing demand for sustainable and ethically sourced food products has highlighted the importance of effective sustainability communication within the food supply chain. Existing sustainability communication approaches encounter limitations such as a lack of standardised frameworks, information overload, greenwashing, and an absence of transparent reporting. These challenges hinder their effectiveness and reliability in communicating sustainability efforts and commitments to businesses and consumers in a food chain. Blockchain technology, with its transparent, traceable, verifiable, and immutable features, offers a promising solution to address these limitations and facilitate effective sustainability communication. This paper explores the benefits of applying blockchain traceability to enhance sustainability communication in food supply chains. Using the system architecture approach, this paper proposes a high-level architectural framework, which can navigate the design and development of a blockchain-enabled solution for food sustainability communication. To assist with the translation of the architectural framework into a tailored solution, this paper further presents an action design pathway and discusses the design considerations around organisation, technology, governance, cost, and the user interface. The discussions and insights offered by this study can guide system developers and business analysts in the design and development of industry-oriented solutions, helping them make informed decisions before and during the design process. This paper contributes to advancing and expanding blockchain applications with a particular focus on sustainability communication in food supply chains.

Keywords: blockchain; traceability; food supply chain; sustainable food; sustainability communication; design consideration; design pathway

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Citation: Cao, S.; Xu, H.; Bryceson, K.P. Blockchain Traceability for Sustainability Communication in Food Supply Chains: An Architectural Framework, Design Pathway and Considerations. *Sustainability* **2023**, *15*, 13486. https://doi.org/10.3390/su151813486

Academic Editors: Valentina Di Pasquale, Maria Elena Nenni and James Boyer

Received: 18 July 2023
Revised: 27 August 2023
Accepted: 4 September 2023
Published: 8 September 2023

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1. Introduction

The significance of addressing sustainability issues in the food industry has been widely acknowledged for many years [1]. This recognition can be attributed to various factors, including the global expansion of the agri-food industry, shifts in consumer behaviours, the concentration of power among retailers, and the evolution of food delivery methods, as identified by Fritz and Matopoulos [2]. In response, numerous sustainability initiatives driven by policies and market forces have been implemented to improve various aspects of sustainability in the food industry [3]. These initiatives support achieving the UN sustainable development goals by addressing environmental impacts, social responsibility, ethical sourcing, and economic viability. A range of associated measures have been developed to implement these initiatives within the food industry, such as sustainability standards and certification [1], corporate social responsibility practices [4], sustainability labels [5], and sustainability reporting [6]. These initiatives and measures facilitate the communication of sustainable practices to supply chain stakeholders. Nevertheless, within the contemporary

landscape, agri-food supply chains are increasingly vulnerable to unpredictable environmental, social, and economic changes throughout the production-distribution-consumption cycle [7]. In light of these challenges, supply chain stakeholders question the effectiveness of existing mechanisms for sustainability governance [8]. Meanwhile, there is an urgent need for the food industry to enhance sustainability transparency [9]. Food producers and suppliers are therefore compelled to effectively communicate their sustainable practices to relevant stakeholders, which not only helps meet these expectations but also ensures their long-term business viability.

Sustainability communication has become an imperative or a good practice for businesses across industries [10–13]. The food industry is also actively engaging in sustainability communication, demonstrating its commitment to support global sustainability initiatives whilst meeting the rising consumer demand for sustainable food products [14]. However, current approaches for sustainability communication are not very effective due to factors such as the ambiguity of sustainability terms [9] and the reliance on simplistic food labels for communication [15]. To enhance sustainability communication, many food companies have endeavoured to provide greater transparency about their sustainable practices. However, merely disclosing sustainability information is not sufficient, as consumers do not always understand or trust the information provided through traditional and/or digital channels [9]. This highlights the need to tackle the asymmetry in sustainability information and reporting [16].

Blockchain technology, originally developed as the underlying technology for cryptocurrencies like Bitcoin, has demonstrated its potential to redefine trust and foster collaboration in the food supply chain [17]. Although blockchain remains an evolving technology, its applications have been expanded across various sectors, particularly in the food industry [18]. Several studies have explored blockchain applications in the food supply chain domain, seeking to enhance various aspects, including traceability [19–21], visibility [22], transparency [23,24], and integrity [25]. These studies have demonstrated that blockchain can enhance the food supply chain and address crucial challenges with its decentralised, transparent, traceable, and immutable features. These unique attributes have also positioned blockchain as a promising solution to address numerous challenges related to agrifood supply chain sustainability [15,26,27]. One prosperous benefit is that businesses can enhance sustainability communication by providing accurate, real-time information about the origin, production practices, certifications, and other relevant data related to food products [28]. However, some technical, economic, and social barriers hinder the implementation of a blockchain solution for sustainable food supply chains [27,29]. As such, this requires a good understanding of current sustainability communication practices and the potential benefits of implementing blockchain for enhanced sustainability communication. This understanding is vital for designing appropriate blockchain solutions to improve sustainability communication within the food supply chain.

This paper aims to shed light on the design and development of a tailored solution for sustainability communication using blockchain that can transform the way sustainability information is shared, verified, and accessed among multiple stakeholders across the food supply chain. Particularly, this paper seeks to (i) provide an overview of existing sustainability communication approaches within the food supply chain domain; (ii) explore how blockchain technology can enhance sustainability communication across the food supply chain; (iii) introduce a high-level architectural framework facilitating the user-centric design of a blockchain-enabled solution for enhanced food sustainability communication; and (iv) navigate the design and development process through a design pathway with a focus on critical design considerations. By achieving these research objectives, this paper contributes to a better understanding of the transformative impacts of blockchain on sustainability communication and could navigate the design and development of tailored blockchain solutions for enhanced food sustainability communication.

The remainder of this paper is organised as follows. Section 2 overviews existing food sustainability communication approaches and their limitations. It is followed by

identifying the opportunities for blockchain-enabled food sustainability communication in Section 3. A high-level architecture of blockchain-based traceability for food sustainability communication is proposed in Section 4. Section 5 introduces an action design pathway and discusses critical design considerations when translating the architectural framework into a technically feasible and economically viable solution. Section 6 presents the discussion of our findings against previous studies. The final Section 7 concludes this paper with main points, limitations, and directions for future research.

2. Overview of Existing Sustainability Communication across Food Supply Chains

Sustainability communication is a strategic approach adopted by organisations to engage stakeholders and demonstrate their efforts and progress in sustainability commitments [30]. It involves conveying an organisation's engagement and commitment to sustainability initiatives to various stakeholders, including investors, suppliers, customers, and communities. Sustainability communication has garnered growing attention and importance across industries, including the food sector [28,31]. The food industry has already leveraged global sustainability initiatives and standards, such as sustainability reporting [32] and the implementation of labels and certifications [33,34], to communicate their commitments to sustainable practices and the sustainability attributes of their products. These initiatives and measures provide a framework for assessing and verifying sustainable attributes, encouraging food producers and suppliers to adopt sustainable practices, and facilitating consumers to make informed choices. As the food industry escalates its commitment to sustainability and consumers seek more sustainability information to guide their purchase decisions [35], there is an increasing range of market-led voluntary sustainability initiatives and standards emerging or already in place. Table 1 summarises some prominent voluntary sustainability initiatives in the food industry that align with market-driven expectations and/or address the demand for informative communication with sustainability-conscious consumers.

Table 1. Examples of voluntary sustainability initiatives in the food industry.

Initiative	Objective	Source
Sustainable Agriculture, Food, and Environment	Address challenges of sustainable agriculture and improve the inclusion of smallholder farmers in global value chains	https://sdgs.un.org/partnerships/safe-sustainable-agriculture-food-and-environment-platform (accessed on 7 June 2023)
Ethical Trade Initiative	Ensure compliance with international labour standards in global supply chains	https://www.ethicaltrade.org/ (accessed on 7 June 2023)
Food Reform for Sustainability and Health	Drive the transformation of the food system and create business solutions for industry change	https://eatforum.org/initiatives/fresh/ (accessed on 7 June 2023)
Fair Trade	Promote fair prices, partnerships, and sustainable farming practices for small-scale farmers	https://www.fairtrade.net/ (accessed on 8 June 2023)
Sustainable Agriculture Initiative	Communicate and support sustainable agriculture involving diverse stakeholders	https://saiplatform.org/ (accessed on 8 June 2023)
GLOBALG.A.P.	Assure customers that the standard of operation on the farm consistently produces safe and traceable food	https://www.globalgap.org/uk_en/ (accessed on 10 June 2023)
Sustainable Supply Chain Initiative	Guide sustainable supply chain practices, including fair working conditions and the prevention of forced labour	https://www.theconsumergoodsforum.com/ (accessed on 10 June 2023)

Numerous sustainability standards and certifications have been established in alignment with policy-driven and voluntary sustainability initiatives to promote and communicate sustainable practices in the food industry [3]. Examples include organic certifications,

carbon footprint labels, nutrition labels, eco-labels, fairtrade labels, certifications for responsible sourcing or animal welfare, and so on [36]. There are also numerous international standards, including ISO 9000, ISO 26000, GMP (Good Manufacturing Practices), HACCP (Hazard Analysis and Critical Control Points), SPC (Statistical Process Control), and FMEA (Failure Mode and Effects Analysis) that guide various aspects of sustainability within the food industry. Leveraging these sustainability standards and certifications to communicate sustainability practices in the production, processing, distribution, and consumption of food products is valuable and impactful. However, certain limitations need to be highlighted. These limitations include an absence of standardised data, information overload, limited availability of information, greenwashing, and a lack of collaboration, as presented in Table 2.

Table 2. Limitations in existing sustainability communication across food supply chains.

Existing Barriers	Description	Sources
Lack of standardised data	Lack of a standardised framework for multiple sustainability dimensions	[9,37]
Limited availability of information	Restricted availability of sustainability information beyond simple labels/claims	[15]
Information overload	The abundant of sustainability labels, certifications, and claims	[36,38]
Greenwashing	False or exaggerated claims about sustainability practices	[39,40]
Lack of collaboration	Fragmented efforts in designing and communicating sustainable practices	[41]

Due to the availability of numerous sustainability initiatives that define sustainability and other related concepts from diverse dimensions, there is a lack of standardised frameworks and guidelines for sustainability metrics and rating systems in the food industry [9,37]. This further results in inconsistency and confusion in interpreting sustainability messages by humans and machines. As noted by Schiano et al. [9], consumers have a limited understanding of commonly used sustainability terms such as organic, non-GMO, and animal warfare. This ambiguity makes consumers tend to disregard or question such claims when making purchasing decisions. Furthermore, many sustainability initiatives and standards are facing increasing criticism from stakeholders due to perceived flaws in their design, transparency levels, worker engagement, governance, oversight models, and their limited impact [42]. While sustainability labels, certification, and claims as a means of communication can simplify information delivery to consumers, they limit the availability of information beyond the surface-level labels [15].

The excessive use of sustainability labels, certifications, and claims can enhance the accessibility of sustainability information. However, it can result in information overload, making it difficult for consumers to make well-informed decisions [38]. The abundance of sustainability labels and certifications also opens the door to greenwashing, where companies make false or exaggerated claims about their sustainability practices to improve their brand image and reputation [39,40]. Greenwashing can damage consumers' trust in sustainability claims and undermine their confidence in making environmentally responsible choices. Digital solutions help enhance transparency in sustainability communication. However, they are unable to ensure the reliability of the information [28]. The lack of transparency and trust in sustainability disclosure makes it challenging for consumers to navigate through misleading claims. A lack of collaboration among supply chain stakeholders [41] is another significant barrier to food sustainability communication in a multi-stakeholder supply chain. Fragmented efforts by individual stakeholders can result in inconsistent sustainability messages and confuse other supply chain stakeholders [9]. As such, existing sustainability communication approaches fail to provide consistent and

reliable information to stakeholders. Thus, there is a growing demand among stakeholders to reconsider their design and implementation approaches by adopting multi-stakeholder initiatives and transparent communication frameworks.

3. Blockchain-Based Traceability Applications for Sustainability Communication in Food Supply Chains

Blockchain technology, originally developed as the underlying technology for cryptocurrencies like Bitcoin, has been expanded across various industries [43]. Given that blockchain can guarantee a single authentic record of activity, scholars have explored the application of blockchain-based traceability to improve food supply chain sustainability [28,44,45]. In addition to immutability, blockchain technology offers several other attributes that align well with sustainability communication, which requires traceability, transparency, trust, and engagement in the standardised recording and verification of sustainability-related data. Figure 1 presents five attainable application opportunities/scenarios and explains in which ways blockchain-based traceability facilitates these opportunities via enabling the traceable, verifiable, and immutable (TVI) records of environmental, social, economic, and nutritional dimensions of sustainability. The availability of the TVI records strengthens the credibility of sustainability claims and enables stakeholders to make informed decisions based on accountable information.

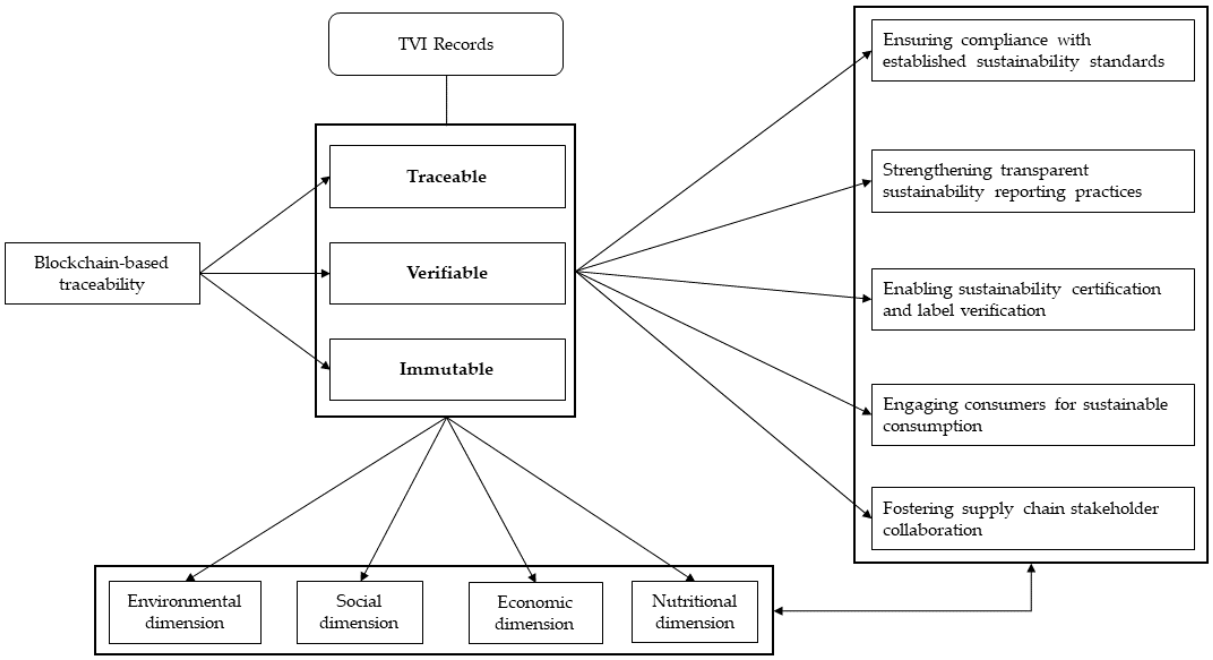

Figure 1. The Application of blockchain-based traceability for sustainability communication.

3.1. Ensuring Compliance with Established Sustainability Standards

Effective sustainability communication in a multi-stakeholder supply chain relies heavily on compliance across various dimensions of sustainability standards and frameworks [46]. Blockchain is a shared digital ledger that enables multi-source data to be recorded and stored in a standardised format. This ensures consistency and uniformity in accordance with the sustainability-related standards at each stage of the food supply chain. Blockchain-based traceability can be harnessed in conjunction with a global sustainability framework to empower the accurate documentation of sustainability information pertaining to environmental, social, economic, and nutritional standards. By integrating blockchain-based traceability with an established global sustainability standard, supply chain stakeholders can access and agree upon the standardised set of sustainability claims, metrics, and ethical guidelines. This integration ensures data consistency and

harmonisation across the food supply chain and further allows for meaningful verification, benchmarking, and assessment of sustainability performance.

Some studies have advocated the potential of blockchain to enhance sustainability data standardisation and to advance sustainability standards and practices [47,48]. Balzarova and Cohen [47] maintained that blockchain technology can serve as a useful tool for enhancing the accuracy and consistency of sustainability standards and metrics. Kshetri [48] highlighted the significant role of monitoring and enforcing sustainability standards in supply chains and pointed out that blockchain's specific characteristics can effectively ensure compliance with sustainability standards. Köhler et al. [49] examined the interaction between blockchain technology and voluntary sustainability standards using 16 case studies. Their findings shed light on integrating blockchain with voluntary sustainability standards for effective sustainability governance. These studies have highlighted the potential of blockchain-based traceability as a viable solution to drive the adoption of sustainability standards and facilitate consistent and effective sustainability communication. In addition to ensuring organisations' compliance with established sustainability standards through the availability of TVI records of sustainability information, blockchain-based traceability has the potential to promote the development of shared knowledge for sustainable food practices through a consensual understanding of sustainability standards and metrics across the supply chain.

3.2. Strengthening Transparent Sustainability Reporting Practices

Supply chain transparency is an essential requirement for effective and sustainable management of food supply chains [50]. This transparency plays a vital role in allowing stakeholders to access and validate information regarding sustainability practices throughout the food supply chain. By doing so, it promotes accountability and helps mitigate the risk of greenwashing [51]. The traceability feature of blockchain technology offers the potential to enhance transparency in sustainability reporting. By leveraging blockchain-based traceability for sustainability reporting, it becomes feasible to accurately record what international initiatives and standards are applied to guide sustainability reporting. It also enables the sharing of TVI records of sustainability among various stakeholders involved in the food supply chain. The transparency in sustainability reporting empowered by blockchain-based traceability can further foster trust and accountability by enabling access to immutable records of sustainability information.

Embracing blockchain-based traceability for food supply chain sustainability has attracted scholars' interest. Pham et al. [45] conducted a case study to identify the potential impacts of blockchain-enabled traceability on the sustainability of the pork supply chain in Vietnam. Through interviewing pork supply chain stakeholders and international blockchain experts, they posited the value of blockchain for supply chain transparency and trust building and provided insights on the adoption of blockchain-based traceability for food supply chain sustainability. Cao et al. [28] introduced a blockchain-enabled architectural framework designed to improve the communication of sustainability information to consumers with enhanced sustainability transparency. They addressed the need for a more transparent and reliable means of sustainability communication to consumers beyond the paper-based and conventional digitally enabled sustainability communication methods, such as websites or labels. These studies have demonstrated that blockchain-based traceability can enable greater transparency and accountability in food supply chain sustainability. Additionally, blockchain-based traceability allows access to TVI records of sustainable practices and therefore can reduce information asymmetry prevalent in conventional sustainability communication methods. This can help ensure the reliability of sustainability information and support businesses that place a priority on implementing transparent food sustainability reporting initiatives.

3.3. Facilitating Sustainability Certification and Label Verification

Sustainability certification and labels serve as essential instruments to authenticate sustainability claims made by businesses [52]. The growing recognition of their significance highlights the need for verified sustainability certification and labels to enhance the transparency and integrity of sustainability credentials. The transparent and immutable feature of blockchain technology facilitates verifiable information about, e.g., sustainable farming practices and other sustainability attributes, thereby validating adherence to sustainability standards. By accessing the TVI records on the blockchain, stakeholders can easily verify the authenticity of sustainability claims. Furthermore, smart contracts, which are self-executing agreements with predefined rules and conditions, can be programmed to simplify the verification process and automatically trigger actions or notifications when violations occur. This automation enables the alignment of sustainability standards in verification and validation processes and reduces human error or subjective interpretations associated with sustainability certification and labels.

The potential of blockchain to enhance the verification and certification processes for sustainability certification and labels has been demonstrated [15,49]. As noted by Köhler et al. [49], blockchain-based traceability offers the potential to provide relevant parties with access to sustainability data, particularly in situations where additional auditing is required. This capability can complement on-site audits and enhance monitoring possibilities, thereby strengthening the overall transparency and credibility of sustainability certifications and labels. Additionally, Bager et al. [15] highlighted the significance of blockchain-enabled traceability in enhancing the reliability of sustainability certification and labels within the coffee supply chain. They indicated the ability to cross-check information shared on the blockchain with third-party audits and match specific coffee batches to the certification standards adopted by farmers. This ensures the alignment between farmers' claims and certification standards, promoting transparency, accountability, and trust throughout the supply chain. Blockchain-based traceability therefore offers an opportunity to enable verified sustainability certification and labels. By leveraging TVI records, the authenticity of sustainability certifications and labels can be verified and validated. This capability enhances the credibility of sustainability communication, providing a sense of confidence in the food sustainability credentials.

3.4. Engaging Consumers in Sustainable Food Consumption

Sustainable food consumption is facilitated by effective communication of sustainability attributes [53]. When accessing accountable and transparent information about the sustainability aspects of the food they purchase, consumers can ensure that their choices align with their values and sustainability concerns. Blockchain can empower consumers by providing them with access to more detailed sustainability information about the food they purchase beyond simplistic sustainability labels. Access to sustainability attributes of food products, such as their environmental impact, social responsibility, and ethical sourcing practices, enables consumers to make more informed choices of sustainable food products. Communicating trustworthy sustainability information through blockchain-based traceability can also educate consumers about sustainability practices and foster a sense of trust and connection with the food they consume.

Blockchain technology can engage consumers in sustainable food consumption by, e.g., enabling them to trace and verify sustainability credentials and access information about sustainability attributes and offering rewards for their sustainable choices. By leveraging blockchain-based traceability for sustainability communication, consumers can access and verify information about origin, certifications, and other relevant factors that contribute to sustainability beyond the static sustainability communication methods, such as websites or labels [28]. Blockchain-based traceability can also inform consumers to make more sustainable choices by providing them with a comprehensive understanding of the sustainability impacts of food products. As noted by Bai and Sarkis [54], the track and trace of product life cycles and sustainability production practices can motivate consumers

to engage in green consumption. Additionally, blockchain's incentive mechanisms can be leveraged to nudge consumers to purchase sustainable food products. According to Calandra et al. [55], Poseidon developed a blockchain platform that connects actual purchases with the carbon footprint and rewards consumers with credits for more sustainable choices. Therefore, blockchain can provide consumers with an interactive and participatory approach that helps them make more informed and conscious consumption decisions in alignment with their sustainable preferences.

3.5. Fostering Multi-Stakeholder Collaboration throughout the Supply Chain

Collaboration within a supply chain involving multiple stakeholders is a prerequisite for the successful implementation of sustainable development strategies and practices [56]. Blockchain has a decentralised structure that facilitates active participation of diverse stakeholders in governance and decision-making processes and therefore can serve as a foundational technology for collaborative supply chains [57,58]. By recording and sharing sustainability information on a shared decentralised network, supply chain stakeholders can have a common understanding of food sustainability standards and metrics without the influence of a single authority. The sharing of sustainability information and standards promotes a more inclusive approach to food supply chain sustainability reporting and facilitates the exchange of standardised sustainable records across the supply chain. Blockchain can also guarantee secure and immutable records of sustainability, which can enhance trust and supply chain collaboration, ensuring adherence to sustainability standards by multiple supply chain stakeholders [59].

Leveraging blockchain applications for collaborative supply chain networks in addressing sustainability issues within the food supply chain has recently attracted scholarly interest. A study by Tsolakis et al. [60] investigated the effect of the design of blockchain-enabled food supply chains on achieving the United Nations' sustainable development goals (SDGs) using multiple case studies within the Thai fish industry. They contended that blockchain technology promotes collaborative efforts and enables collaborative decision-making in prioritising different SDGs by enabling access to transparent and reliable sustainability information. Blockchain's distributed nature enables nearly real-time information sharing. By utilising a blockchain-enabled supply chain network, supply chain stakeholders can record, measure, and track the sustainability impact of food products throughout the supply chain in a distributed network. This enables the availability of real-time sustainability information throughout the product life cycle. This in turn fosters supply chain collaboration to communicate their sustainability efforts to consumers, thereby gaining a competitive advantage in the market.

4. An Architectural Framework of Blockchain-Based Traceability for Food Sustainability Communication

To realise the application scenarios described in Section 3 when embracing blockchain-based traceability for sustainability communication within food supply chains, this section presents a high-level architectural framework of blockchain-based traceability for food sustainability communication throughout the production-distribution-consumption cycle. This framework provides a blueprint or structured approach for arranging various components, modules, and functionalities within a blockchain-enabled system for the goal of traceable, verifiable, and immutable (TVI) food sustainability communication. The methodology used to define the architecture, components, and integrated modules for a customised system [61,62] was the system architecture approach.

Drawing upon the architectural framework proposed by [20,61,63] for facilitating the development of blockchain-enabled food supply chains, we introduced a four-layered architectural framework for blockchain-enabled food sustainability communication that comprises the supply chain (business) layer, the application layer, the traceable sustainability layer, and the blockchain layer. These four layers share a conceptual resemblance to the architecture introduced by Vo et al. [61] at a high level but are designed with a cohesive

workflow spanning layers and customised with different components at each layer. The tailored design was formulated based on our established work in blockchain design and supply chain know-how [28,58,64,65] to achieve the TVI sustainability communication goals enabled by blockchain-based traceability. The current architectural framework serves as a structured approach for the design and development of a blockchain-enabled food sustainability communication solution. Figure 2 illustrates the structure of the architecture and detailed modules and components at each layer.

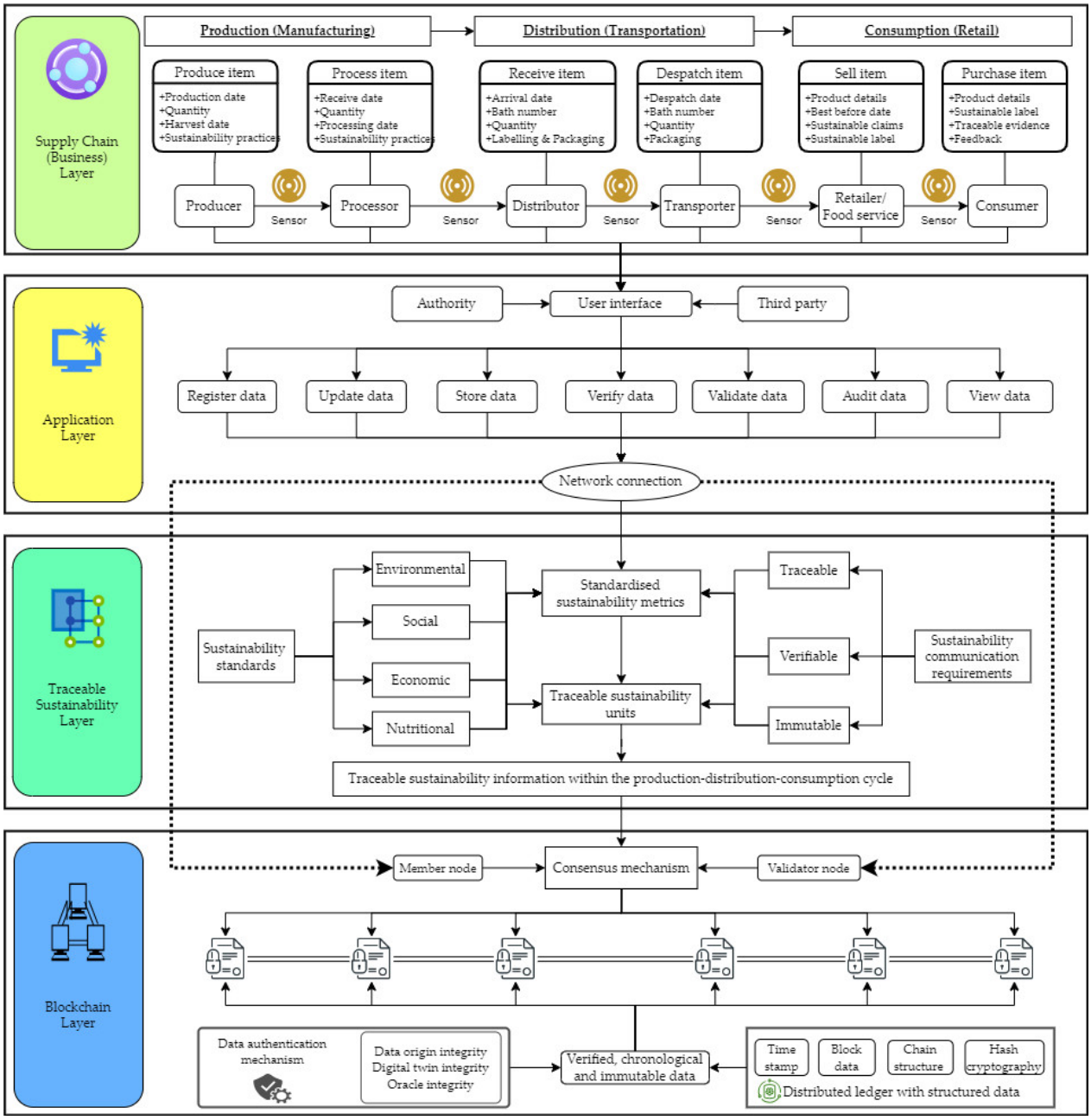

Figure 2. The architecture of blockchain-based traceability for food sustainability communication.

4.1. Supply Chain (Business) Layer

The supply chain (business) layer represents the supply chain processes involving the production and distribution of food products throughout the supply chain from producers to consumers. For simplification without losing generalised purposes, food supply chain processes are categorised into three main stages, production (manufacturing), distribution (transportation), and consumption (retail), in line with the work by Sadraei et al. [66]. The

production-distribution-consumption cycle involves numerous supply chain and business activities. Following the physical flow of food products, we defined two clusters of supply chain activities for every stage within the production-distribution-consumption cycle. These activities include producing and processing items during the production stage, receiving and dispatching items during the distribution stage, and selling and purchasing items during the consumption stage. These clusters of supply chain activities are closely related to various dimensions of sustainability practices. These sustainability practices may include environmental protection, social responsibility, economic viability, and nutrition security. To effectively communicate sustainability practices throughout the supply chain, those stakeholders, including farmers, manufacturers, distributors, transporters, retailers, and consumers, need to be actively engaged to demonstrate their commitments to sustainability practices and claims with accessible evidence. Sustainability-related information, sustainable farming practices, fair labour conditions, and carbon footprint information can be recorded when conducting these supply chain activities within the production-distribution-consumption cycle: produce items, process items, receive items, dispatch items, sell items, and purchase items. Efficient coordination and collaboration among involved stakeholders are therefore essential to communicate with consumers and meet their expectations for sustainable choices.

4.2. Application Layer

The application layer refers to the design of user interfaces that enable humans (i.e., supply chain stakeholders) and/or machines (e.g., IoT sensors and RFID) to easily capture and store sustainability-related information in a distributed network. In addition to producers and their counterparts, authorities and third-party auditing and certification bodies can also be involved to validate and audit the claims and assertions made by supply chain stakeholders. The user interface module can include web apps and mobile apps, which provide supply chain actors and other external stakeholders with easy interaction with the system to register, update, verify, validate, and audit the information about the sustainability attributes of food products. From the perspective of enhanced sustainability communication, these interfaces can display information such as the product's origin, sustainable production methods, certifications, carbon footprint, and other relevant sustainability metrics. The user interfaces can also include interactive features, such as product scanning using QR codes or barcodes, which provides consumers with convenient access to real-time information about the sustainability attributes of a particular item. This design allows for seamless integration between the physical product and the traceable digital sustainability information at each stage of the supply chain, which facilitates sustainability information collection and dissemination.

4.3. Traceable Sustainability Layer

The traceable sustainability layer is the fundamental layer of the architecture that mediates the application layer and the blockchain layer. It defines the standardised sustainability metrics and traceable sustainability units to be used in recording and disseminating sustainability-related information. By adhering to the standardised format of sustainability-related information throughout the production-distribution-consumption cycle, supply chain stakeholders can register and update consistent information through user interfaces. Integrating the traceable sustainability layer with the blockchain layer can enhance transparent and auditable tracking of reported food sustainability practices. To quantify sustainability practices, standardised sustainability metrics are introduced to enable the tracking and communication of food sustainability attributes. Sustainability standards provide a framework for integrating sustainability practices into supply chain activities and quantifying insightful sustainability metrics. These metrics are defined based on established sustainability standards and requirements for effective sustainability communication. Table 3 shows a selection of sustainability metrics that are not exhaustive but are representative in the food supply chain context. These metrics can describe formal

sustainability commitments in terms of environmental, social, economic, and nutritional dimensions, and some of them can be built into the system to track food sustainability attributes. Sustainability communication requirements highlight the importance of creating traceable, verifiable, and immutable (TVI) records to ensure transparency and accountability in sustainability reporting and communication. To enable the availability of TVI records throughout the food supply chain, traceable sustainability units can be further identified in accordance with the adopted standardised sustainability metrics. Traceable sustainability units can include but are not limited to unique product identifiers, product origin, harvesting and production techniques, certification, food safety, and geographical location. Ensuring the accessibility of TVI records can ensure that the information provided regarding food sustainability attributes is traced back to reliable sources and verified for accuracy and that all necessary data for common knowledge about any sustainability claims or labels are available.

Table 3. Sustainability standards and associated sustainability metrics.

Category	Examples of Sustainability Metrics
Environmental standards	carbon emissions, water usage, waste management, resource conservation
Social standards	labour conditions, human rights, fair trade, community engagement
Economic standards	economic inclusivity, return on investment, economic value added
Nutritional standards	sufficient energy, essential nutrients; nutrition security, dietary guidelines

4.4. Blockchain Layer

The blockchain layer severs the fundamental technological infrastructure layer that leverages blockchain technology and other infrastructure for the accountability of sustainability communication and plays a crucial role in ensuring tamper-proof data for sustainability verification and validation in a decentralised and distributed network. This layer consists of a consensus mechanism, a data authentication mechanism, and a distributed ledger with specific data schemas that ensure the reliable and accurate management of sustainability-related data, certifications, and labels. The consensus mechanism is agreed upon by member nodes and validator nodes in the blockchain network to ensure adherence to standardised sustainability metrics as well as secure and cost-effective data storage. Member nodes are supply chain actors, such as producers, manufacturers, distributors, and retailers. Validator nodes can consist of supply chain actors, regulatory authorities, and independent auditing and certification bodies. Member nodes and validator nodes adhere to the metrics and traceable units defined in the traceable sustainability layer to register and update sustainability-related information and use the user interfaces specified in the application layer to add the standardised information to the blockchain network (refer to the workflow marked with dash lines in Figure 2). The data authentication mechanism ensures the integrity of the sustainability data from the origin of the data, digital twins, and oracle (the external source), thereby providing reliable tracking and verification of sustainability information within the production-distribution-consumption cycle. This can facilitate verified sustainability certification and labels. The distributed ledger with specific data schemas (e.g., time stamps, block data, and hash cryptography) records and stores sustainability data in a secure and near real-time accessible manner. This can provide verified chronological and immutable information about the sustainability attributes of the food products, which can further foster supply chain collaboration by tracking the time and location of each supply chain activity and enables consumers to make more informed sustainable choices.

5. Design Pathway and Considerations for Implementing Blockchain-Based Traceability for Food Sustainability Communication

The design and development of a blockchain-based traceability system for food sustainability communication goes beyond the mere development of a blockchain infrastructure. Its design and development should follow an action design approach as presented in Section 5.1 to ensure its buy-in. It also involves the considerations related to organisation, governance, cost, and user interfaces, as discussed in Section 5.2.

5.1. Design Pathway

To facilitate the design and development process, we introduce an action design pathway that involves a multi-stage action approach. Figure 3 illustrates the multi-stage action approach involving (i) engage, (ii) identify, (iii) develop, (iv) evaluate, and (v) demonstrate. This action approach is built on our learnings in designing and developing blockchain for supply chain solutions with industry partners. The design and development of blockchain-based traceability for food sustainability communication involve the engagement with key stakeholders, the identification of adoption strategies and sustainability objectives, the development and evaluation of a technically feasible and economically viable solution, and the demonstration of its usability. This multi-stage action approach informs the upscale development from stakeholder engagement to solution demonstration, while incorporating various design considerations and the sharing of learning across the design stages.

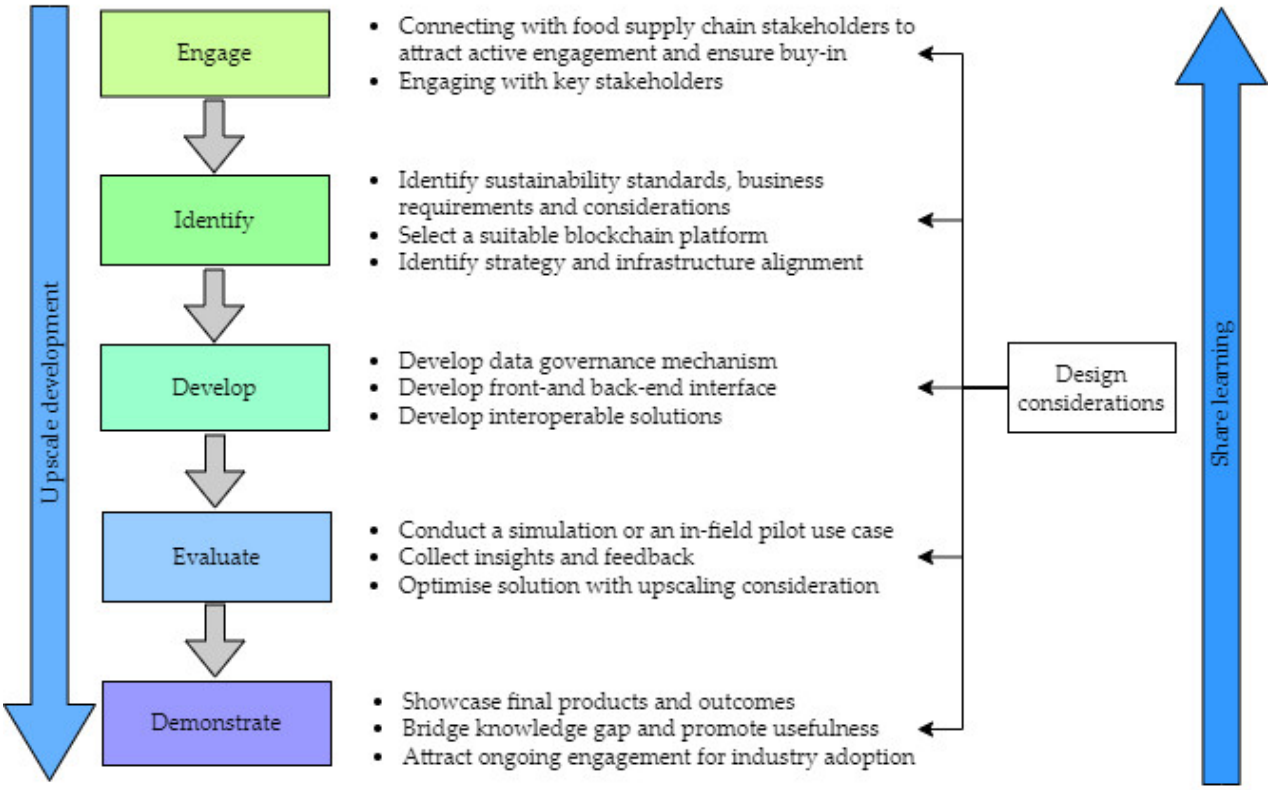

Figure 3. Design pathway for blockchain-based traceability for food sustainability communication.

As indicated by Hall and Dorai [3], the development of new technology involves inclusive planning processes with diverse stakeholders. Following this guideline, the engagement stage involves collaboration between industry stakeholders, regulatory bodies, and/or technology providers to ensure the buy-in from the industry and continuous evaluation and improvement. The collaborative engagement with key stakeholders who can be strategists, implementers, or experimenters is key to the success of designing a blockchain-based traceability system for food sustainability communication. The iden-

tification stage involves working closely with relevant stakeholders to identify sustainability standards and select suitable blockchain platforms. It is important to consider their requirements/considerations related to blockchain traceability for food sustainability communication. The alignment of business and technology strategies and the integration of organisational and technological infrastructure are crucial in informing the development of a customised solution. The development stage focuses on the development of the blockchain-based traceability system for food sustainability communication that encompasses a fit-for-purpose sustainability data governance mechanism as well as front-end and back-end user interfaces. Compatible solutions can be developed to enable the integration of blockchain with other emerging technologies, such as the Internet of things (IoT) and artificial intelligence (AI), that can help reap the full potential of blockchain for food sustainability communication. It is also essential to engage with relevant stakeholders to ensure that the solution aligns with organisations' sustainability communication objectives and requirements. The evaluation stage assesses the trialability of the blockchain-based traceability system for food sustainability communication. A simulated case study or an in-field pilot use case can be conducted to examine where perceived values are achieved at a minimal cost. Insights and feedback from stakeholders can be gathered to identify areas for improvement and optimisation. The final demonstration stage showcases the final product and communicates the benefits and outcomes to stakeholders and the broader community. The final stage helps bridge the knowledge gap, promotes understanding of its usefulness, and attracts ongoing stakeholder engagement, thereby promoting further development and adoption at the industry level.

5.2. Design Considerations

This sub-section discusses various critical considerations around organisation, technology, governance, cost, and user interface in the design process, which helps make more informed decisions in translating the architecture into a tailored solution.

5.2.1. Organisation

Organisations' perception of blockchain trialability and their adoption strategies have a significant influence on the success of implementing blockchain technology for food supply chains [67,68]. Considering the trialability of blockchain and the adoption strategies employed by organisations can facilitate the design and development of a tailored blockchain solution for the food supply chain. Organisations may have different value perceptions of blockchain and business strategies towards the adoption of blockchain-based traceability for food sustainability communication. This requires a better understanding of an organisation's value perceptions and adoption strategies in the design stage. Ostern et al. [69] identified four types of organisations, the strategist, the implementer, the experimenter, and the observer, which have diverse value perceptions and organisational strategies towards the adoption of blockchain applications. Both the strategist and the implementer have a high-value perception towards the adoption of blockchain. The difference is that the strategist focuses on the future value that blockchain can bring, while the implementer aims to capitalise on the current value. The experimenter recognises the potential of blockchain and explores its possible applications. Conversely, the observer perceives little potential value in blockchain and gives low priority to its adoption. When approaching the adoption of blockchain-based traceability for food sustainability communication, the way organisations perceive its value is likely to fall into the four types of organisations discussed previously. Therefore, an organisation's perceptions of blockchain-based traceability for food sustainability communication, together with its adoption strategies, need to be carefully taken into consideration. Furthermore, other organisational factors, such as organisational readiness, top management support, and organisational size, which are identified as important design considerations by Clohessy et al. [70], need to be given special consideration within an organisation's boundary. Additionally, organisations may differ in their intentions to adopt and in their actual implementation actions [69]. This

indicates that design consideration from the organisational perspective should also focus on the alignment between business strategy and technology strategy in the design process, which is key to broad adoption.

5.2.2. Technology

The usability and applicability of blockchain technology have been widely acknowledged in the literature, and potential applications have been extended for sustainability reporting [71] and sustainability communication [28]. It should be noted that blockchain is a complex infrastructure with multiple layers in its architecture and therefore requires specialised knowledge for implementation and maintenance [72]. The nature of technological complexity makes it challenging for non-technical stakeholders to understand and adopt. Blockchain technology is still evolving but not yet becoming a mature technology, and its applications in the food supply chain remain at the experimental stage [44]. To further capitalise on the benefits of blockchain-based traceability for food sustainability communication, scalability and interoperability are the two most important technological considerations that need special attention in the design process. The food supply chain involves multiple stakeholders in the production-distribution-consumption cycle and deals with a vast amount of sustainability-related data. Therefore, scalability is crucial to improve transaction processing speed and reduce delays and even disruptions. With this understanding, the solution design should consider building with scalable capability to handle a large volume of data without compromising performance and efficiency. Interoperability holds significant importance not only as a solution to improve scalability in a blockchain network [73] but also due to its ability to facilitate seamless communication and data exchange across different blockchain networks and even with external systems. Interoperability can enable blockchain networks to integrate with sensor technologies, such as IoT devices, thereby enhancing near real-time data collection and verification capabilities. Interoperability can also extend beyond the blockchain network itself by connecting with external systems, such as regulatory authorities, and independent certification bodies. Interoperable integration can be a significant technical barrier, as it requires robust integration mechanisms and data standardisation efforts. Furthermore, smart contracts can be considered as a powerful tool to automate and enforce sustainability-related standards and frameworks. By leveraging self-executing capabilities, the verification of sustainability claims can be automatically executed without human intervention to provide additional credibility to sustainability communication. Additionally, it should be particularly noted that blockchain cannot eliminate the "garbage in, garbage out (GIGO)" issue [64]. The GIGO problem can compromise the blockchain network. The design process should therefore seek solutions to mitigate this technical limitation and improve data reliability at the registry point.

5.2.3. Governance

Blockchain technology is acknowledged as a consensus-driven technology that is built on a consensus mechanism to enable multiple participants to agree upon and validate transactions within a decentralised network [74,75]. Various consensus algorithms, such as Proof-of-Stake, Proof-of-Authority, and Proof-of-Trust, have been implemented in the process of transaction and data validation and storage. The implementation of blockchain-based traceability for food sustainability communication creates a consensus-driven collaborative supply chain network. By following the consensus process, the collaborative network ensures transparency and integrity in recording sustainability data and enabling accessibility for network participants. However, it poses challenges in protecting business secrets and maintaining privacy, particularly in public or consortium blockchains. Due to the concerns about sharing sensitive data with other participants in the collaborative supply chain network, supply chain stakeholders may be hesitant to adopt the solution. Because of this, it is crucial to balance transparency and data privacy by establishing data governance mechanisms and trust frameworks. Therefore, the design process should in-

corporate governance considerations for potential users and providers. To foster trust and collaboration, while safeguarding business secrets and privacy in a multi-stakeholder environment, the governance mechanism can be designed with the rules for data authentication, data ownership, access rights, and data management on the distributed ledger [71]. The authentication process helps mitigate the technical limitations associated with ensuring the integrity of the data registered on the blockchain network [49]. Through a robust authentication mechanism, organisations can mitigate the malicious risk of frauds and safeguard data integrity. Maintaining the security and privacy of sensitive sustainability-related data is also critical. On-chain and off-chain governance mechanisms [24] can be implemented with data privacy features to protect both on-chain and off-chain data from unauthorised access and tampering. The governance mechanism can also include the development of common standards for data formats, terminology, and processes to ensure interoperability and seamless integration across different blockchain networks. A fit-for-purpose governance mechanism can foster adoption and facilitate seamless communication across different platforms.

5.2.4. Cost

Blockchain is a decentralised technology that removes the need for intermediaries in transactions, resulting in reduced transaction costs for organisations [76]. Due to its cost-saving potential, blockchain has been recognised as a cost-efficient solution for many industries [77]. However, this does not imply that blockchain is inherently a low-cost solution for organisations. New technologies often come with substantial costs associated with adoption, implementation, training, and maintenance [78]. This is also the case when implementing a blockchain-based sustainability solution, which requires extensive resources, including financial investment, technical know-how, and dedicated personnel [79,80]. The financial investment includes but is not limited to initial setup costs, transaction costs (e.g., gas fees), the costs related to data storage on the blockchain, and ongoing expenses for maintaining a secure and scalable blockchain network. The substantial investment could discourage organisations from adopting blockchain-based traceability for food sustainability communication. Smaller companies and producers, who often have limited resources, are likely to face greater challenges and financial constraints. Therefore, organisations should consider the associated costs in the pre-adoption stage and allocate necessary resources to cover the associated costs. Some studies, such as that by Upadhyay et al. [80], posited that the perceived benefits of blockchain adoption on sustainability far outweigh the challenges and investment. Despite this, it is crucial to evaluate the costs associated with the adoption of blockchain-based traceability for food sustainability communication and to ensure that the perceived benefits outweigh the costs incurred. The design process can incorporate incentive mechanisms, such as rewarding sustainable practices and providing incentives for data sharing to develop an economically viable solution that can encourage stakeholder participation.

5.2.5. User Interface

User interfaces serve as an access point for interaction and communication between users and a system or application [81]. They are a critical component contributing to the usability of a blockchain solution [82]. The design of a user-friendly and usable user interface can facilitate the engagement with supply chain participants and consumers when adopting the blockchain-enabled food sustainability communication solution. At the operational level, user interfaces streamline the process of registration and validation of relevant sustainability data and provide easy access to all stakeholders, including suppliers, buyers, and regulatory bodies. The easy-to-use features can promote widespread adoption of the solution and user engagement in collaboration and information sharing. User interfaces can also serve as an effective tool for consumer engagement and the communication of sustainability practices. An interactive user interface for sustainability communication can allow consumers to have access to verified sustainability information, explore product details,

and gain a deeper understanding of various sustainability practices related to their interests. User interfaces can be built with interactive features, such as visualisations, multimedia content, and interactive elements, to enable consumers to make more informed decisions in purchasing sustainable food products. As supply chain stakeholders have limited technical knowledge, user interfaces and applications built on the blockchain-enabled food sustainability communication solution should be intuitive and user-friendly. The design of user interfaces is recommended to engage with users for evaluation and feedback [83] and build with user-friendly features, thereby making it easy-to-use for stakeholders without requiring technical expertise. Gamification elements can also be built into the user interface to interpret sustainability information, as it can increase engagement from stakeholders.

6. Discussion

Sustainability communication has evolved into an imperative or a good practice for businesses across industries, and this principle holds true within the food industry. Our overview of existing sustainability communication approaches revealed that numerous sustainability initiatives, standards, and certifications/labels—policy-driven and voluntary—can be utilised to facilitate the communication of sustainability efforts and commitments. However, these approaches have limited capabilities to enhance food sustainability communication primarily due to the acknowledged constraints, including a lack of standardised data, limited availability of information, information overload, greenwashing, and an absence of collaboration. Blockchain technology possesses unparalleled characteristics that position it as a potential solution to tackle these limitations.

Leveraging the transparent, traceable, verifiable, and immutable attributes of blockchain technology, we identified the five attainable application scenarios throughout the food supply chains that can ensure sustainability compliance, strengthen transparent reporting, facilitate verified certifications/labels, inform trustworthy sustainable choices, and foster collaboration among stakeholders. To realise these application scenarios for more transparent and reliable food sustainability communication, we introduced a high-level architectural framework that consists of four layers: supply chain (business) layer, application layer, traceable sustainability layer, and blockchain layer. To further navigate the translation of the architectural framework into a technically feasible and economically viable solution, we proposed a multi-stage action approach involving (i) engage, (ii) identify, (iii) develop, (iv) evaluate, and (v) demonstrate. This action approach guides the process of involving industry stakeholders in the design and assessment of solutions, experimenting from pilot phases to larger-scale implementations. Finally, we discussed various critical considerations in the aspects of, e.g., organisation, technology, governance, cost, and user interface that offer valuable insights for the development of a blockchain-enabled solution that aims to enhance food sustainability communication.

Drawing upon the limitations of existing sustainability communication approaches and the advantages of blockchain technology, this study makes a special contribution to inform the design and development of blockchain-enabled solutions for enhanced sustainability communication within the food supply chain context. This study extends the application of blockchain technology for food supply chain sustainability [15,26,27], with a particular focus on food sustainability communication. Our design of the high-level architectural framework is in line with the work by Vo et al. [61], which introduced a four-layered architecture, including the business layer, the traceability layer, the blockchain layer, and the application layer, to facilitate the development of a blockchain-enabled sustainable food supply chain system. The novelty of our architectural framework lies in the seamless organisation across four layers and the module components at each layer. We have configured the linkage between the supply chain (business) layer and the application layer and defined the mediating role of the traceable sustainability layer between the application layer and the blockchain layer. This system architecture advocates for user-centric design thinking and highlights the importance of traceable metrics when allowing humans and machines to record sustainability information in accordance with the physical

flow of food products and register/update standardised information in the blockchain network. The components at each layer are customised to enhance the overall efficiency and reliability of information exchange and ensure transparent communication within the ecosystem.

Another significant contribution of this study is to introduce an action design pathway and discuss the critical aspects that need to be carefully considered in the pre-adoption stage. The action design pathway outlines the engagement with supply chain stakeholders to identify the specific needs and align with strategy and infrastructure. This approach helps answer the "where to start" question that is often encountered when designing blockchain-enabled supply chain solutions [84] and navigates the design and development of blockchain-enabled solutions for sustainability communication. The outcomes of design considerations around organisation, technology, governance, cost, and user interface help system developers, business analysts, and supply chain stakeholders make informed decisions before and during the design process.

7. Conclusions

This paper explores the potential of blockchain technology to enhance sustainability communication within the food supply chain context. By acknowledging the utilisation of blockchain-based traceability in five attainable application scenarios within the production-distribution-consumption cycle, this paper proposes a four-layered architectural framework to unlock the benefits of blockchain-based traceability for enhanced food sustainability communication. To assist with the translation of the architectural framework into a practical solution, this paper presents a multi-stage action approach that highlights the engagement of relevant stakeholders in the design and development process to ensure buy-in from the industry and bridge the knowledge gap for industry-based adoption. Finally, this paper discusses several critical aspects in these areas of organisation, technology, governance, cost, and user interface. The findings complement the design pathway to navigate the design and development of a tailored blockchain-enabled solution for food sustainability communication with the food supply chains.

This paper is conceptual and limits its scope to the transformative benefits that blockchain-based traceability can bring to food sustainability communication and the design planning in translating these transformative benefits into practice. Despite these limitations, this paper presents a pioneering contribution to the understanding of the value of blockchain for sustainability communication throughout the food supply chain and provides insights for the design and development of blockchain-enabled solutions for enhanced food sustainability communication. The benefits offered by blockchain-based traceability for food sustainability communication are vast and significant, thereby deserving further exploration. Future research could explore other potential benefits of blockchain-based traceability within the food sustainability realm, such as bio-farming. The development of adaptive and extensible traceable units for food sustainability is also a valuable research area. Another promising and ambitious research direction is to engage with supply chain stakeholders to take up the design pathway to develop and test a technically feasible and economically viable solution. The design process could involve small-scale farmers and suppliers as it helps address the digital divide and promote digital inclusion during the process of digital transition. Short video storytelling could be built into the solution to enhance the effect of communication [85].

Author Contributions: Conceptualization, S.C.; methodology, S.C.; formal analysis, S.C.; investigation, S.C.; resources, S.C., H.X. and K.P.B.; data curation, S.C.; writing—original draft preparation, S.C.; writing—review and editing, H.X. and K.P.B.; visualization, S.C. and K.P.B.; funding acquisition, S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially supported by Queensland University of Technology (QUT)'s Centre for Agriculture and the Bioeconomy (CAB) under the Future Leaders Funding Opportunity 2021 (grant number: 290265-0123/07).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the relevant data has been included in this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Aiking, H.; de Joop, B. Food Sustainability: Diverging Interpretations. *Br. Food J.* **2004**, *106*, 359–365. [CrossRef]
2. Fritz, M.; Matopoulos, A. Sustainability in the Agri-Food Industry: A Literature Review and Overview of Current Trends. In Proceedings of the 8th International Conference on Chain Network Management in Agribusiness the Food Industry, Ede, The Netherlands, 26–28 May 2008.
3. Hall, A.; Dorai, K. *The Greening of Agriculture: Agricultural Innovation and Sustainable Growth*; Link Limited: Brighton, UK, 2010.
4. Maloni, M.J.; Brown, M.E. Corporate Social Responsibility in the Supply Chain: An Application in the Food Industry. *J. Bus. Ethics* **2006**, *68*, 35–52. [CrossRef]
5. Grunert, K.G.; Hieke, S.; Wills, J. Sustainability Labels on Food Products: Consumer Motivation, Understanding and Use. *Food Policy* **2014**, *44*, 177–189. [CrossRef]
6. Jindřichovská, I.; Kubíčková, D.; Mocanu, M. Case Study Analysis of Sustainability Reporting of an Agri-Food Giant. *Sustain. Sci. Pract. Policy* **2020**, *12*, 4491. [CrossRef]
7. Sala, S.; Anton, A.; McLaren, S.J.; Notarnicola, B.; Saouter, E.; Sonesson, U. In Quest of Reducing the Environmental Impacts of Food Production and Consumption. *J. Clean. Prod.* **2017**, *140*, 387–398. [CrossRef]
8. Brown, K.A.; Harris, F.; Potter, C.; Knai, C. The Future of Environmental Sustainability Labelling on Food Products. *Lancet Planet. Health* **2020**, *4*, e137–e138. [CrossRef]
9. Schiano, A.N.; Harwood, W.S.; Gerard, P.D.; Drake, M.A. Consumer Perception of the Sustainability of Dairy Products and Plant-Based Dairy Alternatives. *J. Dairy Sci.* **2020**, *103*, 11228–11243. [CrossRef]
10. Tölkes, C. Sustainability Communication in Tourism—A Literature Review. *Tour. Manag. Perspect.* **2018**, *27*, 10–21. [CrossRef]
11. Lähtinen, K.; Toppinen, A.; Suojanen, H.; Stern, T.; Ranacher, L.; Burnard, M.; Kitek Kuzman, M. Forest Sector Sustainability Communication in Europe: A Systematic Literature Review on the Contents and Gaps. *Curr. For. Rep.* **2017**, *3*, 173–187. [CrossRef]
12. Tesařová, M.; Krmela, A.; Šimberová, I. Digital Support to External Sustainability Communication in Self-Adhesive Labelling Industry. *Entrep. Sustain. Issues Vilnius* **2020**, *7*, 2109–2125. [CrossRef]
13. Tiago, F.; Gil, A.; Stemberger, S.; Borges-Tiago, T. Digital Sustainability Communication in Tourism. *J. Innov. Knowl.* **2021**, *6*, 27–34. [CrossRef]
14. Asioli, D.; Aschemann-Witzel, J.; Nayga, R.M. Sustainability-Related Food Labels. *Annu. Rev. Resour. Econ.* **2020**, *12*, 171–185. [CrossRef]
15. Bager, S.L.; Singh, C.; Persson, U.M. Blockchain Is Not a Silver Bullet for Agro-Food Supply Chain Sustainability: Insights from a Coffee Case Study. *Curr. Res. Environ. Sustain.* **2022**, *4*, 100163. [CrossRef]
16. Cuadrado-Ballesteros, B.; Martínez-Ferrero, J.; García-Sánchez, I.M. Mitigating Information Asymmetry through Sustainability Assurance: The Role of Accountants and Levels of Assurance. *Int. Bus. Rev.* **2017**, *26*, 1141–1156. [CrossRef]
17. Powell, W.; Cao, S.; Foth, M.; He, S.; Turner-Morris, C.; Li, M. Revisiting Trust in Supply Chains: How Does Blockchain Redefine Trust? In *Blockchain Driven Supply Chains and Enterprise Information Systems*; Abdelaziz, B., Khalil, I., Aouni, B., Eds.; Springer Nature: Cham, Switzerland, 2022.
18. Martinez, V.; Zhao, M.; Blujdea, C.; Han, X.; Neely, A.; Albores, P. Blockchain-Driven Customer Order Management. *Int. J. Oper. Prod. Manag.* **2019**, *39*, 993–1022. [CrossRef]
19. Behnke, K.; Janssen, M. Boundary Conditions for Traceability in Food Supply Chains Using Blockchain Technology. *Int. J. Inf. Manag.* **2020**, *52*, 101969. [CrossRef]
20. Feng, H.; Wang, X.; Duan, Y.; Zhang, J.; Zhang, X. Applying Blockchain Technology to Improve Agri-Food Traceability: A Review of Development Methods, Benefits and Challenges. *J. Clean. Prod.* **2020**, *260*, 121031. [CrossRef]
21. Kechagias, E.P.; Gayialis, S.P.; Papadopoulos, G.A.; Papoutsis, G. An Ethereum-Based Distributed Application for Enhancing Food Supply Chain Traceability. *Foods* **2023**, *12*, 1220. [CrossRef]
22. Rogerson, M.; Parry, G.C. Blockchain: Case Studies in Food Supply Chain Visibility. *Supply Chain. Manag. Int. J.* **2020**, *25*, 601–614. [CrossRef]
23. Köhler, S.; Pizzol, M. Technology Assessment of Blockchain-Based Technologies in the Food Supply Chain. *J. Clean. Prod.* **2020**, *269*, 122193. [CrossRef]
24. Cao, S.; Miller, T.; Foth, M.; Powell, W.; Boyen, X.; Turner-Morris, C. Integrating On-Chain and Off-Chain Governance for Supply Chain Transparency and Integrity. In Proceedings of the 5th Symposium on Distributed Ledger Technology, Brisbane, Australia, 11 November 2021.
25. Ali, M.H.; Chung, L.; Kumar, A.; Zailani, S.; Tan, K.H. A Sustainable Blockchain Framework for the Halal Food Supply Chain: Lessons from Malaysia. *Technol. Forecast. Soc. Chang.* **2021**, *170*, 120870. [CrossRef]

26. Leonardo, R.R.; Tricase, C.; Luigi, D.C. Blockchain Technology for a Sustainable Agri-Food Supply Chain. *Br. Food J.* **2021**, *123*, 3471–3485.
27. Friedman, N.; Ormiston, J. Blockchain as a Sustainability-Oriented Innovation? Opportunities for and Resistance to Blockchain Technology as a Driver of Sustainability in Global Food Supply Chains. *Technol. Forecast. Soc. Chang.* **2022**, *175*, 121403. [CrossRef]
28. Cao, S.; Johnson, H.; Tulloch, A. Exploring Blockchain-Based Traceability for Food Supply Chain Sustainability: Towards a Better Way of Sustainability Communication with Consumers. *Procedia Comput. Sci.* **2023**, *217*, 1437–1445. [CrossRef]
29. Mangla, S.K.; Kazançoğlu, Y.; Yıldızbaşı, A.; Öztürk, C.; Çalık, A. A Conceptual Framework for Blockchain-based Sustainable Supply Chain and Evaluating Implementation Barriers: A Case of the Tea Supply Chain. *Bus. Strat. Environ.* **2022**, *31*, 3693–3716. [CrossRef]
30. Baumgartner, R.J.; Ebner, D. Corporate Sustainability Strategies: Sustainability Profiles and Maturity Levels. *Sustain. Dev.* **2010**, *18*, 76–89. [CrossRef]
31. Dressler, M.; Paunovic, I. A Typology of Winery SME Brand Strategies with Implications for Sustainability Communication and Co-Creation. *Sustain. Sci. Pract. Policy* **2021**, *13*, 805. [CrossRef]
32. Becker, J.T.; Ellis, J.D. The Role of Sustainability Reporting in the Agri-Food Supply Chain. *J. Agric. Environ. Sci.* **2017**, *6*, 17–29. [CrossRef]
33. Van Loo, E.J.; Caputo, V.; Nayga, R.M., Jr.; Verbeke, W. Consumers' Valuation of Sustainability Labels on Meat. *Food Policy* **2014**, *49*, 137–150. [CrossRef]
34. Ingrassia, M.; Chironi, S.; Lo Grasso, G.; Gristina, L.; Francesca, N.; Bacarella, S.; Columba, P.; Altamore, L. Is Environmental Sustainability Also "Economically Efficient"? The Case of the "SOStain" Certification for Sicilian Sparkling Wines. *Sustain. Sci. Pract. Policy* **2022**, *14*, 7359. [CrossRef]
35. Simeone, M.; Scarpato, D. Sustainable Consumption: How Does Social Media Affect Food Choices? *J. Clean. Prod.* **2020**, *277*, 124036. [CrossRef]
36. Isabel Sonntag, W.; Lemken, D.; Spiller, A.; Schulze, M. Welcome to the (label) Jungle? Analyzing How Consumers Deal with Intra-Sustainability Label Trade-Offs on Food. *Food Qual. Prefer.* **2023**, *104*, 104746. [CrossRef]
37. García-Herrero, L.; De Menna, F.; Vittuari, M. Sustainability Concerns and Practices in the Chocolate Life Cycle: Integrating Consumers' Perceptions and Experts' Knowledge. *Sustain. Prod. Consum.* **2019**, *20*, 117–127. [CrossRef]
38. Bogliacino, F.; Charris, R.; Codagnone, C.; Folkvord, F.; Gaskell, G.; Gómez, C.; Liva, G.; Montealegre, F. Less Is More: Information Overload in the Labelling of Fish and Aquaculture Products. *Food Policy* **2023**, *116*, 102435. [CrossRef]
39. Montero-Navarro, A.; González-Torres, T.; Rodríguez-Sánchez, J.-L.; Gallego-Losada, R. A Bibliometric Analysis of Greenwashing Research: A Closer Look at Agriculture, Food Industry and Food Retail. *Br. Food J.* **2021**, *123*, 547–560. [CrossRef]
40. Nguyen, T.T.H.; Yang, Z.; Nguyen, N.; Johnson, L.W.; Cao, T.K. Greenwash and Green Purchase Intention: The Mediating Role of Green Skepticism. *Sustain. Sci. Pract. Policy* **2019**, *11*, 2653. [CrossRef]
41. Farooque, M.; Zhang, A.; Liu, Y. Barriers to Circular Food Supply Chains in China. *Supply Chain Manag. Int. J.* **2019**, *24*, 677–696. [CrossRef]
42. OECD. The Role of Sustainability Initiatives in Mandatory Due Diligence: Background Note on Regulatory Developments Concerning Due Diligence for Responsible Business Conduct. Available online: http://mneguidelines.oecd.org/the-role-of-sustainability-initiatives-in-mandatory-due-diligence-note-for-policy-makers.pdf (accessed on 13 August 2023).
43. Lim, M.K.; Li, Y.; Wang, C.; Tseng, M.-L. A Literature Review of Blockchain Technology Applications in Supply Chains: A Comprehensive Analysis of Themes, Methodologies and Industries. *Comput. Ind. Eng.* **2021**, *154*, 107133. [CrossRef]
44. Collart, A.J.; Canales, E. How Might Broad Adoption of Blockchain-based Traceability Impact the U.S. Fresh Produce Supply Chain? *Appl. Econ. Perspect. Policy* **2022**, *44*, 219–236. [CrossRef]
45. Pham, C.; Nguyen, T.-T.; Adamopoulos, A.; Tait, E. Blockchain-Enabled Traceability in Sustainable Food Supply Chains: A Case Study of the Pork Industry in Vietnam. In *Information Systems Research in Vietnam: A Shared Vision and New Frontiers*; Hoang Thuan, N., Dang-Pham, D., Le, H.-S., Phan, T.Q., Eds.; Springer Nature: Singapore, 2023; pp. 65–81. ISBN 9789811938047.
46. Wang, B.; Lin, Z.; Wang, M.; Wang, F.; Xiangli, P.; Li, Z. Applying Blockchain Technology to Ensure Compliance with Sustainability Standards in the PPE Multi-Tier Supply Chain. *Int. J. Prod. Res.* **2023**, *61*, 4934–4950. [CrossRef]
47. Balzarova, M.A.; Cohen, D.A. The Blockchain Technology Conundrum: Quis Custodiet Ipsos Custodes? *Curr. Opin. Environ. Sustain.* **2020**, *45*, 42–48. [CrossRef]
48. Kshetri, N. Blockchain and Sustainable Supply Chain Management in Developing Countries. *Int. J. Inf. Manag.* **2021**, *60*, 102376. [CrossRef]
49. Köhler, S.; Bager, S.; Pizzol, M. Sustainability Standards and Blockchain in Agro-Food Supply Chains: Synergies and Conflicts. *Technol. Forecast. Soc. Chang.* **2022**, *185*, 122094. [CrossRef]
50. Bastian, J.; Zentes, J. Supply Chain Transparency as a Key Prerequisite for Sustainable Agri-Food Supply Chain Management. *Int. Rev. Retail Distrib. Consum. Res.* **2013**, *23*, 553–570. [CrossRef]
51. Dorfleitner, G.; Braun, D. Fintech, Digitalization and Blockchain: Possible Applications for Green Finance. In *The Rise of Green Finance in Europe: Opportunities and Challenges for Issuers, Investors and Marketplaces*; Migliorelli, M., Dessertine, P., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 207–237. ISBN 9783030225100.
52. Hartlieb, S.; Jones, B. Humanising Business through Ethical Labelling: Progress and Paradoxes in the UK. *J. Bus. Ethics* **2009**, *88*, 583–600. [CrossRef]

53. Siraj, A.; Taneja, S.; Zhu, Y.; Jiang, H.; Luthra, S.; Kumar, A. Hey, Did You See That Label? It's Sustainable!: Understanding the Role of Sustainable Labelling in Shaping Sustainable Purchase Behaviour for Sustainable Development. *Bus. Strat. Environ.* **2022**, *31*, 2820–2838. [CrossRef]
54. Bai, C.; Sarkis, J. A Supply Chain Transparency and Sustainability Technology Appraisal Model for Blockchain Technology. *Int. J. Prod. Res.* **2020**, *58*, 2142–2162. [CrossRef]
55. Calandra, D.; Secinaro, S.; Massaro, M.; Dal Mas, F.; Bagnoli, C. The Link between Sustainable Business Models and Blockchain: A Multiple Case Study Approach. *Bus. Strat. Environ.* **2023**, *32*, 1403–1417. [CrossRef]
56. Nayal, K.; Raut, R.D.; Yadav, V.S. The Impact of Sustainable Development Strategy on Sustainable Supply Chain Firm Performance in the Digital Transformation Era. *Bus. Strategy Environ.* **2022**, *31*, 845–859. [CrossRef]
57. Rejeb, A.; Széchenyi István University; Rejeb, K. Higher Institute of Computer Science, Ariana, Tunisia Blockchain and Supply Chain Sustainability. *Logforum* **2020**, *16*, 363–372. [CrossRef]
58. Cao, S.; Foth, M.; Powell, W.; Miller, T.; Li, M. A Blockchain-Based Multisignature Approach for Supply Chain Governance: A Use Case from the Australian Beef Industry. *Blockchain Res. Appl.* **2022**, *3*, 100091. [CrossRef]
59. Sahoo, S.; Kumar, S.; Sivarajah, U.; Lim, W.M.; Westland, J.C.; Kumar, A. Blockchain for Sustainable Supply Chain Management: Trends and Ways Forward. *Electron. Commer. Res.* **2022**, 1–56. [CrossRef]
60. Tsolakis, N.; Niedenzu, D.; Simonetto, M.; Dora, M.; Kumar, M. Supply Network Design to Address United Nations Sustainable Development Goals: A Case Study of Blockchain Implementation in Thai Fish Industry. *J. Bus. Res.* **2021**, *131*, 495–519. [CrossRef]
61. Vo, K.T.; Nguyen-Thi, A.-T.; Nguyen-Hoang, T.-A. Building Sustainable Food Supply Chain Management System Based On Hyperledger Fabric Blockchain. In Proceedings of the 2021 15th International Conference on Advanced Computing and Applications (ACOMP), Ho Chi Minh City, Vietnam, 24–26 November 2021; pp. 9–16.
62. Paul, T.; Islam, N.; Mondal, S.; Rakshit, S. RFID-Integrated Blockchain-Driven Circular Supply Chain Management: A System Architecture for B2B Tea Industry. *Ind. Mark. Manag.* **2022**, *101*, 238–257. [CrossRef]
63. Jo, J.; Yi, S.; Lee, E.-K. Including the Reefer Chain into Genuine Beef Cold Chain Architecture Based on Blockchain Technology. *J. Clean. Prod.* **2022**, *363*, 132646. [CrossRef]
64. Powell, W.; Foth, M.; Cao, S.; Natanelov, V. Garbage In Garbage Out: The Precarious Link between IoT and Blockchain in Food Supply Chains. *J. Ind. Inf. Integr.* **2021**, *25*, 100261. [CrossRef]
65. Miller, T.; Cao, S.; Foth, M.; Boyen, X.; Powell, W. An Asset-Backed Decentralised Finance Instrument for Food Supply Chains--A Case Study from the Livestock Export Industry. *Comput. Ind.* **2023**, *147*, 103863. [CrossRef]
66. Sadraei, R.; Biancone, P.; Lanzalonga, F.; Jafari-Sadeghi, V.; Chmet, F. How to Increase Sustainable Production in the Food Sector? Mapping Industrial and Business Strategies and Providing Future Research Agenda. *Bus. Strat. Environ.* **2023**, *32*, 2209–2228. [CrossRef]
67. Lustenberger, M.; Malešević, S.; Spychiger, F. Ecosystem Readiness: Blockchain Adoption Is Driven Externally. *Front. Blockchain* **2021**, *4*, 720454. [CrossRef]
68. Oguntegbe, K.F.; Di Paola, N.; Vona, R. Behavioural Antecedents to Blockchain Implementation in Agrifood Supply Chain Management: A Thematic Analysis. *Technol. Soc.* **2022**, *68*, 101927. [CrossRef]
69. Ostern, N.K.; Holotiuk, F.; Moormann, J. Organizations' Approaches to Blockchain: A Critical Realist Perspective. *Inf. Manag.* **2022**, *59*, 103552. [CrossRef]
70. Clohessy, T.; Acton, T.; Rogers, N. Blockchain Adoption: Technological, Organisational and Environmental Considerations. In *Business Transformation through Blockchain: Volume I*; Treiblmaier, H., Beck, R., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 47–76. ISBN 9783319989112.
71. Bakarich, K.M.; Castonguay, J.; O'Brien, P.E. The Use of Blockchains to Enhance Sustainability Reporting and Assurance. *Account. perspect.* **2020**, *19*, 389–412. [CrossRef]
72. Zheng, W.; Zheng, Z.; Chen, X.; Dai, K.; Li, P.; Chen, R. NutBaaS: A Blockchain-as-a-Service Platform. *IEEE Access* **2019**, *7*, 134422–134433. [CrossRef]
73. Al-Rakhami, M.; Al-Mashari, M. Interoperability Approaches of Blockchain Technology for Supply Chain Systems. *Bus. Process Manag. J.* **2022**, *28*, 1251–1276. [CrossRef]
74. Treiblmaier, H. Toward More Rigorous Blockchain Research: Recommendations for Writing Blockchain Case Studies. *Front. Blockchain* **2019**, *2*, 1–31. [CrossRef]
75. Powell, W.; Cao, S.; Miller, T.; Foth, M.; Boyen, X.; Earsman, B.; del Valle, S.; Turner-Morris, C. From Premise to Practice of Social Consensus: How to Agree on Common Knowledge in Blockchain-Enabled Supply Chains. *Comput. Netw.* **2021**, *200*, 108536. [CrossRef]
76. Tapscott, D.; Tapscott, A. How Blockchain Will Change Organizations. *MIT Sloan Manag. Rev. Camb.* **2017**, *58*, 10–13.
77. Laroiya, C.; Saxena, D.; Komalavalli, C. Chapter 9—Applications of Blockchain Technology. In *Handbook of Research on Blockchain Technology*; Krishnan, S., Balas, V.E., Julie, E.G., Robinson, Y.H., Balaji, S., Kumar, R., Eds.; Academic Press: Cambridge, MA, USA, 2020; pp. 213–243. ISBN 9780128198162.
78. Appelbaum, D.; Cohen, E.; Kinory, E. Impediments to Blockchain Adoption. *J. Emerg. Mark. Financ.* **2022**, *19*, 199–210. [CrossRef]
79. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain Technology and Its Relationships to Sustainable Supply Chain Management. *Int. J. Prod. Res.* **2019**, *57*, 2117–2135. [CrossRef]

80. Upadhyay, A.; Mukhuty, S.; Kumar, V.; Kazancoglu, Y. Blockchain Technology and the Circular Economy: Implications for Sustainability and Social Responsibility. *J. Clean. Prod.* **2021**, *293*, 126130. [CrossRef]
81. Blair-Early, A.; Zender, M. User Interface Design Principles for Interaction Design. *Des. Issues* **2008**, *24*, 85–107. [CrossRef]
82. Hossain, T.; Mohiuddin, T.; Hasan, A.M.S.; Islam, M.N.; Hossain, S.A. Designing and Developing Graphical User Interface for the MultiChain Blockchain: Towards Incorporating HCI in Blockchain. In Proceedings of the Intelligent Systems Design and Applications, Online. 12–15 December 2020; Springer International Publishing: Cham, Switzerland, 2021; pp. 446–456.
83. Tharatipyakul, A.; Pongnumkul, S. User Interface of Blockchain-Based Agri-Food Traceability Applications: A Review. *IEEE Access* **2021**, *9*, 82909–82929. [CrossRef]
84. van Hoek, R. Exploring Blockchain Implementation in the Supply Chain. *Int. J. Oper. Prod. Manag.* **2019**, *39*, 829–859. [CrossRef]
85. Cao, S.; Foth, M.; Powell, W.; McQueenie, J. What Are the Effects of Short Video Storytelling in Delivering Blockchain-Credentialed Australian Beef Products to China? *Foods* **2021**, *10*, 2403. [CrossRef] [PubMed]

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