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Examining the Evolution of Technological Conditions from the Point of View of the Application of Blockchain-based Data Management in Food Supply Chains

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A critical point in making food chains more sustainable is to find different ways to increase efficiency. These can be aimed at shortening the chain, using more sustainable raw materials, etc. Blockchain technology offers the potential for reliable data management and simplified administration and is, therefore, definitely a tool to consider if the aim is to enhance sustainability in food chains. The question arises as to whether food chain operators have the technology and knowledge needed for widespread uptake. The aim of this research was to investigate whether the technical background and knowledge for the use of cryptocurrencies can be compared with the technological background for monitoring the food chain with blockchain-based data management. If so, since data on the uptake of cryptocurrencies is already available, this analysis will provide information on the realistic scope of such an application. The research showed that there is no significant difference in the technology required for the two applications. The data clearly shows that, overall, there are 4.6 billion people who have the tools to use them. In addition, there is evidence that cryptocurrency penetration is weakly correlated with GDP or banking system development. In other words, if other conditions are right (e.g., the interest of producers), the availability of tools and knowledge should not be a barrier to uptake. Neither is the economic performance of a country or the development of its banking system. It is therefore concluded that, based on the aspects examined in this research, blockchain technology can be applied on a large scale worldwide.

1. Introduction

The food supply chain links many activities, from the sourcing of raw materials through processing to final human consumption and distribution. The process involves not only many steps but often many actors, such as producers, manufacturers, suppliers, retailers and wholesalers. Different actors have different interests and make decisions based on these interests (Myo and Yoon, 2014). But data security is in the interest of all actors who want to do business fairly. The food industry can be competitive if it delivers products that meet demand requirements (price, quality and quantity) and provide a level of profit that allows companies to perform well economically, develop their business and grow (Turi et al., 2014). But it is not enough to meet these conditions: they must also be able to credibly demonstrate that what they claim about a product, or even about their own operations, is true. Thus, the issue of data validation is one that needs to be addressed and will become increasingly important in the future (Pulipati et al., 2022).
As with all supply chains, sustainability is a key issue in the operation of food chains. Sustainability involves not only minimising the environmental impact of the process but also ensuring that there is an appropriate level of trust in its operation (Giuseppe et al., 2017). Efforts to ensure that the supply chain uses as little energy as possible and produces as few harmful substances or emissions as possible are futile if problems that arise regularly, e.g. contaminants in food, disclosure of falsified data (Adrie et al., 2003), etc., undermine trust and thus reduce efficiency (e.g. through additional control points, additional administration) and thus reduce sustainability. This problem can also be addressed by properly validated data.

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Blockchain technology enables reliable data to accompany the entire product lifecycle, which is available to all market participants in an unalterable form. This reduces the amount of control points and administration (bureaucracy) required.

Blockchain technology became widely known with the spread of cryptocurrencies, as it is the basis of their operation. The first digital currency used to keep its ledger was Bitcoin. However, its development can be dated earlier (Sherman et al., 2019). David Chaum, a doctoral student at the University of California, Berkeley, created a blockchain database in his dissertation "Computer Systems Established, Maintain, and Trust by Mutual Suspicious Groups." (Chaum, 1979). Decentralized databases existed before, but he is considered the inventor of the technology. Chaum also wanted to use the tool for business purposes, for which he founded DigiCash in 1989 in order to commercialize his invention, but the attempt was not commercially successful, and the business was later closed. A blockchain is a database where information is stored on a distributed network, as opposed to the widely used solution of using servers for this purpose (Sarmah, 2018). In the case of centralized networks, such as banks or agencies, the data is managed centrally, which requires strong trust in them. Data processed in this way is exposed to serious risks since if there is a problem with central storage, either due to intentional damage or failure, the entire database can be compromised. The source of such a problem can be a hacking attack, a natural disaster, misuse of the registry, etc. In the case of a decentralized network, these problems do not arise since the information is available in several places and can only be modified with extreme effort, which is impossible in practice (Darcy et al., 2019). The best example of a decentralized network is the Internet itself. When customers connect their phone, tablet, or computer to the Internet Service Provider (ISP) to reach a larger provider, they are practically using a decentralized network.

In blockchain data management, transactions are downloaded to computers operating on the distributed network. When the latest information is recorded, software running on all computers on the network checks it and updates the database (Sivula et al., 2021). It follows from the above that blockchain architecture is suitable for tracking various supply chains due to its operation. It meets the requirement of reliability since the information recorded during the process cannot be modified, and even if an error occurs during recording, the correction is only made with a new block, i.e., the originally recorded data can also be seen. This data is accessible to all actors in the food chain, so all participants can be held accountable, and their activities can be monitored throughout the process. As a result, the path of food from farm to table can be tracked in real-time (Yu et al., 2020). The great advantage of the system is that if there is a problem with the product (for example, contamination is found in it), it is possible to trace the source very quickly and isolate the product from other non-affected products (Xin et al., 2020). This avoids having to withdraw goods from the market in too broad a spectrum, i.e., there will be fewer losses, so the process is more sustainable. However, there is a recurring concern in research into the proliferation of blockchain-based data management, and that is whether actors in the food supply chain have the technology and knowledge to implement it on a large scale.

However, in addition to these advantages, there are still few examples of blockchain technology being used in food chain tracking, and thus little practical experience is available. The aim of the paper is to find an answer to the question of whether blockchain technology can be a technological obstacle to widespread use in food chains from the user side.

2. Materials and methods

The study relied primarily on internationally available data. Since a significant part of the penetration data included in the research is not recorded by state organizations or statistical offices, data from well-known research companies such as the Boston Consulting Group were used. The existing data were compared with statistical methods, primarily correlation analysis, according to Eq. (1):

$$r_{yx_j} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

where,
y_i: quality (level) of the sustainability report of the *i* company
x_i: characteristic of the *i* company

In cases where it was not yet possible to publish data from scientific studies due to the freshness of the data, the research relied on up-to-date internet sources. These include data from the International Monetary Fund (IMF) and The Observatory of Economic Complexity (OEC) and Boston Consulting Group (BGC). The countries included in the study were determined primarily on the basis of available data. And for the countries included in the available databases, their relevance to the study was checked. As both developing world countries and countries with higher economic levels were included in the sample, their inclusion was accepted. In addition, a dynamic growing body of literature relevant to the topic was used.

The research was based on the hypothesis that blockchain technology has similar requirements for cryptocurrency traders and food chain trackers.

3. Results and discussion

This research examines the technological conditions for blockchain-based monitoring of the food chain from two angles. On the one hand, it examines the spread of the necessary assets, and on the other hand, it uses the characteristics of the spread of cryptocurrency trading, which can be paralleled with the technology. Using these two methods increases the chances of getting a more accurate result.
Before looking at the characteristics of cryptocurrency trading, it is necessary to consider the technical conditions required for users to monitor the supply chain and then compare them with the system requirements for trading digital currencies.

3.1 Demand requirements

Mobile devices should be used for day-to-day operation and tracking, although the actors often use desktop computers. Solutions available via smartphones were highlighted within mobile devices because, as the data shows, this device is widely available and, therefore, the most convenient for potential users.
An ideal example for this study is found in the employment of one of the largest supermarket chains (Migros) in Switzerland. The TE-FOOD system was developed to track the supply chain of fresh fruit and vegetables on a blockchain-based basis. The app has already been introduced by several manufacturers and dealers, so it is definitely relevant to the topic (Köhler and Massimo, 2020).

The application details as of 31.07.2023 are as follows:
Version: 1.2.20
Updated: 15.06.2023
Download size: 11.67 MB
required OS: Android 7.0 and above
Source: Android Play Store

As you can see, the application does not require significant resources from the user side. To support this, let us look at the prevalence of different Android versions around the world. Android is the most common smartphone operating system, as 72.2 % of users use such a device, so it is a good starting point for testing.
As shown in Table 1, 95.1 % of current Android operating systems are phones running Android 7.0 or higher. In terms of the storage space required, Android 7.0 is orders of magnitude more demanding than the application itself, which requires only 11.67 MB of storage capacity, so this should not be an obstacle to running the system.

Table 1: Android OS version distribution (Composables.com, 2023)

Android version	Distribution	Cumulated distribution
KitKat (4)	0.5 %	99.7 %
Lollipop (5)	1.8 %	99.2 %
Marshmallow (6)	2.3 %	97.4 %
Nougat (7)	3.0 %	95.1 %
Oreo (8)	8.3 %	92.1 %
Pie (9)	11.9 %	83.8 %
Q (10)	17.8 %	71.9 %
R (11)	23.1 %	54.1 %
S (12)	16.3 %	31.0 %
T (13)	14.7 %	14.7 %

The number of smartphone users worldwide reached 6.7 billion in 2022 (Statista.com, 2023). 72.2 % of this number used Android, which means about 4.8 billion users, 95.1 % of which are 4.6 billion users. In other words, about 4.6 billion people could use the above application if they wished. Add to this fewer common platforms, e.g., the IOS (Apple) operating system. The latter system also has a share of more than 20 %, bringing the number of potential users to close to 1.5 billion.
As you can see, blockchain-based supply chain tracking is not hindered from the technological side. However, it is also worth looking at the technological conditions needed to make blockchain as widely used as possible in the world to get a more accurate picture of its potential. To facilitate this, the system requirements for three different cryptocurrency trading platforms are shown below (Table 2).

Table 2: System requirements for Cryptocurrencies Application (Google Play, 2023)

Characteristic	Etoro	Libertex	Binance
Hosting	53,25 MB	17,89 MB	137 MB
Android version	Android 6.0 and above	Android 5.0 and above	Android 5.0 and above
Application version	583.0.0	2.32.0	2.68.3
Updated	2023.07.06	2023.04.06	2023.07.28

In terms of storage space, there are two stricter requirements than TE-FOOD, but this is not significant, since the operating system itself needs orders of magnitude more storage space to function, so this does not mean limited capacity. All three systems are less demanding regarding the Android version number, since two can be used with version 5 of the Android operating system, and the third can be used from version 6.
It means that 4.1 % fewer Android users are able to use the TE-FOOD system developed for food chain tracking than two of the common cryptocurrency trading platforms. In terms of total user numbers, the extent of the difference allows us to draw parallels between the real spread of digital currencies and the possible spread of food chain tracing based on blockchain technology. If the conditions are given for the former, they are also given for the latter.

3.2 Cryptocurrency penetration

In the previous point, it turned out that the two uses are at a similar level in terms of technological conditions. Thus, the next step is to examine the spread of cryptocurrency trading around the world. Unfortunately, there is a relatively small database available for penetration testing, but the study (Tony and Tjun, 2022) by the Boston Consulting Group contains data for 25 countries (Figure 1). The countries include countries with lower and higher levels of economic development, so they are sufficiently heterogeneous. The different levels of development can be seen in the Gross Domestic Product (GDP) per capita data of different levels (Table 3) and in the penetration of traditional banking services. In addition, the sample includes countries from North America, Europe, Asia, Africa, and Australia and Oceania.

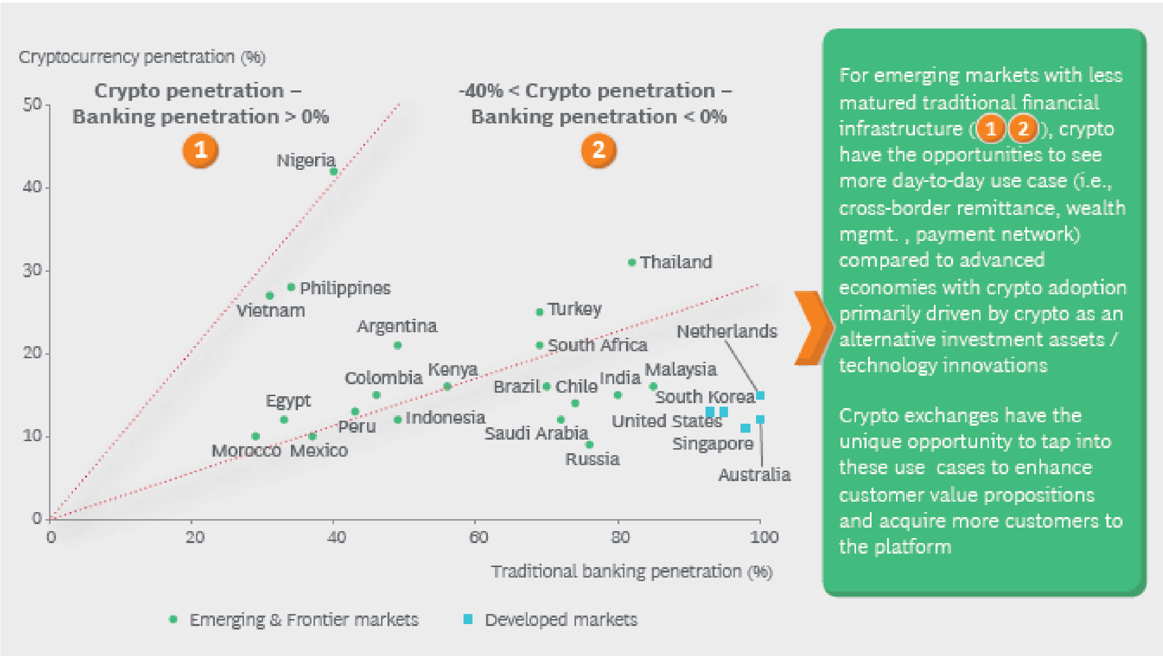

Figure 1: Crypto penetration and Traditional banking penetration (Tony and Tjun, 2022)

Relevant to this topic are the food exports of the given countries. If a country is actively exporting, it means that it is a serious participant in the food chain, so it is definitely worth examining the connections in this respect as well. The relationship between export volume and bank penetration (also included in the above finding) is confirmed, with a correlation value of 0.47. This is not surprising, since advanced exports presuppose a developed banking system. In order for the economy to finance exports efficiently, producers receive timely payments for their crops, transactions are cheap and predictable, and a reliable, well-functioning, and extensive banking system is necessary.

However, when looking at cryptocurrency penetration and banking activity, the relationship is smaller and opposite (-0.2). The reason for the reverse relationship is probably that where the banking system does not function at a high level, i.e., it cannot play its role 100 %, market participants are also more actively using other alternatives, in this case, digital currencies and the platforms necessary for them. The same correlation is even stronger when the correlation between the spread of cryptocurrencies and the level of GDP per capita in a given country is examined. In this case, the correlation is -0.3. So, the weaker a country's economic performance per capita, the more cryptocurrencies are used for payment, investment, or speculation. This may be due to insufficient quality of services or simply a lack of trust. Based on this, a weak negative correlation between exports and the spread of cryptocurrencies is expected (-0.11), as there is a similar correlation as in the case of GDP per capita.

Regarding the above data, it can be said that the spread of digital money is not only a disadvantage if a country has a lower per capita economic performance or a lower level of the financial system, but, on the contrary, it also acts as an incentive for it. Lower economic performance presupposes a lower level of technology, but as can be seen, the use of databases based on blockchain technology means such low system requirements from the user side that it is not difficult to provide it even with a weaker level of technology. However, due to other factors, which are not now included in the scope of the research, it is worth using these solutions for the people living there, as their spread supports this.

Table 3: Penetration and economics data

Country	Foodstuffs Export $ Billion (OEC World, 2023)	Cypto penetration (%) BCG (Tony and Tjun, 2022)	Banking penetration (%) BCG (Tony and Tjun, 2022)	GDP per capita $ (IMF.org, 2023)
USA	49.9	14 %	92 %	70,159
Netherlands	42.5	16 %	99 %	57,996
Brazil	26.5	16 %	70 %	7,754
Thailand	20.0	31 %	82 %	7,226
India	11.6	15 %	80 %	2,234
Argentina	12.4	21 %	48 %	10,616
Russia	8.9	9 %	75 %	12,617
Turkey	9.8	25 %	68 %	9,654
South Korea	7.5	16 %	95 %	34,997
Malaysia	7.2	17 %	85 %	11,449
Singapore	11.4	12 %	98 %	77,710
Indonesia	10.4	13 %	48 %	4,362
Vietnam	7.7	27 %	31 %	3,753
Philippines	2.9	28 %	34 %	3,576
South Africa	4.3	22 %	68 %	6,965
Morocco	2.6	10 %	29 %	3,934
Egypt	2.2	12 %	33 %	4,145
Australia	6.6	13 %	99 %	63,896
Chile	4.4	14 %	73 %	16,059
Peru	4.1	13 %	43 %	6,678
Colombia	1.6	15 %	46 %	6,239
Mexico	18.5	10 %	37 %	9,869
Nigeria	1.2	42 %	40 %	2,088
Kenya	0.6	16 %	55 %	2,215
Saudi Arabia	1.9	13 %	72 %	25,463

All the data indicated in the table refer to the year 2021.

Interestingly, of the countries above 20 % cryptocurrency penetration, only Argentina reaches $10,000 in GDP per capita, while below 10 % can only be seen in Russia.

4. Conclusions

The research shows that although it is difficult to obtain cryptocurrency penetration data for the majority of countries, there is still sufficient coverage of data to draw conclusions. In the case of the spread of blockchain technology outside cryptocurrencies, the question arises whether the technology is given to spread widely in all countries important in supply chains, thus even creating global tracking systems. Looking at the issue from two sides, the clear conclusion is that the low quality of the devices from the user side should not be a barrier to adoption. The hypothesis that blockchain technology imposes similar requirements on cryptocurrency traders and food chain trackers has been proven. On the one hand, there is a very wide range of mobile devices that meet the technological requirements of the applications used (approximately 4.6 billion people). The two largest market shares of smartphones, Android and IOS, are already in the pockets of billions of people, with more than 90 % of them capable of running these operating systems. On the other hand, cryptocurrency trading systems based on the same technology are also widespread in countries where the level of technology is otherwise not among the best in the world (e.g., Nigeria). However, lower GDP per capita or a lower level of banking system usage is not a barrier. Therefore, if other conditions are met, such as the provider of the software (e.g., a government agency or a major market player) or the financial interest of the actors in the chain, the system can be effective and widespread. Of these, finding the financial interest may be the main challenge since, if this is given, it is easy to find a cohesive organization, so it is worthwhile to continue research in this direction.

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