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DISTRIBUTED LEDGER TECHNOLOGY FOR SUPPLY CHAIN AND PUBLIC GOVERNANCE AS A RESPONSE FOR SUSTAINABILITY ISSUES

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Purpose: The purpose of this article is to systematize the problems faced by modern supply chains and problems observed in the field of public governance, as well as to indicate solutions to these problems based on the currently developing Distributed Ledger Technology.
Design/methodology/approach: The purpose of the article was achieved based on a thorough analysis of contemporary scientific articles and a number of industry reports, as well as websites of institutions involved in the development of DLT with particular emphasis on Blockchain technology. Moreover, two case studies on DLT implementation were presented.
Findings: A number of problems have been identified related to the sustainable development of supply chains and societies. They can be systematized by taking into account the concept of the triple bottom line. There are DLT solutions that emphasize sustainable development. Examples of such solutions are described in the article.
Research limitations/implications: (if applicable) If research is reported on in the paper, this section must be completed and should include suggestions for future research and any identified limitations in the research process.
Practical implications: The use of DLT-based systems in supply chain management and in public management solves specific problems. The article shows how the architecture of DLT systems contributes to the increase in the transparency of the supply chain or public service. Moreover, the article indicates that the implementation of blockchain solutions contributes to increasing the trust in the supply chain management and public governance.
Social implications: Described examples of DLT application show a number of benefits for society in terms of pro-ecological behavior, as well as in terms of security of data flowing through the public services system, which is often the subject of public concern.
Originality/value: The originality of the article is to emphasize the importance of DLT for shaping sustainable development and to present the described technology as a way to reduce the negative impact of problems identified in the area of both supply chain management and public governance.

Keywords: Distributed Ledger Technology, blockchain, sustainability, supply chain management, public governance.

Category of the paper: Research paper.

1. Introduction

The modern world increasingly recognizes the importance of information flows for the functioning of logistics systems. Therefore, it seems reasonable to look for the possibility of their optimization (Hacker, 2007). Both the area of supply chain management (SCM) and public governance are subject to the process of continuous strengthening of their effectiveness (Prayogo, 2018). For today's logistics, the efficiency of material flows is largely dependent on the quality of information flow (Rajaguru, Matanda, 2013) and inter-organizational information systems are a key solution for shaping relationships in supply chains (Pereira, 2009). The process of continuous development of information technology suggests a necessity for conduction of analyses concerning the possibility of implementing the newest technological solutions in the context of information flow management supporting material and financial flows. Undoubtedly, possibilities of streamlining these flows fit into the scope of logistic interest (Nowakowska-Grunt, Nowakowska, 2012). One of the technologies, that can be used in the SCM and public governance, is Distributed Ledger Technology (Queiroz, Fosso Wamba, 2019). As it is increasingly considered a next-generation information tool, it is argued that the use of Distributed Ledger Technologies (DLT) in SCM and public governance can affect the efficiency and growth of partnerships, thus affecting its performance (Kim, Shin, 2019).

In the area of SCM and public governance, DLT applications can contribute to the elimination or reduction of a number of problems and difficulties. This article aims to identify these problems based on the analysis of contemporary scientific sources and industry reports. The identified issues were presented in the form of three problem areas corresponding to the triple bottom line concept regarding the sustainable development of supply chains and public governance. Solutions using DLT are presented as a solution to the identified problems. The second part of the article describes the potential of DLT application in the area of pro-ecological activities, presents a selected solution aimed at improving the functioning of information flow in the food industry, and describes the possibilities of using DLT in the area of public governance, based on the example of Estonia – a country that is a pioneer in the use of Blockchain technology for public services. Therefore, the potential of using DLT was emphasized in the sustainability aspects.

2. Supply chain management and public governance problems in the context of sustainability

The issue of sustainable development firstly was noticed on the agenda of the World Commission for Environment and Development as early as 1987 (Imperatives, 1987).

At present, the literature presents many definitions of this term, which proves the considerable interest of researchers coming from various fields of science. From the point of view of economic sciences, sustainable development means, following Robert Solow – the 1987 Nobel laureate of the economy, the ability for future generations to live on a similar level to today's (Solow, 1991). In this context, one can recall the United Nations (UN) definition that defines sustainability through the prism of three main domains. Currently, ensuring the sustainable development of supply chains is considered in three basic dimensions: economic sustainability, social sustainability and environmental sustainability, which – for many years – have been referred to as the Triple Bottom Line (Elkington, 1998). Achieving sustainable development in all three dimensions requires collective commitment on the part of both public sector institutions and private business. The issue of aligning its operations with the UN's broad-based Sustainable Development Goals is beginning to be seen as a key one.

Among the main problems of modern supply chains regarding the aspect of economic sustainability, the following can be distinguished: insurance claim (Klibi, Martel, 2010), supply chain procurement contracts (Ghosh, Shah, 2015), high overseas financial transaction fees (Niepmann, Schmidt-Eisenlohr, 2017), loss due to discrepancy in information sharing among the supply chain stakeholders in real-time (Dubey, 2020) and cost of monitoring sustainability (Kshetri, 2018). Efforts in the field of environmental sustainability are therefore directed at limiting the negative impact on the environment, treated as a side effect of the conducted business activity. Organizations put their efforts in the context of energy efficiency, the amount of generated waste and the broadly understood emissions from economic activity (Saberi et al., 2019; Sarkis, 2003). The main goal of environmental sustainability is to ensure intergenerational equality in the possibility of natural resources usage. In SCM, the main problems in this context appear in the nature-economy (transformation of natural resources into materials for production) and economy-nature (utilization of economy by-products) connection. In the first of these cases, every effort should be made to constantly reduce the use of natural resources, while in the second to limit the emission of substances harmful to the environment. To sum up problems of the last aspect of triple bottom line – environmental sustainability – they are related to such issues as: supply chain wastage, pollution issues, footprint, illegally traded animal parts or plants (Giannakis, Papadopoulos, 2016). In the area of social sustainability, the impact of business on the lives of employees, customers and local communities living near the organizations should be taken into account. This element of the triple bottom line conception is relatively rarely studied in management sciences (Venkatesh et al., 2020). However, the topic of socially responsible behavior when purchasing resources is sometimes raised. A clear example here is the supply chain of diamonds coming often from the war zone, which is sometimes referred to as "the blood diamond problem". The emphasis is put on the ethical aspect of diamonds supply chain, which is frequently connected with forcing children to work (Epstein, Yuthas, 2011). Summing up this area, problems related to the aspect of social sustainability are: child labor, employee wages, sourcing from local communities and public health, or food traceability. It is anticipated that the use of DLT may contribute to solving the above problems, thanks to the use of smart contracts, ensuring transparency of information flow, invariability of records in databases, easy access to data by stakeholders and broadly understood traceability (Chandan, Potdar, Rosano, 2019).

Contemporary SCM and public governance issues

A modern supply chains are characterized by a huge spectrum of information flowing through this system and a huge amount of documentation produced within it (EPRS, 2020). The majority of it is created and processed at individual stages of the flow within the supply chain – manually (Skiba, 2020). The use of DLT could significantly automate these processes, while also maintaining a high level of security for their implementation (Szewczyk, 2019). Storing data on transactions between the links of the supply chain in a dedicated, private blockchain would provide full transparency of activities performed within the supply chain for its participants. The actors in a given supply chain would, thus, gain access to transaction data and the stage of its execution in real time. The above-outlined issues in the SCM seem to suggest the statement that it is possible to use the DLT for SCM in order to reduce the impact of identified problems on supply chains.

Among the applications of DLT in SCM, some sources indicate: recording the flow of resources through individual links in the supply chain; tracking orders, receipts, invoices, payments and any other official documents; tracking digital assets (such as warranties, certificates, copyrights, licenses, serial numbers, barcodes) in a standardized way and in parallel with physical assets; sharing information on the production process, delivery, maintenance and consumption of products between suppliers and sellers, introducing new opportunities for cooperation on complex assembly lines with the use of IoT (Litke, 2019). In relation to other studies (Hackius, Petersen, 2017), 4 areas of DLT application in logistics can be identified: document processing/reduction of paperwork; identification of counterfeit products; facilitating traceability; Internet of Things support.

Documents summarizing the research conducted by the European Parliament Research Service (EPRS, 2020) indicate, in turn, four key areas of blockchain applications in relation to logistics: digitalization of resource exchange within the supply chain; cargo security in maritime transport; enforcement of trademarks and property rights; providing additional traceability and transparency in trade.

Other current problems, faced by modern supply chains, are indicated on the basis of (UNECE, 2019) in Table 1.

Table 1
Modern issues of SCM

Problem	Explanation
Proving the origin of goods	Many transactions are made on the basis that the delivered goods are of the declared quality or origin. Buyers do not have a cost-effective way to verify the authenticity of supplier's claims. This increases the dependence on contracts with established players and creates natural entry barriers for new and smaller suppliers.
Customs delays	Customs and excise officials at each border rely on the provided information while making decisions. The ability of unscrupulous actors to alter or fabricate information increases the risk and distrust of the process. This risk and distrust then become delays, costs and uncertainties for all actors in the supply chain, who do not know whether they are good or bad players.
Poor transparency in supply chains	Some of the biggest inefficiencies in many supply chains are the time and effort required to gather accurate information on the location, condition and estimated time of arrival of goods in the supply chain.
Supply chain resilience	When a supply chain breaks, it is often very difficult to recreate it in order to understand the root cause of problems. Being able to prevent and intelligently respond to these incidents has a huge impact on the costs and performance of enterprises, even outside the supply chain.
Errors in payments processing	Sometimes, an audit may not identify all potential discrepancies in the financial flows of the involved links in the supply chain.
Data-driven scams	Audits can overlook the signs of fraud hidden in thousands of data files. Blockchain technology already enables today's supply chain players to reduce and more easily identify fraud attempts.
Dispute resolution	As with the supply chain resilience discussed above, disputes that arise due to time, quantity or quality could be more easily resolved, if reliable data on these (for example time and date of delivery) were recorded on the blockchain. In theory, some disputes could also be avoided by using a set of smart contracts that self-execute based on terms pre-agreed by all parties, thus reducing administrative costs and legal bills.
Information flow that ends at the point of sale	Under current supply chain arrangements, with the limited exception of warranty items, the supply chain ends at the final consignee. Contact with the product is lost and important information about its use is not recorded.

Source: own elaboration based on: The United Nations Centre for Trade Facilitation and Electronic Business. (2019). *White Paper Blockchain in Trade Facilitation.*

3. DLT technology as a solution for sustainability threats

The issues described above correspond to the problem areas suggested in the section on the triple bottom line concept. In this part of the article, the author focuses on describing a few selected DLT-based solutions used in both the private and public sectors. Solutions that fucuses on all three components of the triple bottom line concept were chosen to emphasize the wide range of DLT applications in the context of sustainable development.

Selected DLT solutions for environmental issues

In the area related to the environmental aspect, a number of solutions supporting waste management can be identified. The speed of waste generation in modern cities undoubtedly results from the increased pace of progressive urbanization, economic development and population growth in the world (Kouhizadeh, Sarkis, 2018). Solutions based on DLT can be used in the following problem areas (Ahmad et al., 2021a):

- tracing and tracking of waste of smart cities,
- reliable channelization of waste,
- protection of waste management documentation,
- efficient waste resources management,
- penalties for non-compliance,
- transparency in waste collection and trucks route optimization,
- robots-assisted and reliable waste segregation,
- accountability of waste management operations.

Modern cities generate huge amounts of various types of waste. Such waste then goes to various links in the waste management system (landfills, recycling plants, etc.). Traceability systems can therefore be useful in verifying the authenticity of data and ethical practices related to waste management (Mingaleva et al., 2020). It is based on precise tracking of the current location and condition of waste at every stage of its flow. The centralized solutions used today are susceptible to modifications and changes due to deliberate or accidental database corruption (Ahmad et al., 2021a). Therefore, DLT has the potential to replace the systems used so far in the area of waste management. Blockchain can control the condition and location of waste by creating digital asset tokens to track specific waste. Such tokens allow for a record of transaction history regarding property rights to waste, thus helping authorities to reduce waste management costs (Laurent et al., 2018). The immutability of DLT-based databases allows for ongoing verification of compliance with the actual waste management guidelines, as well as effective tracking of the waste life cycle (Gopalakrishnan et al., 2021). By assuming unchanging records in a distributed database, blockchain can verify the compliance of waste by, for example, comparing the weight of received and shipped waste without the possibility of falsifying such information. In this regard, solutions based on the Ethereum platform can be used. It is an open source platform that allows waste management entities to send and receive micropayments as rewards for participating in Ether cryptocurrency activities through smart contracts. The system built with the use of the Ethereum network enables full transparency of the waste flowing through the supply chain for all its participants, moreover, it enables the construction of a system that promotes ecologically responsible actions.

Waste sewerage, on the other hand, consists in detailed tracking of individual groups of waste characterized by a different degree of harmfulness to the environment and that can be recycled. DLT can ensure that the waste from the products sold is successively collected in the waste management system. Knowing unadulterated data on the sale and use of products, the flow of waste generated from them can be tracked. Producers are able to collect waste through a retail network or dedicated waste collection points. Centralized solutions require maintaining trust towards entities responsible for the system. Blockchain makes it possible to overcome this need for trust by using smart contracts. Consistent and transparent DLT solutions also offer the creation of a system of incentives to participate in an effective waste disposal system. The system participant is motivated by micropayments for the correct direction of the waste flow. The speed of settlements and the high level of security of distributed registers determine the potential of DLT application. Smart contracts are able to provide access to data and the possibility to participate in the waste management system to authorized participants. In addition, they provide authorities with the ability to monitor waste activities and take regulatory action. An example of this solution is taking a deposit amount from a customer when purchasing a product. This amount is automatically reimbursed (thanks to the smart contract included with the purchase) upon return of the waste at the end of the product life cycle (Poongodi et al., 2020). The use of smart contracts in this way creates an incentive for product users to produce less waste. In addition to the function of encouraging responsible waste management, this solution virtually eliminates the possibility of fraud related to this waste. Due to the security of data of system participants, it seems that private blockchain platforms should be used. For example, the Hyperledger Fabric platform offers such solutions. It directs waste thanks to the separation of the manufacturer and seller modules. Transactions between them are verified and approved by validating nodes on the basis of a consensus mechanism. The Hyperledger Fabric code snippets allow you to register new system participants, buy and sell waste, pass it on, make returns, and update the amount of waste remaining in the system.

The implementation of waste management policy in cities requires the safe recording of documents related to invoices, proofs of purchase and various types of contracts. This results in an increased need to care for their safety and protection against manipulation. Decentralization of DLT solutions helps to validate documents coming from organizations involved in the system by comparing document signatures in the public and private key architecture. Blockchain is therefore able to minimize the amount of frauds related to the counterfeiting of documents regarding waste trade (ADDALIA, 2021). This is another use of smart contracts that are executed automatically and their effects are irreversible. Documents accompanying the waste turnover can be encrypted and stored, for example, in the InterPlanetary File System (IPFS). The content of such documents is available to authorized users via the blockchain platform. All changes in them are recorded on an ongoing basis, and system participants can quickly verify their authenticity. The consensus protocols used make falsification of the documentation theoretically impossible. Thanks to the DLT mechanisms, it is possible to verify on an ongoing basis which entity is responsible for the creation or modification of a given document. Due to the General Data Protection Regulation in force, it is suggested to use private blockchains in this case as well. Their use ensures that only entities authorized to do so have access to the data enabling the verification of compliance of documents.

The use of IoT devices allows remote monitoring of the flow of objects thanks to a network of sensors collecting huge amounts of data. The analysis of these data allows managing the waste management system more effectively, developing plans and striving to reduce the emission of negative substances to the environment (Esmaeilian et al., 2018). With the help of IoT devices, the use of key resources of the waste management system (waste transport trucks, garbage cans, employees, landfills, etc.) can be optimized. The lack of transparency in the functioning of these resources leads to the ineffective functioning of the entire system. Thanks to the use of DLT, it is possible to register entities responsible for the operation of devices and track their activities by recording them in an unchanging database. RFID sensors can, for example, be used to track the currently used capacity of garbage containers, informing the entities responsible for collecting waste and substituting a new container about its approaching exhaustion. The sensor networks are also DLT authenticated, ensuring that no one can send incorrect data to the blockchain. Thanks to the data collected in the blockchain system, it is possible to estimate the frequency of the need to transfer waste to the next link in the waste chain. Thanks to this, it is also possible to estimate the amount of waste flowing through the system and calculate the costs of its flows. It also creates a useful database for creating a network of entities responsible for waste treatment, taking into account the proximity of their location to the place where the waste is generated. Data from IoT sensors and recorded in distributed registers can also be used to optimize the allocation of waste storage devices, taking into account carefully researched needs in terms of the type and amount of collected waste.

Pursuant to the applicable documents, entities generating waste are obliged to segregate and store waste in appropriate containers and deliver it to the indicated places for further waste management. All types of waste, both municipal and industrial, must be stored in separate containers. Therefore, it is common to impose various types of penalties and fines for any non-compliance with the practices indicated in the legal acts. Decentralized blockchain architecture with the possibility of approving transactions with a precise indication of the time of their conclusion is a solution ensuring compliance of the activities of waste management authorities with applicable law. Moreover, it enables the automation of the process of imposing contractual penalties in the event of irregularities being detected (Ahmad et al., 2021b). The architecture of the smart contract used here should take into account the roles of its individual users. It is of particular importance to grant appropriate powers to the bodies responsible for imposing penalties, preventing them from being charged by unauthorized bodies. The penalty calculation functionality validates the data collected in a distributed database and imposes appropriate penalties on the authorities carrying out illegal activities.

Selected blockchain solutions for economic issues

In the area of SCM, there are many solutions based on DLT that are in the pilot phase or already operating solutions. Many of them are created thanks to the actions of the IT industry tycoons. The first solution described in this fragment of the article is a solution offered by IBM to increase data transparency in the food supply chain. The increasing availability of food products for consumers nowadays leads to an increase in the complexity of supply chains. With this growth, there is a growing need to build trust among participants in this supply chain. The IBM Food Trust solution builds trust through the use of DLT, building transparency in the food supply chain. This solution provides authorized participants with access to data on the flow of food from the place of its production to the point of sale. Complete flow history with an indication of the time the food remained at specific locations, test data, storage temperature data or food accompanying certificates are available to users in seconds. The IBM Food Trust architecture enables a number of goals to be achieved in relation to the food supply chain (IBM, 2021):

- effectiveness of the supply chain – identification of ineffective processes, demand forecasting,
- brand building – increased transparency allows you to build the brand of food producers, wholesalers and retailers based on a transparent history of their activities on the market,
- ensuring the quality of the food offered – unprecedented insight into data on the food flow through individual links in the supply chain, including data from IoT sensors providing information about product parameters at individual stages of the flow,
- ensuring food safety – detection of deviations in food parameters in terms of its safety in real time, detection of cross-contamination and contact with substances hazardous to food, reduction of food-borne diseases (enabling the withdrawal of contaminated batches from the market),
- limitation of fraud – full transparency thanks to digitization of transaction records, storing them in a decentralized and unchanging manner, easy detection of attempts to modify food flow history records,
- waste reduction – optimization of the waste collection system, transparent data on waste turnover,
- ensuring the authenticity of origin – digitization of certificates and documents proving the origin and authenticity of food.

The solution described in this part of the article uses the previously mentioned Hyperledger Fabric open source architecture and integrates a number of solutions dedicated to the food industry. The simplified architecture of the IBM Food Trust is presented in Figure 1. The method of collecting and processing data in a distributed database is schematically illustrated in Figure 1.

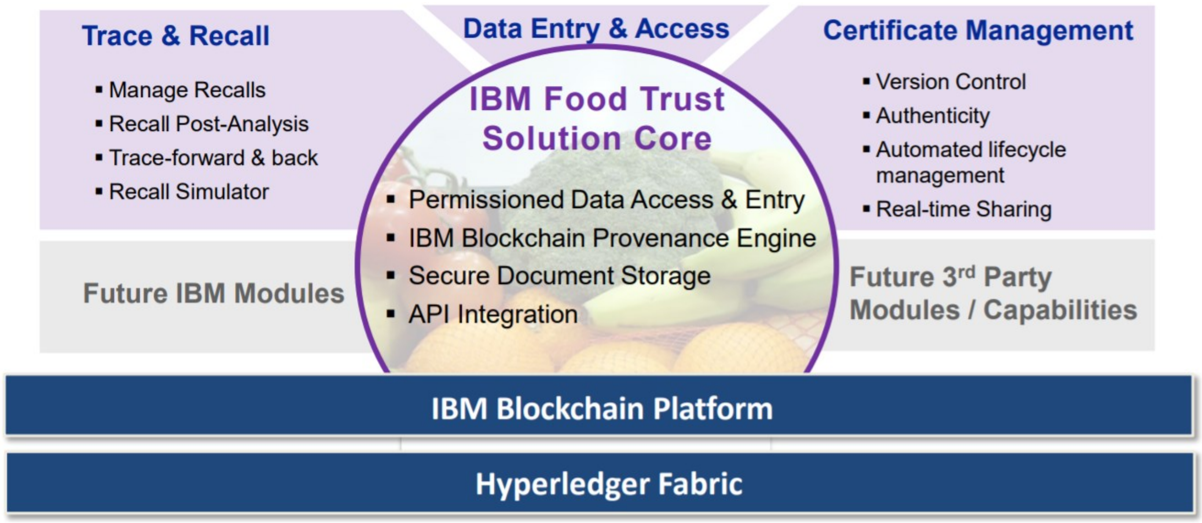

Figure 1. The simplified architecture of the IBM Food Trust. Adapted from: https://www.ecrireland.ie/uploadedfiles/leaders-congress/leaders-congress-2018/10.00-Michael-McMahon-IBM.pdf, 30.12.2021.

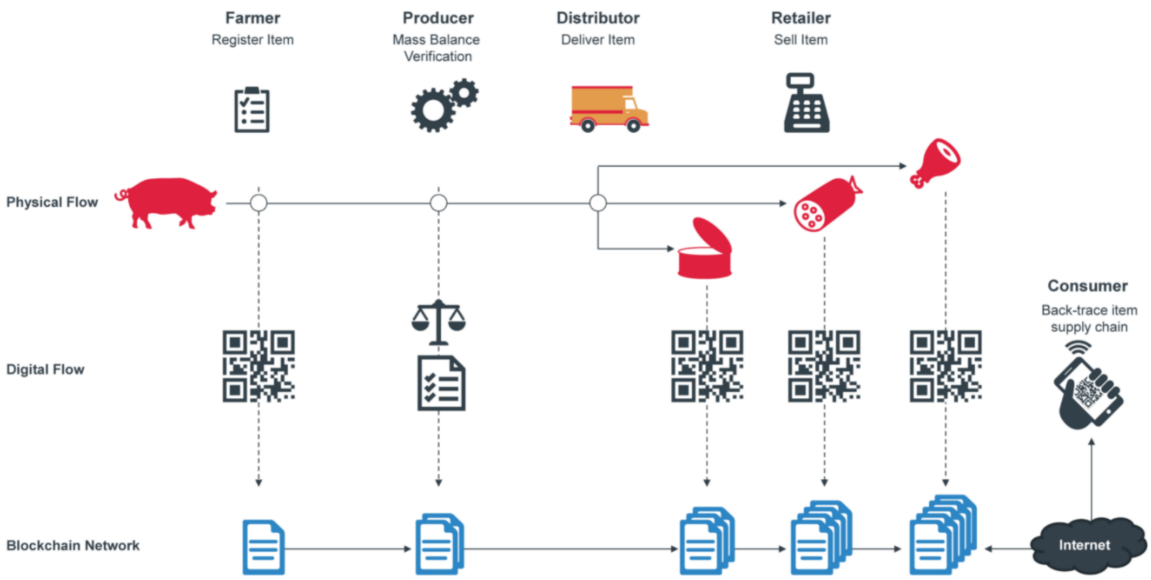

Figure 2. Physical and digital flow for IBM Food Trust blockchain network. Adapted from: https://www.innovativeleaders.world/insights/item/32-nestle-bets-on-blockchain-for-food-traceability.html, 30.12.2021.

Figure 1 suggests that the current architecture is open to the appearance of additional modules that can supplement the described solution with new functionalities. These solutions can be added both by IBM and by external organizations and validated in accordance with the consensus mechanisms resulting from the use of DLT. Figure 2 shows, however, that at each stage of the physical flow of goods through the food supply chain, there is a digitized flow of information that is stored in a distributed database in the form of non-modifiable records. The final recipient of food (consumer) has access to the history of data on the physical flow of the product, gaining full information transparency.

IBM Food Trust provide value for lot of food supply chain members. The value provided for particular food supply chain node is presented in Table 2.

Table 2
The value provided for food supply chain's nodes

Food supply chain node	Value added by IBM Food Trust
Growers	-Proving the farm is not a source of outbreak, -connectivity to the supply chain
Food manufacturers	-Instill trust between retails, suppliers and customers -Automated and reduced manual certificate management
Distributors	-Conduct targeted recalls -Enable internal data sharing
Logistic companies	-Enhanced ability to meet compliance standards -Manual processes reduction
Retailers	-Assure customers food supplied is safe -Conduct targeted recalls quickly
Consumers	-Learn about recalls and increased transparency -Reduce risk of being victimized by food fraud
Certification bodies	-Reduce fraudulent certificates -Increase renewal speed
Food services (HORECA)	-Assure customers food supplied is safe -Reduce wasted food
Regulators	-Identify contamination quickly -Reduce unnecessary testing

Selected blockchain solutions for public governance

The last group of DLT-based solutions that refer to the problems related to the tripple bottom line concept are those related to the social sphere. A case study that emphasizes the largest number of aspects is the example of Estonia as a country that has made a large adoption of blockchain-based solutions. Estonia is a country that started building digital solutions for society in the form of e-governance system in 1997. According to the PwC report, as of today, 99% of public services can be performed fully digitally (PwC, 2021). For example, it takes less than 5 minutes for an Estonian citizen to file a tax return, elections are online and all patients have electronic medical records. It is possible to set up a business completely online and tons of documents are signed electronically. Report shows that Estonia saves 2% of GDP annually thanks to the implementation of electronic solutions in the field of public services. The cornerstone of Estonia's digital society is X-Road. It is a technological and organizational environment that enables secure data exchange on the Internet between various IT systems. X-Road is therefore an interoperable ecosystem combining the functionalities of separate IT systems. This ecosystem is also currently implemented in Finland, Azerbaijan, Namibia and the Faroe Islands, and one of its functionalities is also the automatic connection of systems of individual countries. Such a connection is established between Estonia and Finland. The PwC report indicates that Estonian X-Road currently connects over 1,300 IT systems and offers over 2,700 services. X-Road's architecture is fully decentralized and multi-lateral, which allows any member of X-Road to access data related to other services provided through X-Road. The security of data flowing through the X-Road ecosystem is ensured by blockchain technology, and the logic of its operation is presented in Figure 3.

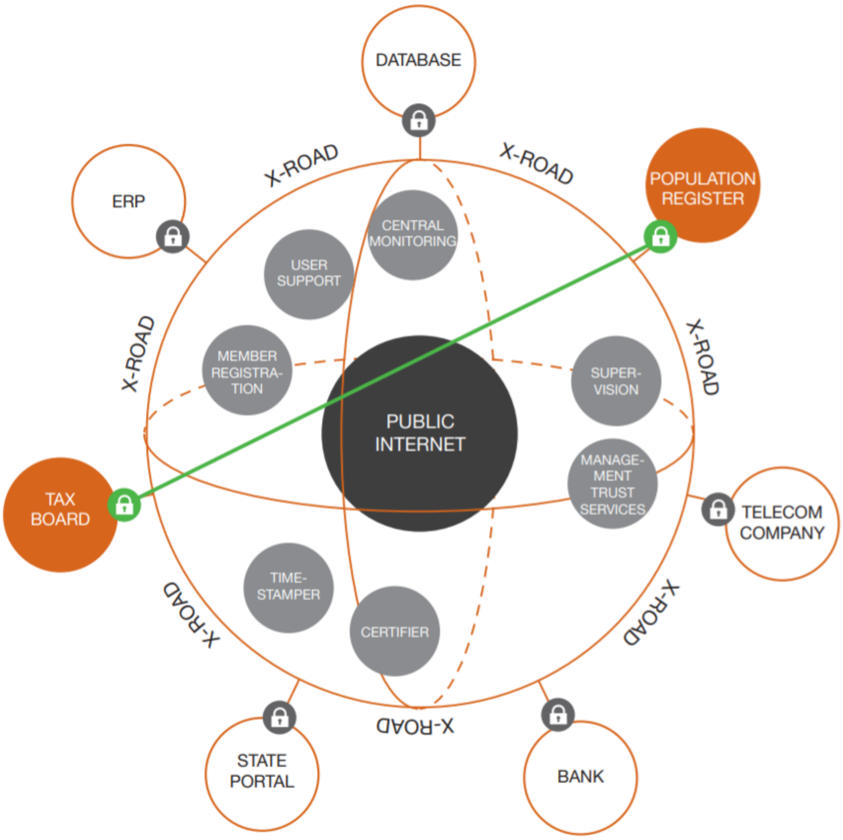

Figure 3. The X-Road ecosystem structure. Adapted from: https://www.pwc.com/gx/en/services/legal/tech/assets/estonia-the-digital-republic-secured-by-blockchain.pdf, 30.12.2021.

To ensure the security of such a wide-ranging decentralized ecosystem, Estonia was the first country in the world to start using blockchain solutions. In 2012, the first service embedded in DLT was the inheritance register kept by the Estonian Ministry of Justice. The technology used in this case is Keyless Signature Infrastructure (KSI). This solution is also used by NATO and the US Department of Defense and ensures that the data never leaves the KSI system, only the hash (a function that meets the encrypted demands needed to solve for a blockchain computation) is sent to the blockchain-based service. For this reason, the system is widely scalable and can ensure immutability of huge amounts of data. Among the national registers whose security is maintained by means of blockchain, the following can be indicated: Healthcare Registry, Property Registry, Business Registry, Succession Registry, Digital Court System, State Gazette. The logic of the blockchain-based solution is shown in Figure 4.

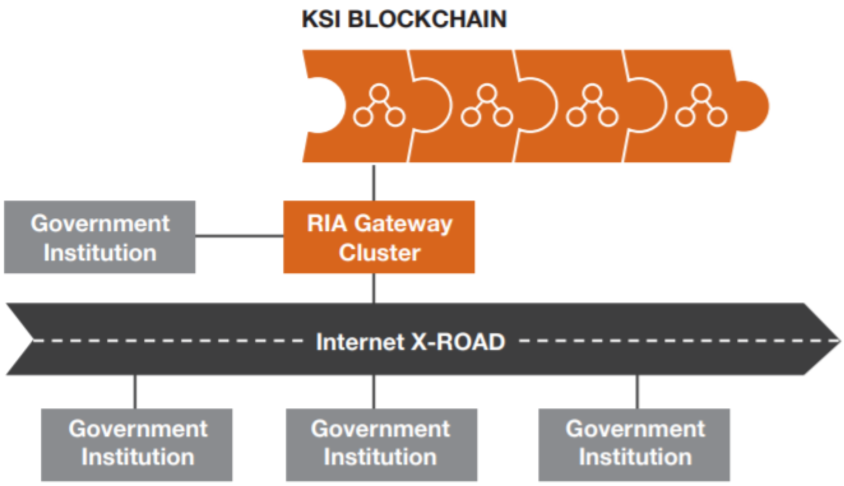

Figure 4. KSI Blockchain solution for Estonian X-Road ecosystem. Adapted from: https://www.pwc.com/gx/en/services/legal/tech/assets/estonia-the-digital-republic-secured-by-blockchain.pdf, 30.12.2021.

The data collected across the entire X-Road ecosystem by connecting a number of government institutions is processed using the RIA Gateway Cluster. Then the data from the databases is validated with a digital signature, and the encrypted information in the form of a hash is placed in the KSI Blockchain. Thanks to this, the confidentiality of the data is maintained (because full information never leaves the system in which it was created), and the blockchain stores information about the entity validating the correctness of the data and the time of its approval. Thanks to this, the information placed in the system integrated with the use of a blockchain cannot be modified retrospectively, while its confidentiality is maintained thanks to the use of hashing functions that are the foundation of DLT. The logic of the system can be explained in more detail by showing an example of the data flow coming from the system of an exemplary public governance area. The judiciary is such an example. Figure 5 shows how data is moved to the KSI Blockchain. Data on individual court cases is collected in an internal court system connected to the KSI Blockchain. Using the hash functions and electronic signature, only information about the document signatures of individual cases, the time of their closing and entities validating the transmission of data to the blockchain are sent to the blockchain. Detailed data on cases, legal acts remain stored in the internal system, while blockchain ensures their integrity and immutability.

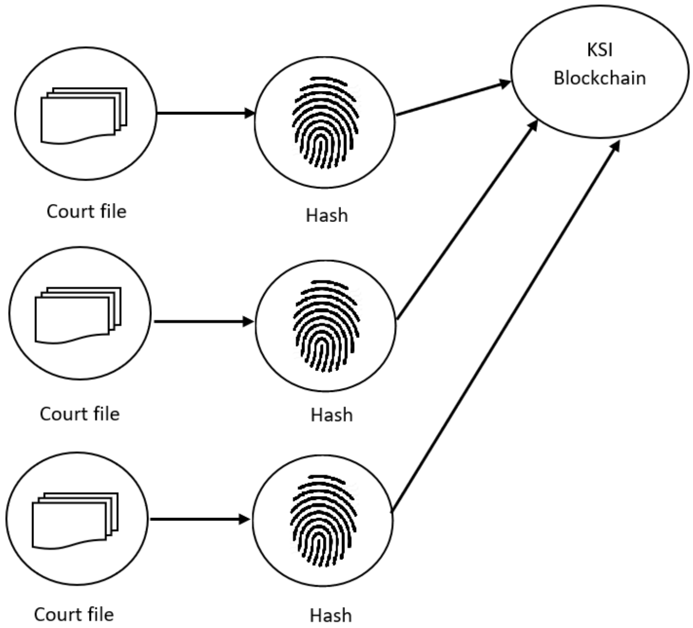

Figure 5. KSI Blockchain solution for Estonian X-Road ecosystem. Adapted from: https://riigipilveinfopaev18.publicon.ee/userfiles/RIA/kevad2018/riigipilv2018/7.2_Riigipilve_infop%C3%A4ev_GT.PDF, 30.12.2021.

4. Conclusion

Solutions based on DLT using Blockchain already streamline a number of processes in the SCM and public governance. However, they are at an early stage of development and show great potential for the future. This article has sorted out the problems of contemporary supply chains and public governance taking into account the aspects of sustainability. The author described the potential of DLT in solving these issues. The constantly appearing new DLT applications indicate the need to constantly analyze areas of their application. The future research work of the author of this article will focus on subsequent implementations of DLT solutions in the field of broadly understood logistics. The author is firmly convinced that Blockchain solutions have many challenges ahead of them, overcoming which they can be widely used. Considering the Estonian example described, there is a good chance that DLT will be used by mass users in other countries in the near future. Examples of pro-environmental applications are an interesting area of research for researchers in this field, and solutions improving the transparency of the flow of goods through the supply chain should contribute to increasing the awareness of its participants and reducing the possibility of data-based frauds.

References

1. ADDALIA (2016). *Document Management in Times of Blockchain*. Available online https://blog.addalia.com/en/document-management-in-times-of-blockchain, 30.12.2021.
2. Ahmad, R.W., Salah, K., Jayaraman, R., Yaqoob, I., Omar, M. (2021). *Blockchain for Waste Management in Smart Cities: A Survey*.
3. Ahmad, R.W., Salah, K., Jayaraman, R., Yaqoob, I., Omar, M., Ellahham, S. (2021). Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies. *IEEE Access, 9,* pp. 44905-44927.
4. Chandan, A., Potdar, V., Rosano, M. (2019). *How Blockchain can help in Supply Chain Sustainability*.
5. Dubey, R., Gunasekaran, A., Childe, S.J., Papadopoulos, T., Luo, Z., Roubaud, D. (2020). Upstream supply chain visibility and complexity effect on focal company's sustainable performance: Indian manufacturers' perspective. *Annals of Operations Research*, *290(1),* pp. 343-367.
6. Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21stcentury business. *Environmental Quality Management*, *8(1),* pp. 37-51.
7. Epstein, M.J., Yuthas, K. (2011). Conflict minerals: Managing an emerging supply- chain problem. *Environmental Quality Management*, *21(2),* pp. 13-25.
8. Esmaeilian B., Wang B., Lewis K., Duarte F., Ratti C., Behdad S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Management, vol. 81,* pp. 177-195.
9. European Parliament Research Service (2020) *Blockchain for supply chains and international trade, Report on key features, impacts and policy options.* Available online https://www.europarl.europa.eu/RegData/etudes/STUD/2020/641544/EPRS_STU(2020)641544_EN.pdf, 24.08.2021.
10. Ghosh, D., Shah, J. (2015). Supply Chain Analysis under Green Sensitive Consumer Demand and Cost Sharing Contract. *International Journal of Production Economics, 164,* pp. 319-329.
11. Giannakis, M., Papadopoulos, T. (2016). Supply Chain Sustainability: A Risk Management Approach. *International Journal of Production Economics, 171*, pp. 455-470.
12. Gopalakrishnan, P.K, Hall, J., Behdad, S. (2021). Cost analysis and optimization of blockchain-based solid waste management traceability system. *Waste Management*, *vol. 120,* pp. 594-607.
13. Hacker, W. (2007). Informationsflussgestaltung als Arbeits und Organisationsoptimerung. *Jenseits des Wissensmanagements. vdf Hochschulverlag AG an der ETH Zürich*.

14. Hackius, N., Petersen, M. (2017). *Blockchain in Logistics and Supply Chain: Trick or Treat*. Available online https://tubdok.tub.tuhh.de/bitstream/11420/1447/1/petersen_hackius_blockchain_in_scm_and_logistics_hicl_2017.pdf, 7.09.2021.
15. IBM Food Trust. Available online https://www.ibm.com/downloads/cas/8QABQBDR, 30.12.2021.
16. Imperatives, S. (1987). *Report of the World Commission on Environment and Development: Our Common Future*.
17. Klibi, W., Martel, A., Guitouni, A. (2010). The Design of Robust Value-Creating Supply Chain Networks: A Critical Review. *European Journal of Operational Research, 203, 2,* pp. 283-293.
18. Kouhizadeh, M., Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in greening supply chains. *Sustainability*, *vol. 10, no. 10,* p. 3652.
19. Kshetri, N. (2018). Blockchain's Roles in Meeting Key Supply Chain Management Objectives. *International Journal of Information Management, 39*, pp. 80-89.
20. Laurent, P., Chollet, T., Burke, M., Seers, T. (2018). The tokenization of assets is disrupting the financial industry. Are you ready. *Inside magazine*, *19,* pp. 62-67.
21. Litke, A., Anagnostopoulos, D., Varvarigou, T. (2019). Blockchains for Supply Chain Management: Architectural Elements and Challenges Towards a Global Scale Deployment. *Logistics*, *3,* 5.
22. Mingaleva, Z., Vukovic, N., Volkova, I, Salimova, T. (2020). Waste management in green and smart cities: A case study of Russia. *Sustainability, vol. 12, no. 1,* p. 94.
23. Niepmann, F., Schmidt-Eisenlohr, T. (2017). International Trade, Risk and the Role of Banks. *Journal of International Economics, 107*, pp. 111-126.
24. Nowakowska-Grunt, J., Nowakowska, A. (2012). Selected tools of information flow management in logistics. *Studia Ekonomiczne, 121.* Uniwersytet Ekonomiczny w Katowicach, pp. 73-82.
25. Pereira, J.V. (2009). The new supply chain's frontier: Information management. *International Journalof Information Management, 29,* pp. 372-379.
26. Poongodi, M., Hamdi, M., Vijayakumar, V., Rawal, B.S. Maode, M. (2020). *An effective electronic waste management solution based on blockchain smart contract in 5G communities.* Proc. IEEE 3rd 5G World Forum (GWF), pp. 1-6.
27. Prayogo, G. (2018). Bitcoin, regulation and the importance of national legal reform. *Asian Journal of Law and Jurisprudence, 1(1),* pp. 1-9.
28. PwC Estonia Report. Available online: https://www.pwc.com/gx/en/services/legal/tech/assets/estonia-the-digital-republic-secured-by-blockchain.pdf, 30.12.2021.
29. Queiroz, M.M., Fosso Wamba, S. (2019). Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. *International Journal of Information Management, 46,* pp. 70-82.

30. Rajaguru, R., Matanda, M.J. (2013). Effects of inter-organizational compatibility on supply chain capabilities: Exploring the mediating role of inter-organizational information systems (IOIS) integration. *Industrial Marketing Management, 42,* pp. 620-632.
31. Saberi, S., Kouhizadeh, M., Sarkis, J., Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research, 57,* pp. 2117-2135.
32. Sarkis, J. (2003). A strategic decision framework for green supply chain management. *Journal of Cleaner Production, 11,* pp. 397-409.
33. Skiba, R. (2020). *Blockchain Technology as a Health and Safety Contributor in the Transport and Logistics Industry – Human Resource Requirements*, pp. 544-550.
34. Solow, R.M. (1991). *Sustainability: An. Economist's Perspective.* Woods Hole, MA, USA: Marine Policy Center.
35. Szewczyk, P. (2019). Application of Blockchain Technology in Supply Chain Management. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, pp. 591-600.
36. The United Nations Centre for Trade Facilitation and Electronic Business (2019). *White Paper Blockchain in Trade Facilitation*.
37. Venkatesh, V., Kang, K., Wang, B., Zhong, R.Y., Zhang, A. (2020). System architecture for blockchain based transparency of supply chain social sustainability. *Robotics and Computer-Integrated Manufacturing, 63,* 101896.