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The Integration of the Internet of Things, Artificial Intelligence, and Blockchain Technology for Advancing the Wine Supply Chain

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Abstract: The study presents a comprehensive examination of the recent advancements in the field of wine production using the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain Technology (BCT). The paper aims to provide insights into the implementation of these technologies in the wine supply chain and to identify the potential benefits associated with their use. The study highlights the various applications of IoT, AI, and BCT in wine production, including vineyard management, wine quality control, and supply chain management. It also discusses the potential benefits of these technologies, such as improved efficiency, increased transparency, and reduced costs. The study concludes by presenting the framework proposed by the authors in order to overcome the challenges associated with the implementation of these technologies in the wine supply chain and suggests areas for future research. The proposed framework meets the challenges of lack of transparency, lack of ecosystem management in the wine industry and irresponsible spending associated with the lack of monitoring and prediction tools. Overall, the study provides valuable insights into the potential of IoT, AI, and BCT in optimizing the wine supply chain and offers a comprehensive review of the existing literature on the study subject.

Keywords: BCT; IoT; AI; wine; supply chain

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1. Introduction

Wine profoundly impacts society and economies, playing a critical role in human life beyond just being a drink [1]. The history of winemaking dates back over 8000 years, with archaeological evidence pointing to the South Caucasus region, specifically Georgia, as the cradle for grapevine [2]. Numerous artifacts and residues found in the region have confirmed the presence of wine production and consumption in ancient times [3,4]. This longevity of winemaking as a profession highlights the enduring impact of wine on human culture and underscores its continued relevance today [5].

Besides its cultural significance, wine has remarkable economic importance because it is a key driver of economic growth in many regions, generating wealth and workplaces and attracting tourists interested in wineries and local culture [6]. Additionally, quality wine has been shown to have numerous health benefits when consumed in moderation. These benefits include reducing the risk of heart disease, improving cognitive function, and promoting longevity [7].

Consequently, wine has a significant impact on both society and economies, playing a crucial role in many aspects of human life. Whether it is as a cultural icon, an economic driver, or a healthful drink, wine continues to play an important role in the future of society and the global economy [8].

The production of wine, a product with a rich cultural heritage that spans thousands of years, has been subject to numerous technological innovations in recent times [9–11].

Precisely, advances in technologies have opened up new opportunities for optimizing the wine supply chain, from the vineyard to the consumer [12]. The Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain Technology (BCT) are transforming the way that wine is produced, managed, and distributed, offering numerous benefits to all stakeholders in the wine industry [13,14]. This presents a unique opportunity to enhance the traditional methods of wine production with novel approaches, resulting in a more efficient and sustainable production process.

The implementation of IoT, AI, and BCT in the wine industry has the potential to revolutionize the entire supply chain, from the vineyard to the consumer. These technologies enable precise monitoring and control of the wine production process, from grape harvesting to wine aging, resulting in a more consistent and high-quality end product. Furthermore, the use of BCT provides a secure and transparent supply chain, ensuring that the authenticity and provenance of the wine can be traced from the vineyard to the consumer [15].

Indeed, food producers have expressed an interest in incorporating BCT with some aspects of information and communication technologies (ICTs), such as IoT devices, AI and others, to confront the complex challenge of food safety, traceability, quality, and control of internal processes in the agri-food production [16].

Additionally, the role of the integration of novel technologies in the agri-food supply chains is essential for achieving a sustainable industry where data availability and management are crucially important because they are a precondition for demonstrating product quality and characteristics to the stakeholders while ensuring safe food, tracking, and all of the product-related and institutional sustainability values [17–19].

Despite the prospective role of IoT-AI-BCT in the wine supply chain being evident, to the best of our knowledge, there is a lack of research focusing on safety, environmental and economic aspects of the wine industry, making a comprehensive review of the contribution of IoT-AI-BCT implementation to the sustainability of the wine supply chain. In order to make a constructive addition to the current body of knowledge, this study conducts a comprehensive literature review and develops a solid IoT-AI-BCT framework for sustainability in the wine supply chain.

2. Background Research

2.1. Wine Supply Chain

The wine supply chain encompasses a complex network of interconnected processes spanning from vineyard to consumers. It begins with grape cultivation and harvesting, followed by the winemaking process, including fermentation, aging, and bottling. After production, wines are distributed through various channels, such as wholesalers, retailers, and direct-to-consumer sales [20,21]. Throughout this journey, multiple stakeholders are involved, including grape growers, wineries, distributors, retailers, and consumers (Figure 1) [22]. Each stage of the supply chain presents unique challenges, including vineyard management, quality control, transportation logistics, and market dynamics [23,24].

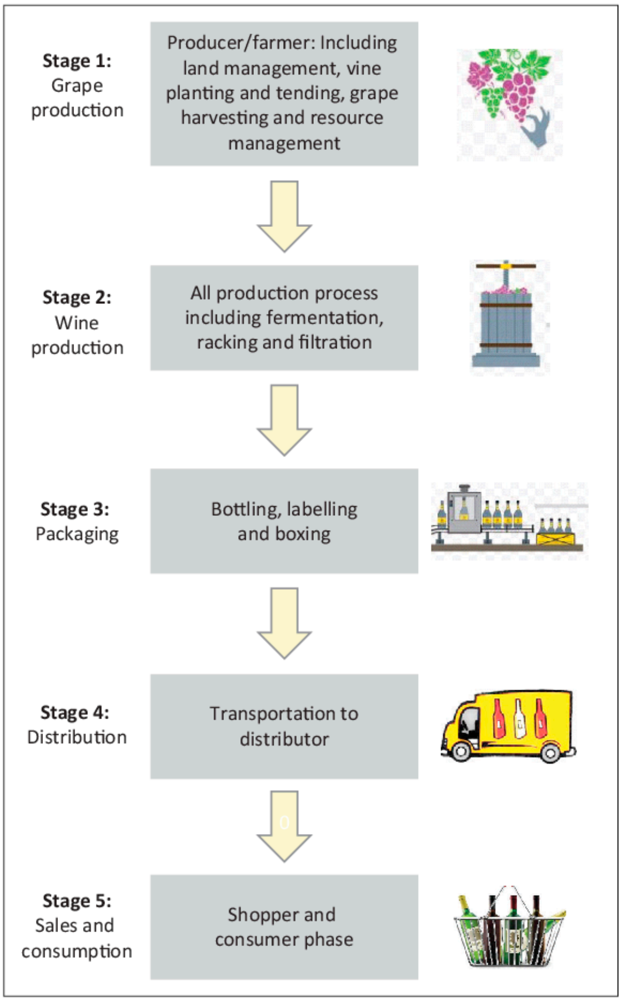

Figure 1. Wine Supply Chain. Source: [23,24].

Despite its rich tradition and cultural significance, the wine supply chain faces several challenges that can hinder its efficiency and sustainability [25]. Sustainability criteria for the wine industry emphasize the reduction of negative environmental consequences, such as water shortages, energy use and production waste, organic and inorganic waste, greenhouse gas emissions, land issues, and the usage of pesticides have all been related to detrimental environmental consequences [26,27]. Sustainability criteria also take into account the production of social value and a company's capacity to contribute to the development of an area in which it works. Consequently, they evaluate the enterprises' efforts to conserve the surrounding ecosystems and the cultural and viticultural heritage of the area [28].

One of the challenges is the lack of transparency and traceability, which makes it difficult to track the origin of grapes, monitor the production process, and verify the authenticity of the final product [29]. This opacity can lead to issues such as fraud, counterfeiting, and mislabeling, undermining consumer trust and confidence in the industry [30]. Additionally, the wine supply chain often suffers from inefficiencies related to inventory management, transportation logistics, and demand forecasting, resulting in higher costs and longer lead times [31,32]. According to Kunnapapdeelert and Pitchayadejanant [33], supply chain strategies addressed properly can improve collaboration between actors along this supply chain and, consequently, improve operational performance. Authors argue that suppliers' and consumers' integration, as well as internal integration, have a positive impact on the operational performance of the supply chain. Similarly, Kadlubek [34] asserts that supply chain strategy is essential for its optimized management, and in the circumstances of globalization, regionalization, constant technological development and changing needs and expectations of customers, there is a need for further evolution. Chopra and Meindl [35] and Canavari and collagues [36] also highlight the role of information technology utilization in advancing and monitoring the performance of modern supply chains.

Indeed, in the era of digitalization, there is an opportunity to address the identified challenges and improve the wine supply chain through the adoption of innovative technologies such as BCT, AI, and IoT. These technologies can enhance transparency, traceability, and efficiency by digitizing supply chain processes, enabling real-time monitoring and data sharing among stakeholders [37,38]. By leveraging digitalization, the wine industry can overcome traditional barriers, optimize operations, and deliver greater value to consumers while ensuring the sustainability and integrity of the supply chain [39].

2.2. IoT, AI, and BCT in the Wine Industry

2.2.1. IoT in the Wine Supply Chain

IoT is a network of interconnected items that communicate and share data with each other [40]. The IoT is quickly integrating with a vast array of technologies, including Cloud Technology, Machine Learning (ML), Data Analysis, and Modeling. Rapid growth in IoT has a favorable impact on the IT sector as a whole, fostering its expansion. IoT facilitates the development of fresh commercial strategies; one of its fundamental characteristics is the enhancement of data, which will impact the growth of the ICT sector [41].

If the wine business used modern technologies that enable traceability, customers would be able to check and verify each stage of the process, from the cultivation of vines to the disposal of wine bottles and packaging [15]. Barcodes, Quick Response (QR) codes, and Radio-Frequency IDentification (RFID) tags are a few of the supply chain monitoring technologies that have arisen with the growth of IoT technology [42]. Barcodes use a series of parallel gaps and bars to represent 10 digits. This information may be read by an optical device and sent to a system for storage and processing. QR codes are extensively used in traceable labels because of their capacity to hold more information than typical one-dimensional barcodes [43]. RFID is comparable to barcoding in that a device reads information from a tag or label and stores it in a database, but it has significant benefits over barcode asset monitoring software [44]. Information contained in RFID tags may be read from a distance, unlike barcodes, which need physical alignment with a scanner. Moreover, its storage capacity (about 32–128 Bit) is greater than that of previous systems, and it can be continuously updated to provide the highest level of security [45].

Specifically, Li and colleagues [46] describe an IoT platform that enables product tracing and monitoring, which provides crucially useful services for the surveillance of the prepackaged food supply chain and, therefore, the adoption of suitable and informed decisions. In a similar spirit, Pal and Kant [47], in their work, provide the technical requirements for integrating a sensing and communication platform based on the IoT into a food distribution network, including a consideration of the data that must be obtained and the most efficient means for gathering it. Jabbari and Kaminsky [48] review the design of BC systems and their impact on the food supply chain. Several benefits are highlighted, including the preservation of trust between the user and the system, the removal of the need for a third party to maintain trust, and the ability to trace the origin of individual components. The most challenging and outstanding concern is the ease with which RFID tags and sensors may be replicated and manipulated.

According to Montecchi and colleagues [49], a BCT-based food distribution system might be used to identify the provenance of each sold item. This may help level the playing field between businesses and customers by giving consumers access to the same product information as enterprises. Compared to Luvisi and colleagues [50] and Kamilaris and colleagues [51], investigate the impact of the BCT-based food supply chain on the agriculture market. Despite the extensive regulation of wine supply chain activities, wine fraud is prevalent (by both European and national legislation). It has been observed that there is a lack of technological solutions in the research literature that attempt to promote supply chain transparency and efficiency in the wine business. Enterprises that have traditionally played significant roles at different points along the wine distribution are less likely to use electronic traceability systems [52], while larger companies are more likely to do so. It is essential that technological advances be made in the field of traceability, with the aim of proving the origins and authenticity of wines to protect wine consumers and producers [53].

2.2.2. AI in the Wine Supply Chain

AI tools, such as ML algorithms, are increasingly integrated into the various stages of the wine supply chain described in Section 2.1 [54].

In the *grape preproduction stage*, farmers utilize ML algorithms to predict crop yield, assess soil conditions, and optimize irrigation strategies [55]. This predictive capability aids in disease identification and weather anticipation, which is crucial for enhancing agricultural productivity [56].

During the *wine production stage*, ML algorithms facilitate production planning in order to ensure a high-quality wine output. Predictive algorithms help optimize fermentation processes, monitor grape ripeness, and manage fermentation temperatures to maintain wine quality and consistency [57,58].

At the *packaging stage*, AI algorithms and the presence of robots assist in optimizing packaging processes for efficiency and sustainability. Predictive maintenance models help minimize downtime by identifying potential equipment failures before they occur, ensuring uninterrupted packaging operations [59].

In the *distribution stage*, retailers and distributors leverage AI for tasks such as inventory management, shipping optimization, and customer profiling. Predictive analytics algorithms forecast demand patterns, enabling retailers to stock the right products in the right quantities at the right locations, reducing inventory costs and minimizing stock-outs [60]. In addition, including AI tools, such as decision support systems in the business processes, considerably reduces the risk of inefficient output, especially in terms of sustainable practices [61].

Throughout the supply chain (*sale and consumption stage*), AI-powered recommendation systems enhance customer experiences by providing personalized product recommendations based on individual preferences and purchase histories. Natural language processing (NLP) algorithms analyze customer feedback and sentiment to identify emerging trends and preferences, enabling wineries to adapt their product offerings and marketing strategies accordingly [62].

By integrating AI technology across these stages, the wine industry can optimize processes, improve product quality, and enhance customer satisfaction while promoting sustainability and efficiency throughout the supply chain [54].

2.2.3. BCT in the Wine Supply Chain

Sustainability issues are pressuring and encouraging the agriculture sector within the worldwide economic system to evolve towards greater sustainability [63]. Consequently, the past decade has seen rapid growth in the promotion of intelligent systems and the discovery of novel solutions across all sectors [64,65].

BCT is considered to be a game-changer in several economic areas. BCT is a distributed, decentralized system comprised of blocks that are linked by cryptographic hashes and timestamps. As a preventive approach to safeguard data integrity across the supply chain, it has been widely used [66]. Consequently, no party in the supply chain may alter the existing information as a result of BCT's assistance in creating trust mechanisms to address transparency and security issues [67]. In the field of agricultural research, BCT offers great potential. Low-quality supplies result in low-quality plants, and it may have a detrimental influence on farmers' revenue and costs [68]. BCT's ability of transparency enables both small and large farms to make informed decisions and access high-quality commodities [69]. Through BCT, users can verify whether seed suppliers have delivered inferior seeds.

Additionally, BCT is applied in the agricultural industry to optimize supply chain operations, enhance traceability, increase food safety, and reduce transaction times, costs, food fraud, and inefficient processes. In addition to increasing farmers' earnings, BCT has the ability to further the cause of ethical businesses by exposing their support to issues such as fair trade, animal welfare, and pollution avoidance [70,71]. Applying the BCT enhances the ability to track and monitor the meal throughout all of its stages [72]. It may lessen the need for excessive pesticide and fertilizer use, which may lead to harmful residue build-up in humans [73]. The adoption of BCT specifically promotes sustainable agriculture [74,75]. Given that consumers put a high value on understanding the origin of their agri-foods and that this technology may be used to fight product counterfeiting and forging, BCT has the potential to play a significant role and find broad use [39]. Indeed, BCT permits the detection and containment of hazardous goods, as well as the monitoring of their journey through the supply chain by suppliers, farmers, manufacturers, merchants, and government agencies.

Particularly, the aforementioned characteristics of BCT enable a far quicker recall in the event that a potentially hazardous product shows up in retailers. Consequently, it mitigates supply chain inefficiencies that may otherwise result in disastrous consequences [76,77]. Accurately detecting dangerous goods in a timely way promotes product recalls before they spread to consumers and only to those who are affected, thus lowering health risks, financial losses, and reputational damage [78,79].

2.2.4. IoT, AI, and BCT Integration in the Wine Supply Chain

Among the numerous potential advantages of merging IoT, AI, and BCT are an increase in system efficiency, information transparency, environmentally intelligent farming, and logistics. In conjunction with IoT sensors and AI, BCT may give a more comprehensive and relevant image of the agriculture economy [80]. Precisely, utilizing IoT, the product or service will have full connection to all required materials and components throughout the whole manufacturing process because these sensors transmit their data to the BCT.

Connecting devices and sensors is another advantage of the IoT, and using IoT in conjunction with BCT has been demonstrated to be an effective strategy that saves both time and money while creating vast quantities of data. Manufacturers may utilize cutting-edge deep learning (ADL) algorithms to examine this data in order to make wiser decisions [81]. Sadly, only a small percentage of food and beverage sector firms are now using the IoT and smart manufacturing processes. BCT-enabled IoT systems may be enhanced using methods of deep reinforcement learning [82].

Combining IoT with BCT ensures supply chain transparency and traceability. Precisely, by linking IoT devices to smart contracts based on BCT, the supply chain can keep track of where products are, how many are in stock, and who owns what at all times. With this knowledge, companies may be better prepared for any kind of disaster. In addition, the usage of smart contracts allows companies and customers to verify the legitimacy of food products by tracing their origins [83].

In 2018, AgriBlockIoT solution has been presented, which used IoT and BCT through Ethereum and Hyperledger Sawtooth to create a food traceability system. The agri-food tracking system [84] might benefit from AgriBlockIoT's fault tolerance, immutability, auditability, and openness of data.

2.2.5. Some Practical Applications

In recent years, the wine industry has witnessed a surge in the adoption of AI, IoT, and BCT to optimize various aspects of the supply chain.

IBM is recognized as a leading provider of enterprise BCT [85]. The IBM Blockchain platform, open and cloud-based, offers end-to-end capabilities that enable businesses to rapidly activate, develop, manage, and successfully secure their enterprise networks. On IBM Blockchain Transparent Supply, VinAssure™ is developed, and it runs on IBM Cloud to leverage advanced technologies such as blockchain, AI, and cloud to optimize the entire supply chain with benefits for all stakeholders involved. VinAssure™ connects wine producers, sellers, importers, transporters, distributors, restaurants, and retailers, contributing to increased traceability, efficiency, and profitability, facilitated by the ability to efficiently and securely share data [86]. The first brand to join VinAssure™ is De Maison Selections, a US importer of responsibly sourced wines, cider, and spirits from independent Spanish and French producers. VinAssure™ has also been adopted by other leading wine brands, such as Ste. Michelle Wine Estates, Export Division, the third-largest premium wine company in the United States by size, and Maison Sichel, a Bordeaux winemaker and merchant for seven generations. These three companies collectively produce millions of wine bottles distributed worldwide. The companies highlighted the benefit of adopting technology related to transparency, storytelling, and communication with consumers [87].

EY (Ernst & Young) collaborated with various wine producers to develop blockchain solutions aimed at improving supply chain transparency and combating wine fraud. Their blockchain platform allows consumers to trace the journey of wine from vineyard to bottle, ensuring authenticity and quality assurance. Antient Italian Winery Placido Volpone developed a solution in 2017 in collaboration with EY Italy for tracing the wine supply chain, enabling the self-certification of the entire production process. The system offers a virtual KM-zero, establishing a digital connection between the producer and the end consumer. Through a smart label on the wine bottle, consumers can access information about the entire production and transformation process of the wine. Blockchain ensures the immutability of the data. This solution helped to winery in strengthening consumers' trust and brand loyalty [30].

Wineries Rucci Curbastro, Ruffino, and Torrevento utilize the My Story platform by DNV GL to trace their wine bottles from the vineyard to the certification entity. Among the active producers are Ricci Curbastro from Franciacorta, Ruffino from Tuscany, and Torrevento from Puglia. The technology involves scanning a QR code on the label, allowing consumers to access the wine's history and specific information verified by DNV GL regarding its characteristics and production processes. Wineries declare increased brand visibility after this intervention [88].

On the other hand, Robert Mondavi, one of the largest brands in the luxury alcohol industry joining the BCT, plans to sell its unique, limited-edition bottles of wine through cryptocurrencies with an estimated price of USD 3,500 [89]. Meanwhile, Chateau Angélus sold one barrel, thus 300 bottles of wine with BC-certified ownership for USD 110,000 with 'stablecoin' cryptocurrency [90]. One of Napa Valley's pioneering wineries, Trefethen Family Vineyards, created traceable wine (cabernet sauvignon Trefethen) through BCT with an added artist label dedicated to wine collationers. The winery sold nine items in one week for around USD 700 per each, which is 10 times more expensive than the regularly issued same wine [91].

3. Methodology

A systematic literature review (SLR) was selected to investigate and evaluate the available literature on the use of IoT, AI, and BCT in the winery supply chain for the purpose of optimizing operations. The proposed methodology uses a scientific, transparent, and demonstrable protocol to search and critically analyze the current publications [92,93] and reduces bias in the identification, selection, evaluation, and synthesis of the existing research body when compared with traditional narrative reviews [94–96]. In addition, Christofi and colleagues [97], as well as Rana and co-authors [98], stressed the significance of SLR, indicating that it is a useful method for summarizing the key findings of vast and complex research subjects, bridging present gaps, and identifying unexplored areas for future research [99–101].

Masi and colleagues [102] and Moher and co-authors [103] employed a five-step method to investigate the available literature extensively. This method was used to study the literature (Figure 2).

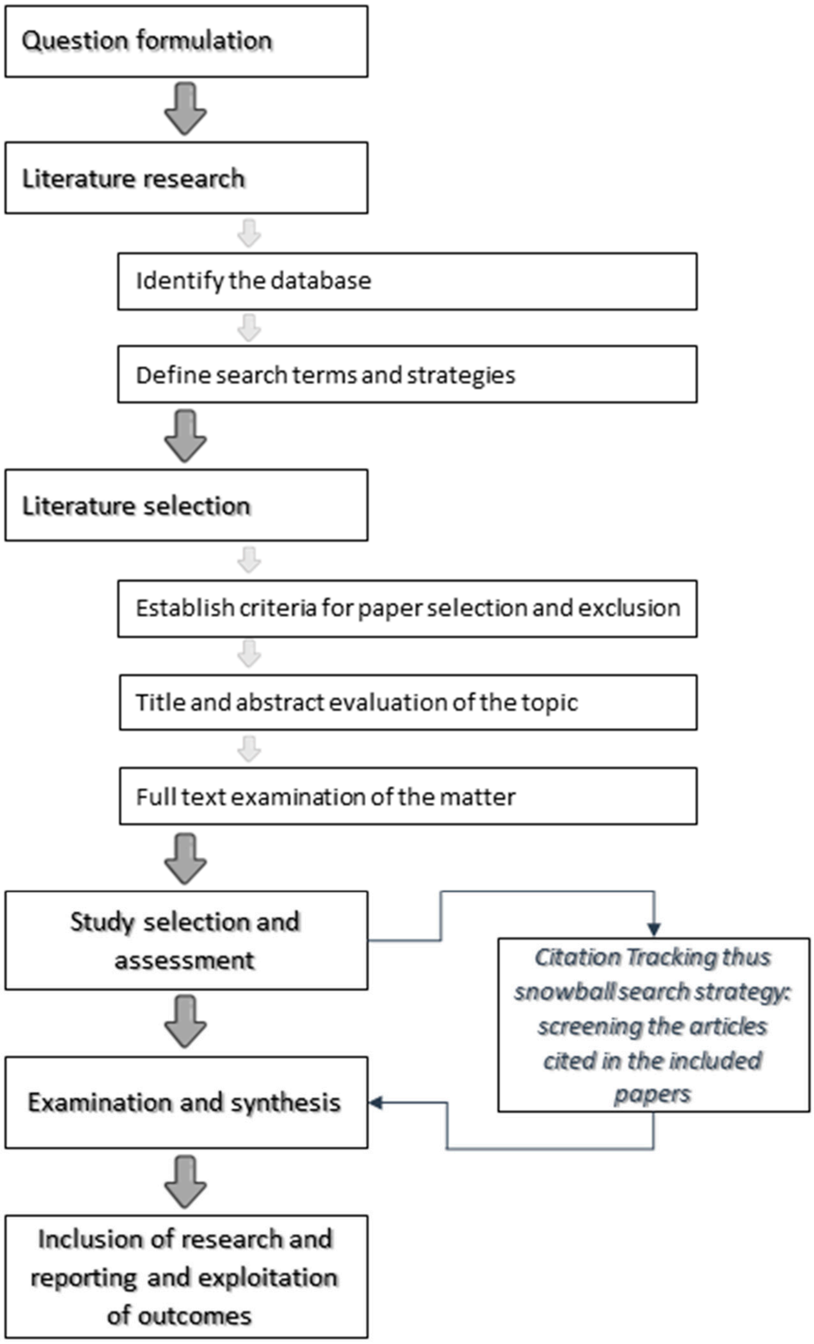

Figure 2. Graphical representation of literature investigation methodology. Source: Own elaboration based on the works of Masi et al. [102] and Moher et al. [103].

Establishing a research question that will serve as the foundation for the organizing of search words is the first step in topic development [104]. In this respect, the topic of the study was identified by an early and exploratory literature review [94], and the research question was then established and clarified [105]. The chosen words were included in the construction of the query string. Particularly, the literature revealed that terms such as "IoT", "AI(ML)", "BCT", and "Wine" were associated with IoT-BCT in agriculture (wine case study), whereas "safety" and "sustainability" were frequently used in studies examining the use of IoT-BCT in the wine industry and agriculture in general. This resulted in the formulation of the following research questions: How can IoT, AI, and BCT be used to guarantee the safety of the winemaking process? How might IoT, AI, and BCT be used to achieve environmental sustainability in the wine supply chain? How may BCT help the wine industry become commercially viable?

In the second step, identification of the material, we limited our search for relevant works in this research topic to the database with the highest coverage of the examined subjects, Google Scholar. This database was chosen because it allows simple access to many high-quality studies published in reputable journals [94,106]. This is also a typical method for various sorts of systematic reviews [107].

The following criteria were established to reduce the search for suitable publications:

1. All selected papers were written in English;
2. The filter 'TITLE-ABS-KEY' (scanning in titles, abstracts, and keywords) was applied in the Google Scholar database;
3. The search was not restricted to a specific timeframe (even though it was expected to uncover papers from 2008, the year BCT was created);
4. The sources of data chosen were only academic journal papers [94];
5. Using Boolean operators, we then selected a list of keywords to include in the search query (specifically, AND to reduce the number of papers retrieved and OR to increase it).

We analyzed the search string along three key dimensions to get the most comprehensive relevant results [106,108], focusing on specific aspects of the search problem. With an initial application of a broad term such as "IoT-BCT" in the wine industry, we uncovered a substantial amount of generic academic papers in the selected database (a total of 2730 pieces). This was the search term: ((IoT-BCT) AND (wine OR AI(ML)) OR Sustainability.

In total, 482 Google Scholar papers were obtained and analyzed based on predefined inclusion and exclusion criteria. Reading the titles and abstracts of the scientific papers relevant to the topic of the review was the third step in the screening process [96]. Specifically, Google Scholar results were examined for duplication elimination.

Subsequently, only papers with substantial contributions to the problem at hand were examined. A second-round screening was conducted on empirical work in which the 'Research focus' was not indicated in the title or abstract to avoid discarding essential publications in the field [92]. Therefore, 120 research articles were selected in total.

The fourth step, "Analysis and synthesis", was the examination of the full-text articles for eligibility. In addition, a full-text analysis was conducted to further assess the relevance of these articles to the study's objectives. Specifically, several publications were discarded because of the following:

a. They did not integrate IoT into BCT;
b. They did not include AI(ML) in IoT-BCT models;
c. The issues of safety, economic, and environmental sustainability were not discussed in the IoT-BCT architecture;
d. None of them are associated with the wine industry.

In this study, 29 studies have been included for this purpose. In addition, snowball searching strategies were used by reviewing the reference lists of the selected articles to locate more relevant articles and to validate that a substantial percentage of the primary literature had been captured by the selection procedure [109]. A total of 5 more papers were discovered as a result of these extra studies, increasing the total number of works to be examined to 34. Each article's descriptive and thematic contents were appraised [99,110,111]. It was essential to establish structural dimensions and the corresponding analytical groups in order to classify, encode, and then retrieve the final data using a spreadsheet [111].

4. Results and Discussion

4.1. The Increase of Wine Safety under IoT, AI, and BCT

Traceability throughout the supply chain is essential for ensuring the products' safety [112]. However, the wine supply chain includes several stakeholders, some of whom are geographically distant from one another (such as the growers, processors, and retailers that stock the final goods). Due to the incompatibility of software and data structures, it is impossible to develop a unified monitoring system for information. As a result, every company involved in the wine supply chain has its own data recording system. Lin and colleagues [112] envisioned an ecosystem based on BCT and IoT for smart agriculture. According to the authors, everyone participating in the system may use their smartphones to submit information, and the system will automatically collect data from IoT devices without human intervention.

The information saved through the BC network cannot be changed without the approval of all involved parties [113]. A reliable system is created using this strategy that protects its users from scammers and prevents fraud before it occurs. In a dependable system, high availability (to authorized users) and service integrity must be assured [114]. Price increases, for instance, are difficult to execute without first having a discussion about pricing and locating a skilled team of software engineers that charge reasonable rates and have a diverse portfolio that includes agriculture-related experience. For example, the company must be able to provide a high-quality product that fulfills all market requirements, including a comprehensive set of data records [115].

ICT provides a number of potential benefits for food safety, such as concurrent monitoring of agri-food products throughout distribution and storage [116], RFID tagging, GPS, and QR code-like electronic labeling that is easy to synchronize with the cloud, and better traceability due to BCT [73,117]. Incorporating AI-based Big Data Analysis (BDA) as a rapid reaction towards food safety outbreaks enables BCT and the IoT to interact synergistically for the improving of the food surveillance framework [118,119]. It is anticipated that the IoT will aid in the development of comprehensive research methods in food handling, in which key drivers such as environmental issues, human behavior, and the economic system can be integrated to foresee food safety hazards, and BCT will improve the security and privacy of data [67,82–84].

By making the whole food production process more open and available to consumers, BCT enables direct consumer-to-producer connection [119,120]. It increases consumer confidence and trust in food safety by lowering obstacles to commodity movement [30]. From the perspective of regulatory agencies, BCT enables the efficient and effective application of legislation based on accurate and trustworthy data [121]. Moreover, BCT's compatibility with regulations, such as geographical indications (GI) and protected designation of origin (PDO), further enhances its value in the wine industry [122]. By facilitating compliance with regulatory requirements and standards, BCT not only safeguards wine safety but also strengthens the integrity of the supply chain, fostering consumer trust and brand reputation [123].

In Table 1, several findings are synthesized from the analyzed literature regarding the integration of IoT, AI, and BCT, and their impact on safety within the wine supply chain.

Table 1. Safety guaranteed in the wine supply chain under IoT, AI, and BTC.

Concept	To describe the safety achieved by means of applied technologies in the wine supply chain.
Tech.	Intervention
BCT	1. The BCT is used to trace the origin and history of wine bottles. This enables complete transparency and accountability throughout the whole winemaking and distribution process. Using this approach, concerns with product or food safety, such as contamination or recalls, are also identified [38,39,49,67,71,73,74,84,117,124]. 2. BCT is used to generate digital wine authenticity certificates that are used to verify the provenance and legitimacy of a bottle of wine. In addition to reducing the likelihood of falsification and fraud, this offers purchasers more certainty about the quality and authenticity of the wines they purchase [15,30,49,121,122]. 3. In terms of logistics and supply chain management, BCT is used to maintain an electronic record of wine bottles and other goods as they are carried from A to B. The wine's quality may be affected if, for instance, the temperature varies during delivery, although this is detectable [125]. 4. Blockchain is used to record and keep immutable information on the ingredients and storage temperatures of wine, all of which may impact the safety of the final product [121].

Table 1. *Cont.*

Concept	To describe the safety achieved by means of applied technologies in the wine supply chain.
Tech.	Intervention
BCT	5. The use of BCT increases consumer trust and confidence in wine safety due to direct interaction between producers and consumers [30,49,119,123]. 6. BCT makes reliable and accurate information available to regulatory agencies and helps them carry out informed and efficient regulations [121,122].
IoT	1. IoT-enabled sensors monitor the wine's temperature throughout its entire lifespan. This helps to preserve the wine's quality and safety throughout storage and transport [46,49]. 2. IoT-enabled sensors are used to monitor wine quality during the manufacturing and storage processes, allowing winemakers to make adjustments in real-time that improve product integrity [46,47,49]. 3. IoT-enabled devices are used to track inventory in wineries and warehouses, simplifying the safe storage and shipment of wine bottles [112]. 4. Information on food safety, such as ingredients and storage temperatures, is kept and transmitted using IoT-enabled devices [38,44,117]. 5. The data recorded by IoT-enabled devices is used to design valuable and high-quality products [38,44,117]. 6. Data records by IoT-enabled devices are useful in disease and outbreak deterrence and risk evaluation, which empowers food safety conclusions and supports decision-making [47].
AI	1. The quality of the wine is monitored and managed at every step of production using AI-enabled technologies by analyzing data from IoT devices [55,126,127]. 2. AI-enabled systems analyze the data from IoT sensors in vineyards to predict when equipment will need maintenance, therefore lowering the probability of unanticipated malfunctions and accidents [56,124]. 3. AI-enabled systems analyze the data to ensure that the whole production and logistics chain adheres to all relevant safety and regulations [57,126,127]. 4. AI-enabled technology is also used to improve the quality of the final product by predicting the wine's quality using historical data obtained during production [57,124]. 5. In order to ensure the safety of the final product, AI-enabled systems analyze the data on materials and storage temperatures [59,126,127]. 6. Based on the forecasts from the ML, the macro-control for the production, processing and handling of wine products can be effectively performed [124]. 7. AI reduces the time spent on manual labor, freeing employees to make more valuable contributions to a business [59].

4.2. The Impact of IoT, AI, and BCT on the Environmental Sustainability of the Wine Supply Chain

Established in 1987, the United Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the capacity of future generations to meet their own needs". According to the International Organization for Vine and Wine [128], sustainable viticulture is an "international policy on the level of the wine processing and production processes, integrating at the same time the financial viability of frameworks and regions, generating quality goods, considering prerequisites of precision in sustainable vineyards, risks to the environment, product safety, and consumer health, and appreciating of heritage, historical, social, cultural, and environmental facets". According to Gilinski and colleagues [129], leaving the land in better condition than the present one for future generations is a top priority for individuals in the wine industry. Access to more information about wine production through the IoT-BCT enables health-conscious and ecologically conscientious customers to put a greater value on their wine purchases [39].

With a thorough understanding of how to integrate sustainability into a company's operations while minimizing the costs associated with adopting sustainability certification requirements, such as data collection and management techniques, the majority of obstacles related to sustainability compliance can be overcome. In this regard, BCT offers potential as a way of enhancing ecosystem development in relation to concerns of transparency, food safety, and provenance in agri-food chains [130]. In addition, BCT has shown potential for enhanced management of global supply chains in terms of transparency, traceability, and security, all of which are reflected in a rise in efficiency [125,131].

BCT can simplify supply chain - wide data collecting, storage, and certification [132]. In pursuit of increased environmental responsibility, the efficient management of data is a significant topic. Every day, a vast amount of information is generated in the food industry, and recognizing methods to extract vital information from diverse sources will aid in bacterial risk assessment [120], outbreak prevention, and identification of trends through pathogen monitoring [73], which strengthens food safety inferences and facilitates decisions. In fact, the lack of a defined approach for data collection throughout the whole manufacturing process and storage is one of the greatest obstacles to ecological sustainability in business. The assessment of a product's carbon footprint, for instance, requires a cradle-to-grave understanding of the product's sourcing, processing practices, and logistics across the supply chain, necessitating a concerted effort and, consequently, the assertive contribution of the various actors along the supply chain [133]. BCT has shown great potential as a solution to this issue because it is a technology that can monitor and map the whole supply chain in a unified, secure, transparent, and time-efficient way [134].

Overall, this tracking has shown promise in terms of assuring ethical sourcing and monitoring ecological responsibility [135], streamlining the green supply chains [136], and ensuring social sustainability [137]. In Table 2, evidence is summarized from the analyzed literature regarding the integration of IoT, AI, and BCT, focusing on their role in environmental protection and management within the wine supply chain.

Table 2. Environmental sustainability guaranteed in the wine supply chain under IoT, AI, and BCT.

Concept	To describe the environmental protection and/or management within the wine supply chain by the intervention of used technologies.
Tech.	Intervention
BCT	1. BCT is used to trace the origin and history of wine bottles which enables transparency and accountability in the wine supply chain that contributes to the implementation of environmentally friendly methods [13,14,39,75,125,138,139]. 2. By tracking wine bottles and other materials across the production and transportation, BCT-enabled supply chain management is used to improve logistics and lower the wine industry's carbon emission [39,125]. 3. The origin and validity of a bottle of wine may be validated by the use of BCT-based digital authenticity certificates. As a result, the wine supply chain will be sustainable and enhance responsible ecological wine production [14,15,135,136]. 4. BCT is used to record and verify organic and sustainable winemaking credentials [135,136]. 5. A traceability system, with the combination of BCT and IoT, permits the conducting of hazard analysis, which leads to environmental protection [38,136].
IoT	1. Vineyards are monitored using IoT-enabled devices to gather data on soil conditions, weather conditions, and inputs application and uptake. Using this data, farmers regulate inputs more accurately [47,49]. 2. IoT-enabled devices monitor and control grapes' power use. It is feasible, for instance, to save energy expenditures by monitoring and regulating wine production tank temperatures using sensors [46,47]. 3. In vineyards, IoT-enabled sensors detect the humidity of the soil, allowing more accurate irrigation system management and reduced water waste [46,47]. 4. Data availability via the IoT-BCT increases transparency and enables the increase of environmental protection/management initiatives [112,117]. 5. IoT devices ensure ethical sourcing and monitoring of the environmental supply chain, reducing barriers and complexity to the green supply chain and social sustainability [44].
AI	1. With the use of AI-based algorithms, it is possible to predict the optimal harvest time depending on factors such as weather and vine growth. Therefore, the vineyard may become more efficient and produce less food waste [124]. 2. AI may contribute to winery management by increasing efficiency and reducing waste throughout the winemaking process. This can be done by monitoring temperature and acidity throughout fermentation, allowing winemakers to make immediate adjustments to the process for optimal quality control [57,127]. 3. AI might help wineries become more eco-friendly by identifying which production processes and supply networks use the least amount of energy [126]. 4. AI is used to predict the quality of a wine before it is bottled, allowing winemakers to make adjustments and reduce waste [55,124].

4.3. The Benefits of BCT on the Local Economy of the Wine Industry

The agriculture industry is considering BCT due to its capacity to enable near-instantaneous payments and automate compliance via smart contracts, as well as enhance security, transparency, transaction speed, and operational expenditures [38]. Due to its de-intermediating, transparent, and listening characteristics, BCT has the ability to cut transaction costs, improve the efficiency of existing value networks, challenge revenue models, and establish new markets [117,140].

BCT has the potential to continue enhancing financial planning, source, traceability, and transparency in food sources, as well as facilitate the establishment of new products and markets for agricultural production in low-income countries [51,69].

While the agri-food industry is vital to national economies, it confronts various issues that diminish its export competitiveness, such as post-harvest losses of fruits and vegetables at the farm gate, storage facilities, retail and wholesale markets and a lack of a direct sales channel [141]. Herewith, in the agri-food industry, there is no certainty of market fairness due to the asymmetry of market data. Mao and colleagues [138] designed an alliance chain-based food trade system to solve these challenges. The authors exploited consortium BCT to design a unique architecture that aids in protecting the integrity of financial transactions. Their BCT allows mobile banking for farmers and substantially reduces transaction fees. The agricultural and food sectors would considerably benefit from the administration of supply chain activities and finances in real-time. Using BCT, farmers can be assured a fair price for their commodities, while merchants can confirm they have received what they paid for [114].

Small business ownership is plagued with obstacles. It might take between one and two years to locate a consistent stream of customers and create a company. Initial Coin Offering (ICO) is a kind of financing similar to crowdsourcing that employs crypto money instead of regular payments; it may aid small farm owners in finding investors and expanding their business [142]. Due to initial coin offerings (ICOs), startups do not need to spend additional money on legal expenses or hire a lawyer to make their ideas a reality; all they need to do is persuade people to participate in the company [143].

In order to speed up the ordering, delivery, and payment of food, companies may use smart contracts, which are network-accessible bits of code developed by software experts. When the commodities are ready, transactions may be performed instantaneously, sparing farmers the inconvenience of waiting months or even years for their cash to be returned. In addition, middlemen are unnecessary. Therefore, both farmers and their clients may feel certain that their agreements will be respected [140]. The BCT is also included on trade platforms. Stock markets may now profit from BCT while doing business as normal. It can be seen how easily farmers may swap future contracts at predetermined prices for crops, livestock, fruits, vegetables, and other agricultural products using the wine supply chain as an example. Farmers and consumers will have a solid understanding of production costs as a result [51].

Bitcoin and other digital currencies often refer to BCT. Due to this, according to Vishakha and colleagues [144], farmers may use PavoCoin, a cryptocurrency designed in a similar fashion to Bitcoin but with characteristics targeted to their requirements. It is the most secure method of online payment and is universally accepted. In addition to increasing transparency, the money may be used to accelerate and simplify transactions with clients [144].

In Table 3, summarized evidence from the analyzed literature pertaining to the integration of IoT, AI, and BCT, and its impact on economic performance, is presented.

Table 3. Economic sustainability guaranteed in the wine supply chain under IoT, AI, and BCT.

Concept	To describe the economic performance achieved by applied technologies in the wine supply chain.
Tech.	Intervention
BCT	1. BCT decreases transaction fees, and actors receive fair payments for their products. Wine supply chain actors, mainly farmers, can make mobile payments and credits. 2. Financing is enhanced in the wine supply chain due to transparency and trust brought by using BCT. Small farm owners are able to find investors and improve their business via BCT. 3. Transparency and traceability systems help wine suppliers achieve a better reputation, which, in return, generates income through increased customers [30,79]. 4. Transactions/payments are performed immediately once the products are available. No delay or waste of time by waiting for the payments to be returned. 5. BCT is represented on exchanges and stock markets. Actors are able to benefit from access to stock markets and exchange services. 6. Chain actors are easily trading upcoming contracts at fixed prices for wine. As a result, they will know their cost, and customers will not be surprised by price changes. 7. The ability to track the origin and history of wine bottles allows for total accountability and transparency throughout the whole winemaking and distribution process. There is a correlation between this and an increase in sales and income since consumers' trust and loyalty to the brand will improve. 8. Using BCT to construct smart contracts that automate monetary transactions and payments between parties may simplify and enhance the wine supply chain's financing. This ultimately results in improved profits and lower expenses for all concerned parties. 9. BCT enables direct-to-consumer sales via the development of digital marketplaces where buyers and sellers interact without the need for middlemen, therefore saving money. 10. Using BCT to record and verify credentials for ecologically friendly and organic wine production enhances the wine's value and marketability.
IoT	1. The recorded data by the IoT-enabled devices are used in the planning of the supply chain and permit the best handling of the wine, therefore increasing the price tag of the wine [112,117]. 2. IoT-enabled devices help farmers incur necessary costs by having all records of the chain on file [112,117]. 3. Operating IoT sensors to measure and regulate the flow of water, energy, and fertilizers is one approach to saving money in the vineyard [46,47]. 4. IoT-enabled devices automate vineyard processes like wine fermentation to increase production and reduce costs [112,117]. 5. IoT-enabled devices are used to monitor vineyard and warehouse inventories, therefore enhancing efficiency and reducing needless stockouts and surpluses [46].
AI	1. AI maintains available products for retailers in a cost-effective way while the stock of retailers can well satisfy the demands of consumers [62,124]. 2. To increase production and profitability, AI is used to analyze data from IoT devices in the wine supply chain in order to anticipate future yields and identify the most efficient use of existing resources [55,124]. 3. Quality control is performed by an AI-enabled system that analyzes Iot devices' data in real-time to detect and anticipate quality issues like spoilage or contamination. In addition to raising sales and profitability, this helps ensure that buyers obtain only safe and high-quality wine [56,124]. 4. AI-enabled devices are used to anticipate when vineyard machinery and equipment may need service, therefore preventing expensive failures [124]. 5. AI is used to analyze customer data and predict consumer demand, hence enhancing marketing and sales strategies and boosting profitability [60,62,124]. 6. The automation of routine operations and enhanced decision-making are two ways in which AI increases winery output and reduces expenses [56,60,83].

4.4. Challenges in Integration of IoT, AI, and BCT in the Wine Industry

Integrating IoT, AI, and BCT in the wine supply chain presents numerous opportunities, but it is not without its challenges [67,72]. While both BCT and AI offer significant benefits, their implementation requires specialized knowledge and expertise, making them less accessible to smaller and medium-sized enterprises. The lack of educational materials and awareness about BCT further complicates its adoption, particularly among stakeholders who may not fully understand its potential. Moreover, skepticism surrounding cryptocurrencies, often associated with BCT, has led to regulatory hurdles and outright prohibitions in certain jurisdictions, hindering its widespread use in the food industry [143].

Legal and regulatory frameworks also pose challenges to the installation and operation of BCT and AI systems in the wine supply chain [84]. Government intervention is necessary to establish guidelines and standards for the use of these technologies, ensuring compliance with industry regulations and data protection laws [73,116]. Additionally, issues related to data sharing and privacy must be addressed to foster trust and cooperation among stakeholders in the supply chain. Farm owners may be hesitant to share sensitive information on a public network, highlighting the need for secure and transparent data-sharing protocols [84].

Overcoming these challenges requires collaborative efforts from industry stakeholders, government bodies, and technology developers [145]. Educational initiatives can help bridge the knowledge gap and promote understanding of BCT and AI among wine producers and distributors. Regulatory reforms should aim to facilitate innovation while safeguarding consumer interests and data privacy. By addressing these challenges, the wine industry can harness the full potential of BCT and AI to enhance transparency, efficiency, and sustainability across the supply chain.

4.5. Proposed Framework

The analysis of massive volumes of data may be used in the whole supply chain to enhance decision-making at each level. Due to the widespread use of networked devices such as trucks, RFID, smartphones, cameras, and sensor networks, large amounts of data are produced. BDA and ML techniques may assist firms in acquiring the proper approach, skills, and tools to become data powerhouses [146]. Moreover, BDA may help in the development of novel techniques for enhancing supply chain decision-making processes, from frontline operations to policy decisions, such as the selection of an acceptable supply chain operating model [126]. The ML-based decision-support system may be used both at the edges and on the data servers to assess the collected data [124,127]. Using BDA and cutting-edge prediction algorithms that take into account elements such as climate, special events, and changing marketing trends, supply chain companies may be able to better anticipate client demands.

To establish an inclusive agricultural and food supply chain, BCT must include cooperating networks [139], social ownership of resources, democratic governance, and a decentralized digital tech platform [125,147].

Chen and colleagues [148] designed a BCT-based architecture to ensure agro-based safety with product tracking in ASC systems, with proof-of-work (PoW) employed to secure global consensus and the integrity of accurate, unique, and unforgeable tracing data.

In light of these efforts, we created an IoT-AI(ML)-BCT framework to assure the safety and sustainability of the wine supply chain from the standpoint of all stakeholders involved (Figure 3). The proposed framework is instrumental to openness and assist chain actors in decision-making. The transparency and accountability assured by our framework are the key aspects that make the wine supply chain ecologically responsible and facilitate chain actors to incur necessary costs.

The proposed IoT-AI(ML)-BCT framework integrates IoT, AI, and BCT to revolutionize the wine industry's logistics and quality control processes. It considers that all actors of the supply chain are part of the system: Grape producers use ML algorithms to predict crop yields, monitor soil conditions, and forecast weather patterns, aiding vineyard management and optimizing production; wineries use IoT devices for tracking wine barrels throughout the supply chain, ensuring proper storage conditions and minimizing spoilage risks. Meanwhile, BCT provides transparency and immutability to supply chain data, enabling consumers to trace the journey of each bottle from vineyard to shelf, guaranteeing authenticity and quality. Precisely, each actor of the supply chain uses BCT in order to keep immutable data, thus information they declare regarding each phase of the wine production. The data comes protected through a hash function that includes the hashes of the previous data. Consequently, as long as the chain is, it becomes more difficult to alter the information. In the end, final consumers are able to track back the information about the product they purchase by simply scanning the QR code given on the label of the product.

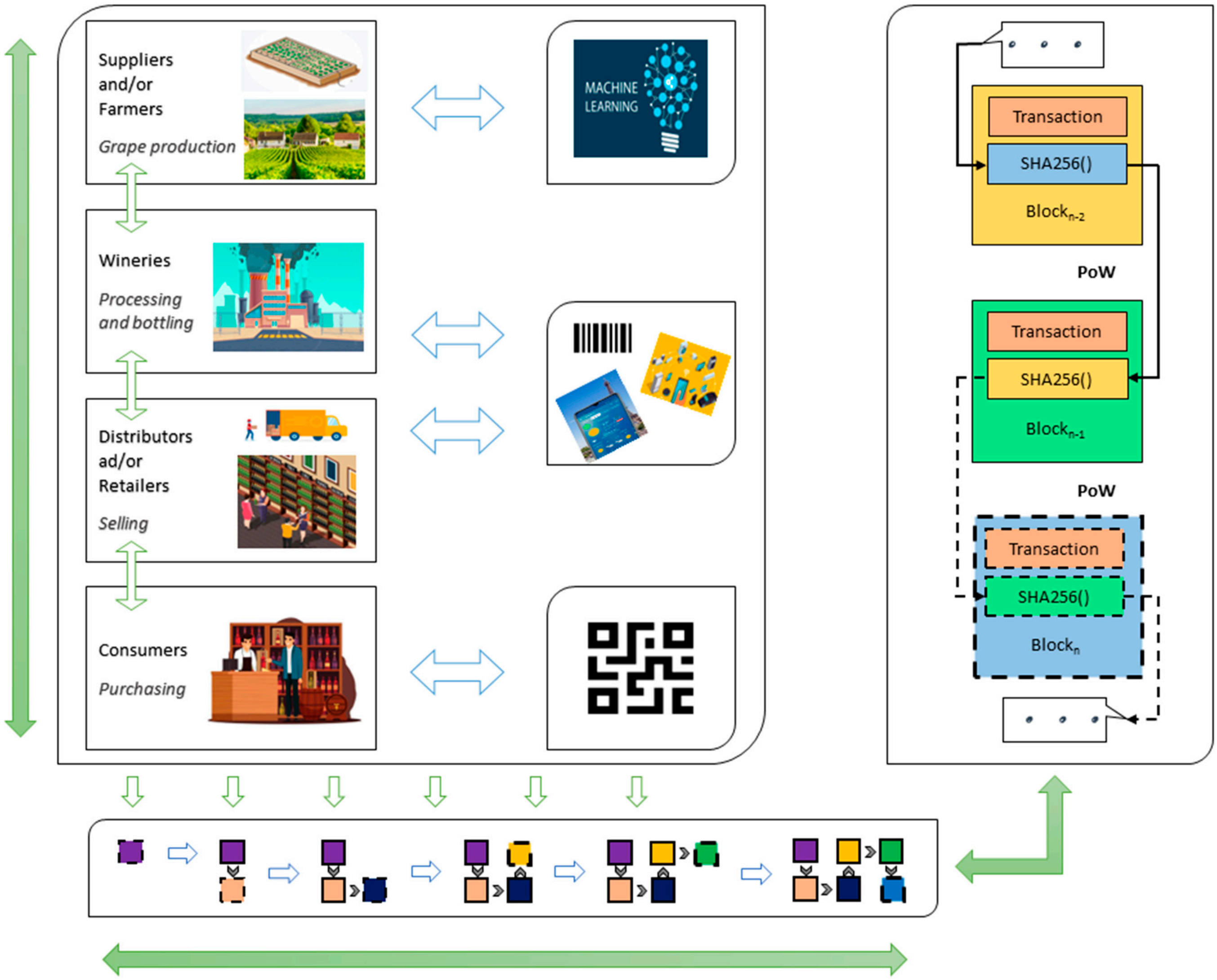

Figure 3. The proposed IoT-AI(ML)-BCT-based framework for secure and sustainable wine supply chain. Source: own elaboration.

4.5.1. Chain Actors

Suppliers: the required data contain information on agri-food inputs (such as seeds, pesticides, and fertilizers) as well as farmer transactions.

Farmers: in the case of farmers, their information includes farm locations, crop cultivation techniques, harvest timings, meteorological conditions, financial transactions with third parties, etc.

Processing and bottling: The data are gathered and used throughout the processing and bottling phases. This data includes information on the factories, fermentation processes, bottling an packaging procedures, transactions with farmers and wholesalers, etc.

Distributors: the information from distributors comprises the routes traveled, the temperatures and humidity levels maintained during storage, the identities of everyone engaged in the supply chain, and much more.

Retailers: retailers have access to tracing data that includes information on agri-food products (such as quality, quantity, price, and expiration dates), as well as storage conditions, transactions with distributors, etc.

Consumers: Consumers may get extensive agri-food product information on their mobile devices (from suppliers to retailers). Using QR codes, consumers may have access to information on the origin, route, batch, and lot numbers of their wine, as well as information regarding environmental monitoring.

4.5.2. IoT Devices

All chain players (producers, growers, processors (wineries), distributors, retailers, and consumers) are examined to assemble a complete time series of wine sector activities. The IoT devices are QR/bar codes, RFID, NFC, sensors, and mobile devices. All chain parameters are tracked by IoT devices, including production area, prices, temperature, carbon dioxide (CO_2), humidity, diseases, soil moisture, soil pH, fermentation, wine grade/quality, packaging weight and date etc. Data are recorded at all stages of the wine supply chain, and each data file is made with indexing and time stamp components. The proposed system entails storing identical data on the BCT in two ways. IoT devices are synchronized to upload data inputs to the ML module and BCT system at the same rate, and sensors collect each piece of chain data at predetermined intervals. If the information on the BCT and the IoT devices do not match, tampering or cloning of the items may be deduced at a later stage of the trace-back procedure due to two ways recording of the data.

4.5.3. ML Module

ML/AI algorithms assist chain actors in managing their processes. This module is accustomed to adhering to fair-trade policies. Real-world databases are prone to problems such as incomplete and noisy data. The data must be cleansed and transformed before being analyzed. This improvement in speed, accuracy, and efficacy is advantageous to the analytical skills of ML algorithms. If a value for a particular field or set of records is missing, it will be substituted with its average value.

The data collected by IoT sensors is sent to the ML module for predictive purposes to support wine supply chain actors in decision-making and subsequently stored in the BCT. ML module modifies standard sales forecasting, and chain data may be significantly reduced. Any anomalies or significant changes in client behavior are recorded in the ML module so that stakeholders may examine the data for efficient planning. All chain stakeholders will have access to the stored information on the BCT and will use the information for their benefit.

4.5.4. BCT Module

A BCT consists of several blocks in a single chain that contains blocks that have been verified by the majority of users. When one member in the BC network finalizes a PoW task, and the other users validate the outcome, the participant's transaction is added to the BCT in a new block. This indicates that BCT may be depended on to protect financial transactions.

Tracing data received at each chain transaction will be uploaded to a block using digital tools. Each block is added to the BCT when members have verified and consented to it. Another area where BCT excels is smart contracts, automating transactions between parties without the need for a third party [149].

Upon the adoption of PoW, any participant in the BCT will have the opportunity to mine blocks [150]. Participants demonstrate their labor in the PoW by completing mining tasks, which are mathematical problems that are very difficult to solve but easy to verify. This dilemma is often characterized as the following.

Find n

$$\text{s.t. SHA256(SHA256(h.n))} < \text{target} \quad (1)$$

where "h" is a block's contents, "n" is a random number, and "." is a string concatenation operator. Using the cryptographic hash technique SHA256(), a 256-bit binary integer is obtained [151]. In this instance, the puzzle is regarded to be solved if this number is smaller than the target value, which represents the mining difficulty.

4.5.5. Transaction in the System

A merchant submits a proposal to a smart contract, which is subsequently sent to a wholesaler by a peer who supports the idea. The distributor will conduct the conclusion of the data files. After the smart contract has validated the predetermined rules, it will seek client confirmation. The orderer will then provide the confirmation to the distributor, and the smart contract will distribute the cash. At the completion of the transaction, all parties involved will be informed of its success.

5. Conclusion and Implication for Theory and Practice

The population of the current world is expanding at an alarming pace. There is an urgent need for revolutionary agricultural advancements to meet the food requirements of so many people. An intelligent farming model and inclusive foods play a crucial role in this business [18]. The importance of cutting-edge technologies such as BCT, IoT, and AI is increasingly recognized. Industrial IoT and cutting-edge ML methods will revolutionize global agriculture. By digitizing the paper-based monitoring system, fast access to information through the wine supply chain will soon be achieved. The suggested management system utilizes BCT, IoT, and AI. Also, the functions for managing the wine supply chain's tracking and all user data are included. All granularities of traceability data management, compliance and environmental information management, and wine product pricing are feasible. The user has total control over who has access to what, and all settings are customizable.

Both BCT and AI have shown tremendous promise, but they need to overcome several challenges before. Both applications need substantial expertise and training, making them difficult for smaller and medium-sized enterprises. There are no educational materials available to inform the general audience about the BCT. People's lack of faith in cryptocurrencies has led to their outright prohibition by a number of nations. In order for this technology to be used in the food sector, the government must adopt certain regulations.

Similarly, the installation of this technology is subject to a number of legal restrictions. Ensuring the right data sharing on the network by farm owners is also problematic. Governments may be able to find answers to these issues if they intervene. Since opposition to such openness may be a sign of bad faith, the government should take the appropriate measures to ensure that all actors in all supply chains share all data.

The deployment of BCT throughout the wine supply chain enables the production and supply of safe and healthy wine. This provides an environment of fair competition and a transparent marketplace where consumers can search for wine products with total confidence.

According to Lin and colleagues [152], the next step for IoT-enabled e-agriculture schemes is to incorporate BCT into current e-agriculture and IoT systems. Data transparency and a secure, sustainable agricultural environment can be provided by using BCT and IoT. A system for dependable monitoring of data stored in a BCT with a decentralized ledger can be developed using this prototype.

By applying smart supply chain system, regulated or modified environmental storage, handling, IoT-enabled transportation, and logistics, the architecture might improve pre- and post-harvest management of the wine from an ecological safety standpoint. Smart farming, which includes the IoT and AI, is vital for the most efficient use of inputs in the wine-growing. Emissions of carbon dioxide, methane, and hydrocarbons are categorized as greenhouse gases that may be monitored using IoT-AI-BCT, contributing to environmental sustainability.

The corporate sector can use cutting-edge technology such as BCT, AI, and IoT to develop a trustworthy supply chain management system. Implementing a data-driven smart agricultural supply chain using IoT, AI, and BCT is the most effective way to address these concerns. The ideal would be if the supply chain could give a stream of data that could be utilized to influence choices. This may aid the global challenges of food quality, safety, foodborne infections, data interchange throughout the manufacturing process, etc. Consideration is given to potential applications of BCT, AI, and IoT in the logistics sector [83].

The proposed framework employs the integration of AI, IoT, and BCT to make the trade compliance process more reliable and efficient. Therefore, these architectural components contribute to economic sustainability. To attract investors and expand their enterprises, farmers may now utilize crypto money as an alternative to regular payments and the aforementioned technologies. Smart contracts provide immediate payments of financial commitments. Users may now investigate the origin and supply chain of wine due to the combination of BCT with IoT and AI.

Using the suggested immutable framework, participants may enhance their businesses by getting demand predictions and trends for wine in the future with the use of ML algorithms. In particular, the findings suggest that the proposed IoT-AI-BCT-based wine supply chain architecture can successfully assure reliable product safety and extend the economic model of the wine sector. IoT-enabled participants (suppliers, farmers, processors, distributors, retailers, and consumers) provide assurance that the product was handled in accordance with safety and healthy food standards, and each transaction on this framework is timestamped and encrypted.

Due to shifts in client behavior and viewpoint, real-world wine supply chain needs are changing at a quick rate. The production, processing, and administration of wine products may all benefit from the use of ML approaches that provide accurate predictions. Thus, manufacturers' production can be maintained at a cost-effective level for retailers, while retailers' inventory can sufficiently fulfill consumer's demand.

6. Limitations and Future Works

While this study endeavors to provide a comprehensive examination of the integration of BCT, IoT, and AI in the wine supply chain, certain limitations merit acknowledgment. These limitations, along with avenues for future research, are discussed below.

Weaknesses Addressed:

While the SLR approach was deemed appropriate for this academic research paper and was justified in the methodology section, we recognize the importance of empirical validation for the proposed framework. Practical cases have been integrated into the paper to provide real-world context and validation to address this concern.

Additionally, the emphasis on technological solutions in the paper may have inadvertently overshadowed other critical aspects, such as regulatory, cultural, and economic factors integral to the wine supply chain. Although it is challenging to comprehensively cover all dimensions in a single paper, efforts have been made to shortly incorporate also these aspects.

Remaining Limitations:

One notable limitation is the absence of case studies or empirical data demonstrating the practical application and effectiveness of the proposed technologies in real-world scenarios. While the research is based on the SLR and proposes a theoretical framework, empirical validation through case studies is essential to ascertain its real-world applicability and effectiveness. This limitation has been acknowledged, and future research endeavors will focus on conducting empirical studies to validate the proposed framework.

Future Research Directions:

Future research endeavors will concentrate on several key areas to address the identified limitations and further advance the understanding and application of BCT, IoT and AI in the wine supply chain moving forward. These include the following:

Conducting case studies or empirical studies to validate the proposed framework in real-world settings, thereby demonstrating its practical application and effectiveness.

Exploring the regulatory landscape surrounding the adoption of BCT, IoT, and AI in the wine industry, considering factors such as data privacy, security, and compliance with industry standards and regulations.

Investigating the cultural and economic implications of integrating these technologies into the wine supply chain, including stakeholder perceptions, adoption barriers, and economic feasibility.

Continuously monitoring technological advancements and emerging trends in BCT, IoT and AI to ensure the proposed framework remains relevant and up-to-date.

Furthermore, the use of deep learning and time series algorithms in more complex wine supply chain management scenarios with demands derived from actual data would be exciting to examine.

Finally, while this study lays the groundwork for understanding the potential of BCT, IoT and AI in the wine supply chain, future research endeavors will focus on addressing the identified limitations and further exploring the multifaceted implications of integrating these technologies into the industry.

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References

1. Harutyunyan, M.; Malfeito-Ferreira, M. The Rise of Wine among Ancient Civilizations across the Mediterranean Basin. *Heritage* **2022**, *5*, 788–812. [CrossRef]
2. Imazio, S.; Maghradze, D.; De Lorenzis, G.; Bacilieri, R.; Laucou, V.; This, P.; Scienza, A.; Failla, O. From the cradle of grapevine domestication: Molecular overview and description of Georgian grapevine (*Vitis vinifera* L.) germplasm. *Tree Genet. Genomes* **2013**, *9*, 641–658. [CrossRef]
3. McGovern, P.; Jalabadze, M.; Batiuk, S.; Callahan, M.P.; Smith, K.E.; Hall, G.R.; Kvavadze, E.; Maghradze, D.; Rusishvili, N.; Bouby, L.; et al. Early Neolithic wine of Georgia in the South Caucasus. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, E10309–E10318. [CrossRef] [PubMed]
4. Hamon, C.; Jalabadze, M.; Agapishvili, T.; Baudouin, E.; Koridze, I.; Messager, E. Gadachrili Gora: Architecture and organi-sation of a Neolithic settlement in the middle Kura Valley (6th millennium BC, Georgia). *Quat. Int.* **2016**, *395*, 154–169. [CrossRef]
5. Casadó-Marín, L.; Anzil, V. The semiotics of wine. Analysis of wine-related cultural consensus in two Spanish wine-producing regions. *Int. J. Gastron. Food Sci.* **2022**, *28*, 100536. [CrossRef]
6. Strickland, P. Innovative Wine Tourism Marketing Strategies in the Victorian Wine Industry A Wine Stakeholders' Perspective. Ph.D. Thesis, Department of Management & Marketing, La Trobe Business School—ASSC, La Trobe University, Victoria, Australia, 2022.
7. Fiore, M.; Alaimo, L.S.; Chkhartishvil, N. The amazing bond among wine consumption, health and hedonistic well-being. *Br. Food J.* **2020**, *122*, 2707–2723. [CrossRef]
8. Ohana-Levi, N.; Netzer, Y. Long-Term Trends of Global Wine Market. *Agriculture* **2023**, *13*, 224. [CrossRef]
9. Maicas, S. Advances in Wine Fermentation. *Fermentation* **2021**, *7*, 187. [CrossRef]
10. Spadoni, R.; Nanetti, M.; Bondanese, A.; Rivaroli, S. Innovative solutions for the wine sector: The role of startups. *Wine Econ. Policy* **2019**, *8*, 165–170. [CrossRef]
11. Higgins, L.M.; Wolf, M.M.; Wolf, M.J. Technological change in the wine market? The role of QR codes and wine apps in consumer wine purchases. *Wine Econ. Policy* **2014**, *3*, 19–27. [CrossRef]
12. Adamashvili, N.; Colantuono, F.; Conto, F.; Fiore, M. Investigating the role of community of practice for sharing knowledge in agriculture sectoR. *J. Glob. Bus. Adv.* **2020**, *13*, 162. [CrossRef]
13. Luzzani, G.; Grandis, E.; Frey, M.; Capri, E. Blockchain Technology in Wine Chain for Collecting and Addressing Sustainable Performance: An Exploratory Study. *Sustainability* **2021**, *13*, 12898. [CrossRef]
14. Tsolakis, N.; Schumacher, R.; Dora, M.; Kumar, M. Artificial intelligence and blockchain implementation in supply chains: A pathway to sustainability and data monetisation? *Ann. Oper. Res.* **2022**, *327*, 157–210. [CrossRef]

15. Danese, P.; Mocellin, R.; Romano, P. Designing blockchain systems to prevent counterfeiting in wine supply chains: A multiple-case study. *Int. J. Oper. Prod. Manag.* **2021**, *41*, 1–33. [CrossRef]
16. Lehmann, R.J.; Reiche, R.; Schiefer, G. Future internet and the agri-food sector: State-of-the-art in literature and research. *Comput. Electron. Agric.* **2012**, *89*, 158–174. [CrossRef]
17. Lamine, C. Sustainability and Resilience in Agrifood Systems: Reconnecting Agriculture, Food and the Environment. *Sociol. Rural.* **2014**, *55*, 41–61. [CrossRef]
18. Folinas, D.; Manikas, I.; Manos, B. Traceability data management for food chains. *Br. Food J.* **2006**, *108*, 622–633. [CrossRef]
19. Bhat, S.A.; Huang, N.-F. Big Data and AI Revolution in Precision Agriculture: Survey and Challenges. *IEEE Access* **2021**, *9*, 110209–110222. [CrossRef]
20. Hamam, M.; Chinnici, G.; Di Vita, G.; Pappalardo, G.; Pecorino, B.; Maesano, G.; D'amico, M. Circular Economy Models in Agro-Food Systems: A Review. *Sustainability* **2021**, *13*, 3453. [CrossRef]
21. Maesano, G.; Milani, M.; Nicolosi, E.; D'amico, M.; Chinnici, G. A Network Analysis for Environmental Assessment in Wine Supply Chain. *Agronomy* **2022**, *12*, 211. [CrossRef]
22. Goncharuk, A.G. Wine value chains: Challenges and prospects. *J. Appl. Manag. Invest.* **2017**, *6*, 11–27.
23. Naudé, R.T.; Badenhorst-Weiss, J.A. The challenges behind producing a bottle of wine: Supply chain risks. *J. Transp. Supply Chain Manag.* **2020**, *14*, 1–15. [CrossRef]
24. Petti, L.; Raggi, A.; De Camillis, C.; Matteucci, P.; Sára, B.; Pagliuca, G. Life cycle approach in an organic wine-making firm: An Italian case-study. In Proceedings of the Fifth Australian Conference on Life Cycle Assessment, Melbourne, Australia, 22–24 November 2006; pp. 22–24.
25. Ting, S.; Tse, Y.K.; Ho, G.; Chung, S.H.; Pang, G. Mining logistics data to assure the quality in a sustainable food supply chain: A case in the red wine industry. *Int. J. Prod. Econ.* **2014**, *152*, 200–209. [CrossRef]
26. Ohmart, C.P. What does sustainability really mean? *Wines Vines* **2004**, *85*, 3.
27. Christ, K.L.; Burritt, R.L. Critical environmental concerns in wine production: An integrative review. *J. Clean. Prod.* **2013**, *53*, 232–242. [CrossRef]
28. Fondazione Symbola. 2020 Il Futuro del Vino Italiano. Qualità, Sostenibilità e Territorio. ISBN 978-88-99265-56-4. Available online: https://www.prosecco.it/wpcontent/uploads/2020/05/2020_0430_per-download.pdf (accessed on 4 April 2020).
29. Matos, F.; Alcobia, T.; Matos, A.J. Blockchain technology and traceability in the wine supply chain industry. In Proceedings of the ECIAIR 2021 3rd European Conference on the Impact of Artificial Intelligence and Robotics, Academic Conferences and Publishing Limited, Online, 18–19 November 2021; p. 90.
30. Silvestri, R.; Adamashvili, N.; Fiore, M.; Galati, A. How blockchain technology generates a trust-based competitive advantage in the wine industry: A resource based view perspective. *Eur. Bus. Rev.* **2023**, *35*, 713–736. [CrossRef]
31. Chandes, J.; Estampe, D.; Berthomier, R.; Courrie, L.-A.; Han, L.; Marquevielle, S. Logistics Performance of Actors in the Wine Supply Chain. *Supply Chain Forum Int. J.* **2003**, *4*, 12–27. [CrossRef]
32. Adamo, C. A Global Perspective of the Wine Supply Chain: The Case of Argentinean Wineries and the US Market. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2004.
33. Kunnapapdeelert, S. Analyzing the effect of supply chain strategies and collaboration on performance improvement using MIMIC model. *Int. J. Ind. Eng. Manag.* **2021**, *12*, 216–225. [CrossRef]
34. Kadlubek, M. Supply chain in the strategic approach with the aspect of quality. *Int. J. Qual. Res.* **2022**, *16*, 1255–1268. [CrossRef]
35. Chopra, S.; Meindl, P. *Supply Chain Management: Strategy, Planning, and Operation*, 3rd ed.; Pearson Education, Inc.: Hoboken, NJ, USA, 2007.
36. Canavari, M.; Akgüngör, S.; Borsellino, V.; Mauracher, C.; Naspetti, S.; Stanton, J.L.; Stranieri, S.; Drejerska, N.; Fiore, M.; Galati, A.; et al. Editorial. *Econ. Agro-Aliment.* **2019**, *3*, 577–585. [CrossRef]
37. Khan, M.; Parvaiz, G.S.; Dedahanov, A.T.; Abdurazzakov, O.S.; Rakhmonov, D.A. The Impact of Technologies of Traceability and Transparency in Supply Chains. *Sustainability* **2022**, *14*, 16336. [CrossRef]
38. Khan, P.W.; Byun, Y.C.; Park, N. IoT-blockchain enabled optimized provenance system for food industry 4.0 using advanced deep learning. *Sensors* **2020**, *20*, 2990. [CrossRef]
39. Adamashvili, N.; State, R.; Tricase, C.; Fiore, M. Blockchain-Based Wine Supply Chain for the Industry Advancement. *Sustainability* **2021**, *13*, 13070. [CrossRef]
40. Li, S.; Xu, L.D.; Zhao, S. The internet of things: A survey. *Inf. Syst. Front.* **2015**, *17*, 243–259. [CrossRef]
41. Newsroom, G. Gartner Says Worldwide IoT Security Spending Will Reach $1.5 Billion in 2018. Available online: https://www.gartneR.com/newsroom/id/3869181 (accessed on 5 March 2024).
42. Haroon, A.; Ali, M.; Asim, Y.; Naeem, W.; Kamran, M.; Javaid, Q. Constraints in the IoT: The World in 2020 and Beyond. *Int. J. Adv. Comput. Sci. Appl.* **2016**, *7*, 252–271. [CrossRef]
43. Liang, K.; Thomasson, J.; Shen, M.; Armstrong, P.; Ge, Y.; Lee, K.; Herrman, T. Ruggedness of 2D code printed on grain tracers for implementing a prospective grain traceability system to the bulk grain delivery system. *Food Control* **2013**, *33*, 359–365. [CrossRef]
44. Fan, B.; Qian, J.; Wu, X.; Du, X.; Li, W.; Ji, Z.; Xin, X. Improving continuous traceability of food stuff by using barcode-RFID bidirectional transformation equipment: Two field experiments. *Food Control* **2019**, *98*, 449–456. [CrossRef]
45. Bosona, T.; Gebresenbet, G. Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food Control* **2013**, *33*, 32–48. [CrossRef]

46. Li, Z.; Liu, G.; Liu, L.; Lai, X.; Xu, G. IoT-based tracking and tracing platform for prepackaged food supply chain. *Ind. Manag. Data Syst.* **2017**, *117*, 1906–1916. [CrossRef]
47. Pal, A.; Kant, K. IoT-Based Sensing and Communications Infrastructure for the Fresh Food Supply Chain. *Computer* **2018**, *51*, 76–80. [CrossRef]
48. Jabbari, A.; Kaminsky, P. Blockchain and Supply Chain Management. Department of Industrial Engineering and Operations Research University of California, Berkeley. January 2018. Available online: https://og.mhi.org/downloads/learning/cicmhe/blockchain-and-supply-chain-management.pdf (accessed on 5 March 2024).
49. Montecchi, M.; Plangger, K.; Etter, M. It's real, trust me! Establishing supply chain provenance using blockchain. *Bus. Horiz.* **2019**, *62*, 283–293. [CrossRef]
50. Luvisi, A.; Pagano, M.; Bandinelli, R.; Rinaldelli, E.; Gini, B.; Scartòn, M.; Manzoni, G.; Triolo, E. Virtual vineyard for grapevine management purposes: A RFID/GPS application. *Comput. Electron. Agric.* **2011**, *75*, 368–371. [CrossRef]
51. Kamilaris, A.; Fonts, A.; Prenafeta-Boldύ, F.X. The rise of blockchain technology in agriculture and food supply chains. *Trends Food Sci. Technol.* **2019**, *91*, 640–652. [CrossRef]
52. Cimino, M.G.; Marcelloni, F. Enabling traceability in the wine supply chain. In *Methodologies and Technologies for Networked Enterprises*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 397–412. [CrossRef]
53. Bonello, F.; Cravero, M.C.; Dell'oro, V.; Tsolakis, C.; Ciambotti, A. Wine Traceability Using Chemical Analysis, Isotopic Parameters, and Sensory Profiles. *Beverages* **2018**, *4*, 54. [CrossRef]
54. Monteiro, J.; Barata, J. Artificial Intelligence in Extended Agri-Food Supply Chain: A Short Review Based on Bibliometric Analysis. *Procedia Comput. Sci.* **2021**, *192*, 3020–3029. [CrossRef]
55. Ramdinthara, I.Z.; Bala, P.S.; Gowri, A.S. AI-Based Yield Prediction and Smart Irrigation. *Internet Things Anal. Agric.* **2022**, *3*, 113–140.
56. Newlands, N.K. Artificial Intelligence and Big Data Analytics in Vineyards: A Review. *Grapes Wine* **2022**, *8*, 65.
57. Yu, H.; Liu, S.; Qin, H.; Zhou, Z.; Zhao, H.; Zhang, S.; Mao, J. Artificial intelligence-based approaches for traditional fermented alcoholic beverages' development: Review and prospect. *Crit. Rev. Food Sci. Nutr.* **2022**, 1–11. [CrossRef]
58. Alsobeh, A.; Shatnawi, A. Integrating Data-Driven Security, Model Checking, and Self-adaptation for IoT Systems Using BIP Components: A Conceptual Proposal Model. In *International Conference on Advances in Computing Research*; Springer Nature: Cham, Switzerland, 2023; pp. 533–549.
59. Gonzalez Viejo, C.; Torrico, D.D.; Dunshea, F.R.; Fuentes, S. Emerging Technologies Based on Artificial Intelligence to Assess the Quality and Consumer Preference of Beverages. *Beverages* **2019**, *5*, 62. [CrossRef]
60. Anica-Popa, I.; Anica-Popa, L.; Radulescu, C.; Vrincianu, M. The Integration of Artificial Intelligence in Retail: Benefits, Challenges and a Dedicated Conceptual Framework. *Amfiteatru Econ.* **2021**, *23*, 120–136. [CrossRef]
61. Vieira, A.A.; Figueira, J.R.; Fragoso, R. A multi-objective simulation-based decision support tool for wine supply chain design and risk management under sustainability goals. *Expert Syst. Appl.* **2023**, *232*, 120757. [CrossRef]
62. Patel, N.; Trivedi, S. Leveraging Predictive Modeling, Machine Learning Personalization, NLP Customer Support, and AI Chatbots to Increase Customer Loyalty. *Empir. Quests Manag. Essences* **2020**, *3*, 1–24.
63. Lin, W.; Huang, X.; Fang, H.; Wang, V.; Hua, Y.; Wang, J.; Yin, H.; Yi, D.; Yau, L. Blockchain Technology in Current Agricultural Systems: From Techniques to Applications. *IEEE Access* **2020**, *8*, 143920–143937. [CrossRef]
64. Ciruela-Lorenzo, A.M.; Del-Aguila-Obra, A.R.; Padilla-Meléndez, A.; Plaza-Angulo, J.J. Digitalization of Agri-Cooperatives in the Smart Agriculture Context. Proposal of a Digital Diagnosis Tool. *Sustainability* **2020**, *12*, 1325. [CrossRef]
65. Jennath, H.S.; Adarsh, S.; Anoop, V.S. Distributed IoT and Applications: A Survey. In *Integrated Intelligent Computing, Communication and Security*; Krishna, A., Srikantaiah, K., Naveena, C., Eds.; Studies in Computational Intelligence; Springer: Singapore, 2019; Volume 771.
66. Andoni, M.; Robu, V.; Flynn, D.; Abram, S.; Geach, D.; Jenkins, D.; McCallum, P.; Peacock, A. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renew. Sustain. Energy Rev.* **2018**, *100*, 143–174. [CrossRef]
67. 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]
68. Christensen, C.M.; Meronuck, R.A. *Quality Maintenance in Stored Grains and Seeds*; U of Minnesota Press: Minneapolis, MN, USA, 1986.
69. Tripoli, M.; Schmidhuber, J. *Emerging Opportunities for the Application of Blockchain in the Agri-Food Industry*; Licence: CC, BY-NC-SA; FAO: Rome, Italy; ICTSD: Geneva, Switzerland, 2018; Volume 3.
70. Fernandez, A.; Waghmare, A.; Tripathi, S. Agricultural Supply Chain using Blockchain. In Proceedings of the International Conference on Intelligent Manufacturing and Automation, Mumbai, India, 27–28 March 2020; Lecture Notes in Mechanical Engineering. Vasudevan, H., Kottur, V., Raina, A., Eds.; Springer: Singapore, 2020; pp. 127–134.
71. Caballero, R.; Rivera, B. Blockchain: An Alternative to Enable Traceability in the Agricultural Supply Chain in Panama. In Proceedings of the 7th International Engineering, Sciences and Technology Conference (IESTEC), Panama, Panama, 9–11 October 2019; pp. 46–51.
72. Katsikouli, P.; Wilde, A.S.; Dragoni, N.; Høgh-Jensen, H. On the benefits and challenges of blockchains for managing food supply chains. *J. Sci. Food Agric.* **2020**, *101*, 2175–2181. [CrossRef] [PubMed]
73. Mirabelli, G.; Solina, V. Blockchain and agricultural supply chains traceability: Research trends and future challenges. *Procedia Manuf.* **2020**, *42*, 414–421. [CrossRef]

74. Demestichas, K.; Peppes, N.; Alexakis, T.; Adamopoulou, E. Blockchain in Agriculture Traceability Systems: A Review. *Appl. Sci.* **2020**, *10*, 4113. [CrossRef]
75. Song, L.; Wang, X.; Merveille, N. Research on Blockchain for Sustainable E-Agriculture. In Proceedings of the IEEE Technology & Engineering Management Conference (TEMSCON), Novi, MI, USA, 3–6 June 2020; pp. 1–5.
76. Kadariya, J.; Smith, T.C.; Thapaliya, D. Staphylococcus aureus and staphylococcal food-borne disease: An ongoing challenge in public health. *BioMed Res. Int.* **2014**, *2014*, 827965. [CrossRef]
77. Scharff, R.L. Economic Burden from Health Losses due to Foodborne Illness in the United States. *J. Food Prot.* **2012**, *75*, 123–131. [CrossRef] [PubMed]
78. Kshetri, N.; Loukoianova, E. Blockchain Adoption in Supply Chain Networks in Asia. *IT Prof.* **2019**, *21*, 11–15. [CrossRef]
79. Pouliot, S.; Sumner, D.A. Traceability, recalls, industry reputation and product safety. *Eur. Rev. Agric. Econ.* **2013**, *40*, 121–142. [CrossRef]
80. Vangala, A.; Das, A.K.; Kumar, N.; Alazab, M. Smart secure sensing for IoT-based agriculture: Blockchain perspective. *IEEE Sens. J.* **2020**, *21*, 17591–17607. [CrossRef]
81. Wang, J.; Ma, Y.; Zhang, L.; Gao, R.X.; Wu, D. Deep learning for smart manufacturing: Methods and applications. *J. Manuf. Syst.* **2018**, *48*, 144–156. [CrossRef]
82. Liu, M.; Yu, F.R.; Teng, Y.; Leung, V.C.; Song, M. Performance optimization for blockchain-enabled industrial internet of things (IoT) systems: A deep reinforcement learning approach. *IEEE Trans. Ind. Inform.* **2019**, *15*, 3559–3570. [CrossRef]
83. Bhat, S.A.; Huang, N.-F.; Sofi, I.B.; Sultan, M. Agriculture-Food Supply Chain Management Based on Blockchain and IoT: A Narrative on Enterprise Blockchain Interoperability. *Agriculture* **2021**, *12*, 40. [CrossRef]
84. Caro, M.P.; Ali, M.S.; Vecchio, M.; Giaffreda, R. Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. In Proceedings of the 2018 IoT Vertical and Topical Summit on Agriculture—Tuscany (IOT Tuscany), Tuscany, Italy, 8–9 May 2018; pp. 1–4.
85. Montes, J.M.; Larios, V.M.; Avalos, M.; Ramírez, C.E. Applying Blockchain to Supply Chain Operations at IBM Implementing Agile Practices in a Smart City Environment. *Res. Comput. Sci.* **2018**, *147*, 65–75. [CrossRef]
86. García, M.Q.; Schmitz, A.; Martín, A.M.D. La transformación del retail: El papel de la tecnología en la crisis de la COVID-19. *Distrib. Consumo* **2021**, *3*, 36.
87. IBM. eProvenance Annuncia VinAssure™, la Nuova Piattaforma Basata Sulla Tecnologia IBM Blockchain per Ottimizzare la Supply Chain del Vino. 10 December 2020. Available online: https://it.newsroom.ibm.com/VinAssure (accessed on 16 February 2024).
88. Galati, A.; Vrontis, D.; Giorlando, B.; Giacomarra, M.; Crescimanno, M. Exploring the common blockchain adoption enablers: The case of three Italian wineries. *Int. J. Wine Bus. Res.* **2021**, *33*, 578–596. [CrossRef]
89. Vin Vikup (n.d.). How Will NFT Help Protect Collectible Alcohol from Counterfeiting. Available online: https://vikupvin.ru/robert-mondavi-vypuskaet-vina-s-nft-tokenami/?ysclid=lsoxk1qnyu391769507&fbclid=IwAR1Z8-2pkdV4DNHQZjujkH7RhSHOORkhLs0FK1c2qsXlwvuojiQg4QavC1Q (accessed on 16 February 2024).
90. Mercer, C. Angélus and Cult Wines Explore NFT Trend. 27 July 2021. Available online: https://www.decanteR.com/wine-news/angelus-and-cult-wines-explore-nft-trend-462488/ (accessed on 16 February 2024).
91. Venco, E. Tappo Digitalele Aziende Vinicole Usano Sempre più gli NFT. 30 April 2022. Available online: https://www.linkiesta.it/2022/04/vino-nft/ (accessed on 16 February 2024).
92. Leonidou, E.; Christofi, M.; Vrontis, D.; Thrassou, A. An integrative framework of stakeholder engagement for innovation management and entrepreneurship development. *J. Bus. Res.* **2020**, *119*, 245–258. [CrossRef]
93. Rosado-Pinto, F.; Loureiro, S.M.C. The growing complexity of customer engagement: A systematic review. *Euro. Med. J. Bus.* **2020**, *15*, 167–203. [CrossRef]
94. Karaosman, H.; Morales-Alonso, G.; Brun, A. From a Systematic Literature Review to a Classification Framework: Sustainability Integration in Fashion Operations. *Sustainability* **2016**, *9*, 30. [CrossRef]
95. Christofi, M.; Vrontis, D.; Cadogan, J.W. 'Micro-foundational ambidexterity and multinational enterprises: A systematic review and a conceptual framework'. *Int. Bus. Rev.* **2019**, *in press corrected proof*. [CrossRef]
96. Vrontis, D.; Christofi, M. R & D internationalization and innovation: A systematic review, integrative framework and future research directions. *J. Bus. Res.* **2021**, *128*, 812–823.
97. Christofi, M.; Vrontis, D.; Thrassou, A.; Shams, S.M.R. Triggering technological innovation through cross-border mergers and acquisitions: A micro-foundational perspective. *Technol. Forecast. Soc. Chang.* **2019**, *146*, 148–166. [CrossRef]
98. Rana, R.L.; Adamashvili, N.; Tricase, C. The Impact of Blockchain Technology Adoption on Tourism Industry: A Systematic Literature Review. *Sustainability* **2022**, *14*, 7383. [CrossRef]
99. Correia, E.; Carvalho, H.; Azevedo, S.G.; Govindan, K. Maturity Models in Supply Chain Sustainability: A Systematic Literature Review. *Sustainability* **2017**, *9*, 64. [CrossRef]
100. Rastogi, L.; Yazdifar, H.; Alam, A.; Eskandari, R.; Bahloul, M.A. A review of the relationship between leadership style and innovation: Insights and directions for future research. *J. Glob. Bus. Adv.* **2019**, *12*, 625–647. [CrossRef]
101. Giacomarra, M.; Galati, A.; Crescimanno, M.; Vrontis, D. Geographical cues: Evidences from new and old world countries' wine consumers. *Br. Food J.* **2020**, *122*, 1252–1267. [CrossRef]
102. Masi, D.; Day, S.; Godsell, J. Supply Chain Configurations in the Circular Economy: A Systematic Literature Review. *Sustainability* **2017**, *9*, 1602. [CrossRef]

103. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A.; PRISMA-P Group. Preferred reporting items for systematic review and meta analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev.* **2015**, *4*, 1. [CrossRef]
104. De Menezes, L.M.; Kelliher, C. Flexible working and performance: A systematic review of the evidence for a business case. *Int. J. Manag. Rev.* **2011**, *13*, 452–474. [CrossRef]
105. Denyer, D.; Tranfield, D. Producing a systematic review. In *The Sage Handbook of Organizational Research Methods*; Buchanan, D., Bryman, A., Eds.; Sage Publications: London, UK, 2009; pp. 671–689.
106. Tröster, R.; Hiete, M. Success of voluntary sustainability certification schemes—A comprehensive review. *J. Clean. Prod.* **2018**, *196*, 1034–1043. [CrossRef]
107. Pittaway, L.; Robertson, M.; Munir, K.; Denyer, D.; Neely, A. Networking and innovation: A systematic review of the evidence. *Int. J. Manag. Rev.* **2004**, *5–6*, 137–168. [CrossRef]
108. Takacs, B.; Borrion, A. The Use of Life Cycle-Based Approaches in the Food Service Sector to Improve Sustainability: A Systematic Review. *Sustainability* **2020**, *12*, 3504. [CrossRef]
109. Livoreil, B.; Glanville, J.; Haddaway, N.R.; Bayliss, H.; Bethel, A.; de Lachapelle, F.F.; Robalino, S.; Savilaakso, S.; Zhou, W.; Petrokofsky, G.; et al. Systematic searching for environmental evidence using multiple tools and sources. *Environ. Évid.* **2017**, *6*, 1–14. [CrossRef]
110. Broome, M.E. Integrative literature reviews for the development of concepts. In *Concept Development in Nursing*; Rodgers, B.L., Knafl, K.A., Eds.; W.B. Saunders: Philadelphia, PA, USA, 1993; pp. 231–250.
111. Govindan, K.; Bouzon, M. From a literature review to a multi-perspective framework for reverse logistics barriers and drivers. *J. Clean. Prod.* **2018**, *187*, 318–337. [CrossRef]
112. Lin, J.; Shen, Z.; Miao, C.; Zhang, A.; Chai, Y. 2018. Blockchain and IoT based Food Traceability for Smart Agriculture. In Proceedings of the ICCSE'18: 3rd International Conference on Crowd Science and Engineering, Singapore, 28–31 July 2018; p. 6. [CrossRef]
113. Zhang, R.; Xue, R.; Liu, L. Security and Privacy on Blockchain. *ACM Comput. Surv.* **2019**, *52*, 1–34. [CrossRef]
114. Casino, F.; Dasaklis, T.K.; Patsakis, C. Enhanced Vendor-managed Inventory through Blockchain. In Proceedings of the 2019 4th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM), Piraeus, Greece, 20–22 September 2019; pp. 1–8.
115. Blanchard, D. *Supply Chain Management Best Practices*; John Wiley & Sons: Hoboken, NJ, USA, 2021.
116. Torky, M.; Hassanein, A.E. Integrating blockchain and the internet of things in precision agriculture: Analysis, opportunities, and challenges. *Comput. Electron. Agric.* **2020**, *178*, 105476. [CrossRef]
117. Tian, F. An agri-food supply chain traceability system for China based on RFID & blockchain technology. In Proceedings of the 2016 13th International Conference on Service Systems and Service Management (ICSSSM), Kunming, China, 24–26 June 2016.
118. Singh, P.; Singh, N. Blockchain With IoT and AI: A Review of Agriculture and Healthcare. *Int. J. Appl. Evol. Comput.* **2020**, *11*, 13–27. [CrossRef]
119. Hu, S.; Huang, S.; Huang, J.; Su, J. Blockchain and edge computing technology enabling organic agricultural supply chain: A framework solution to trust crisis. *Comput. Ind. Eng.* **2020**, *153*, 107079. [CrossRef]
120. Kumarathunga, M. Improving Farmers' Participation in Agri Supply Chains with Blockchain and Smart Contracts. In Proceedings of the 2020 Seventh International Conference on Software Defined Systems (SDS), Paris, France, 20–23 April 2020; pp. 139–144.
121. Zhou, Q.; Wang, Y.; Fu, X. Information asymmetry, blockchain and food safety. *Res. China Mark. Superv.* **2016**, *11*, 53–56. [CrossRef]
122. Gambill, A.B. Creating Sustainable Food Systems with Trademarks and Technology. *Bus. Entrep. Tax L. Rev.* **2022**, *6*, 58.
123. Centobelli, P.; Cerchione, R.; Del Vecchio, P.; Oropallo, E.; Secundo, G. Blockchain technology for bridging trust, traceability and transparency in circular supply chain. *Inf. Manag.* **2021**, *59*, 103508. [CrossRef]
124. Ilie-Zudor, E.; Ekárt, A.; Kemeny, Z.; Buckingham, C.; Welch, P.; Monostori, L. Advanced predictive-analysis-based decision support for collaborative logistics networks. *Supply Chain Manag. Int. J.* **2015**, *20*, 369–388. [CrossRef]
125. 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]
126. Alicke, K.; Glatzel, C.; Hoberg, K.; Karlsson, P.-M. Big Data and The Supply Chain: The Big Supply Chain Analytics Landscape Part 1 (of 2), McKinsey&Company Operations Extranet, February. 2016. Available online: https://www.mckinsey.com/capabilities/operations/our-insights/big-data-and-the-supply-chain-the-big-supply-chain-analytics-landscape-part-1#/ (accessed on 1 October 2021).
127. Merkert, J.; Mueller, M.; Hubl, M. A Survey of the Application of Machine Learning in Decision Support Systems. In Proceedings of the 23rd European Conference on Information Systems (ECIS 2015), Münster, Germany, 26–29 May 2015.
128. OIV. Resolution CST 1/2008-OIV Guidelines for Sustainable Vitiviniculture: Production, Processing and Packaging of Products. Available online: http://www.oiv.int/public/medias/2089/cst-1-2008-en.pdf (accessed on 5 March 2024).
129. Gilinsky, A., Jr.; Newton, S.K.; Vega, R.F. Sustainability in the Global Wine Industry: Concepts and Cases. *Agric. Agric. Sci. Procedia* **2016**, *8*, 37–49. [CrossRef]
130. Ge, L.; Brewster, C.; Spek, J.; Smeenk, A.; Top, J.; van Diepen, F.; Klaase, B.; Graumans, C.; de Ruyter de Wildt, M. *Blockchain for Agriculture and Food: Findings from the Pilot Study*; Wageningen Economic Research report; No. 2017-112; Wageningen Economic Research: Wageningen, The Nethelands, 2017. [CrossRef]

131. AlSobeh, A.M.R.; Magableh, A.A. BlockASP: A Framework for AOP-Based Model Checking Blockchain System. *IEEE Access* **2023**, *11*, 115062–115075. [CrossRef]
132. Suciu, G.; Nadrag, C.; Istrate, C.; Vulpe, A.; Ditu, M.C.; Subea, O. Comparative analysis of distributed ledger technologies. In Proceedings of the 2018 Global Wireless Summit (GWS), Chiang Rai, Thailand, 25–28 November 2018; Institute of Electrical and Electronics Engineers: Piscataway, NJ, USA, 2018; pp. 370–373.
133. Rana, R.L.; Bux, C.; Lombardi, M. Carbon footprint of the globe artichoke supply chain in Southern Italy: From agricultural production to industrial processing. *J. Clean. Prod.* **2023**, *391*, 136240. [CrossRef]
134. Mathiyazhagan, K.; Govindan, K.; NoorulHaq, A.; Geng, Y. An ISM approach for the barrier analysis in implementing green supply chain management. *J. Clean. Prod.* **2013**, *47*, 283–297. [CrossRef]
135. Unicredit. Industry Book. 2019. Available online: https://www.unicreditgroup.eu/content/dam/unicreditgroup-eu/documents/en/investors/financial-reports/2019/4Q19/2019-Annual-Report-and-Accounts.pdf (accessed on 4 April 2020).
136. Rugani, B.; Vázquez-Rowe, I.; Benedetto, G.; Benetto, E. A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sectoR. *J. Clean. Prod.* **2013**, *54*, 61–77. [CrossRef]
137. Venkatesh, V.G.; Kang, K.; Wang, B.; Zhong, R.Y.; Zhang, A. System architecture for blockchain based transparency of supply chain social sustainability. *Robot. Comput. Integr. Manuf.* **2020**, *63*, 139–144. [CrossRef]
138. Mao, D.; Hao, Z.; Wang, F.; Li, H. Innovative Blockchain-Based Approach for Sustainable and Credible Environment in Food Trade: A Case Study in Shandong Province, China. *Sustainability* **2018**, *10*, 3149. [CrossRef]
139. Di Vaio, A.; Varriale, L. Blockchain technology in supply chain management for sustainable performance: Evidence from the airport industry. *Int. J. Inf. Manag.* **2020**, *52*, 102014. [CrossRef]
140. Xiong, H.; Dalhaus, T.; Wang, P.; Huang, J. Blockchain Technology for Agriculture: Applications and Rationale. *Front. Blockchain* **2020**, *3*, 7. [CrossRef]
141. Balaji, M.; Arshinder, K. Modeling the causes of food wastage in Indian perishable food supply chain. *Resour. Conserv. Recycl.* **2016**, *114*, 153–167. [CrossRef]
142. Ante, L.; Sandner, P.; Fiedler, I. Blockchain-based ICOs: Pure hype or the dawn of a new era of startup financing? *J. Risk Financ. Manag.* **2018**, *11*, 80. [CrossRef]
143. Chohan, U.W. Initial coin offerings (ICOs): Risks, regulation, and accountability. In *Cryptofinance and Mechanisms of Ex-Change*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 165–177.
144. Vishakha, N.S.; Bhushan, B.; Kaushik, I. Blockchain-based Cultivating Ideas for Growth: A New Agronomics Perspective. *Blockchain Appl. Secur. IoT Framew. Technol. Shap. Future* **2021**, *1*, 195.
145. Adamashvili, N.; Fiore, M.; Contò, F.; La Sala, P. Ecosystem for Successful Agriculture. Collaborative Approach as a Driver for Agricultural Development. *Eur. Countrys.* **2020**, *12*, 242–256. [CrossRef]
146. Ogrean, C. Relevance of Big Data for Business and Management. Exploratory Insights (Part I). *Stud. Bus. Econ.* **2018**, *13*, 153–163. [CrossRef]
147. Scholz, T. *Platform Cooperativism. Challenging the Corporate Sharing Economy*; Rosa Luxemburg Stiftung: New York, NY, USA, 2016.
148. Chen, H.; Chen, Z.; Lin, F.; Zhuang, P. Effective Management for Blockchain-Based Agri-Food Supply Chains Using Deep Reinforcement Learning. *IEEE Access* **2021**, *9*, 36008–36018. [CrossRef]
149. Feng, Q.; He, D.; Zeadally, S.; Liang, K. BPAS: Blockchain-Assisted Privacy-Preserving Authentication System for Vehicular Ad Hoc Networks. *IEEE Trans. Ind. Inform.* **2019**, *16*, 4146–4155. [CrossRef]
150. Nakamoto, S. *Bitcoin: A Peer-to-Peer Electronic Cash System*; White Paper: Washington, DC, USA, 2008.
151. Gilbert, H.; Handschuh, H. Security analysis of sha-256 and sisters. In *10th International Workshop on1 Selected Areas in Cryptography (SAC)*; Springer: Berlin/Heidelberg, Germany, 2003; pp. 175–193.
152. Lin, Y.-P.; Petway, J.R.; Anthony, J.; Mukhtar, H.; Liao, S.-W.; Chou, C.-F.; Ho, Y.-F. Blockchain: The Evolutionary Next Step for ICT E-Agriculture. *Environments* **2017**, *4*, 50. [CrossRef]