Sustainability standards and blockchain in agro-food supply chains

Synergies and conflicts

Köhler, Susanne; Bager, Simon; Pizzol, Massimo

Published in:
Technological Forecasting and Social Change

DOI (link to publication from Publisher):
10.1016/j.techfore.2022.122094

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Technological Forecasting & Social Change 185 (2022) 122094

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Sustainability standards and blockchain in agro-food supply chains: Synergies and conflicts

Susanne Köhler [a], Simon Bager [b], Massimo Pizzol [a,*]

[a] Department of Planning, Aalborg University, Aalborg, Denmark
[b] Georges Lemaître Centre for Earth and Climate Research, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

ARTICLE INFO

Keywords:
Supply chain governance
Sustainability
Voluntary sustainability standards
Blockchain technology
Ecolabels

ABSTRACT

Blockchain-based technologies have emerged as a mechanism for governing sustainability in agro-food supply chain, where voluntary sustainability standards have been the main governance mechanisms over the past decades. Despite a growing body of research on blockchain-based technologies, the relationship between these two mechanisms for supply chains remains poorly understood. Therefore, this study aims at addressing this research gap and explaining their interaction. We described and assessed 16 cases of blockchain-based technologies and voluntary sustainability standards against twelve sustainability-related assessment criteria. The results show that the relationship between blockchain-based technologies and voluntary sustainability standards can be co-existing, synergistic, and antagonistic. While most cases fall under the co-existing relationship, we identified a few cases with synergistic relationships, and one case with an antagonistic relationship. We explain each type of relation and show how the system architecture and goal of a blockchain-based technology implementation are key determinants of this relationship. This study can support stakeholders in agro-food supply chain in better understanding the application of blockchain-based technologies for sustainability governance in relation to existing voluntary sustainability standards. It can further inform those stakeholders of possibilities to constructively collaborate and focus on positive social and environmental impacts within agro-food supply chains.

1. Introduction

Blockchain technology is a distributed ledger that is secured by a peer-to-peer network. It is virtually immutable, meaning it cannot be retrospectively changed. Over the past years, Bitcoin, the first implementation of blockchain technology and first digital system with which users could send payments directly to one another without the need of a bank (Nakamoto, 2008), has gained in popularity and inspired numerous other applications. While many applications are still within the financial sector, blockchain-based technologies (BBT) (Köhler and Pizzol, 2020) are increasingly used in other sectors as well, including applications in healthcare, art, and supply chain management.

Within supply chain management, blockchain technology has been proposed as a tool to provide trusted information for consumers and increase the transparency and efficiency of the supply chains (Balzarova and Cohen, 2020; Kshetri, 2018). Supply chain management plays an especially important role in agro-food supply chains, as an effective management of these global and complex chains is key to ensure the supply of sustainable, affordable, safe, and sufficient food (Zhao et al., 2019). Particularly, within agro-food supply chains, BBT have been suggested to address social and environmental problems. Previous studies have suggested that BBT could be used to provide sustainability-related data to actors within the supply chain, third parties, such as auditing bodies, and consumers (Kamilaris et al., 2019; Lim et al., 2021). This could potentially enable actors in the supply chain to address sustainability issues and consumers and upstream companies alike could make more informed purchasing decisions (Kouhizadeh and Sarkis, 2018).

BBT have also been suggested to enhance traceability across supply chains by registering every change in ownership creating a chain-of-custody (Wang et al., 2019). This, in addition to sustainability-related data such as product carbon footprints increases transparency, allows digital monitoring (Queiroz et al., 2020), and enables supply chain participants to market products based on production or origin characteristics (Lim et al., 2021). BBT thereby respond to the increasing consumer demand for information about product origins (Mol, 2015;

* Corresponding author.
E-mail address: massimo@plan.aau.dk (M. Pizzol).

https://doi.org/10.1016/j.techfore.2022.122094
Received 8 July 2021; Received in revised form 3 September 2022; Accepted 1 October 2022
Available online 19 October 2022

Rogerson and Parry, 2020). One example is FairChain's chocolate bar "The Other Bar". This product is promoted as contributing to "radical equality" because by purchasing it, consumers not only get the chocolate bar, but also supposedly increase equality in this particular supply chain, of which consumers see proof in the form of e.g. premiums paid to the farmers (FairChain Foundation, 2021a). Increased supply chain traceability further makes it easier for companies to source products in a sustainable manner (Cole et al., 2019). BBT have further been suggested to make supply chains more efficient (Gurtu and Johny, 2019). By providing financial services for unbanked actors in the supply chain and by automating payments and other transactions, BBT are expected to particularly benefit the upstream actors of agro-food supply chains, especially the farmers (Kamilaris et al., 2019; Wang et al., 2019).

Despite all the potential it is claimed blockchain technology has within sustainable supply chains, several issues remain. Blockchain remains an emerging technology and much needs still to be learned on how to best implement it in supply chains (Rogerson and Parry, 2020). Despite these needs, research on BBT for sustainable supply chains is still in early development stages (Lim et al., 2021).

One open question is, for example, whether to store the data on- or off-chain. While the use of on-chain data allows for data immutability and accessibility, it can lead to long transaction times and increase costs. Vice versa, the use of off-chain data increases transaction speed but does not provide the same level of trustworthiness as recording the data directly on the immutable ledger.

Digitalization of paper-based processes at all stages of the supply chain is another limiting factor and a prerequisite for adoption of BBT. An empirical investigation from the coffee supply chain (Bager et al., 2022) finds the lack of digitalized supply chain processes as a particular barrier to BBT implementation. Additionally, a superficial knowledge of the technology might lead to low trust in its potential and can be an obstacle to its adoption. This can be the case when, for example, senior managers do not fully understand what benefits will be derived from implementing BBT and are reluctant to support BBT projects (Rogerson and Parry, 2020). The use of blockchain applications in emerging economies is also still poorly understood and it is unclear how the technology is optimally implemented and performs in such economies, which are often involved in agro-food supply chains (Queiroz et al., 2020; Bager et al., 2022).

Finally, it is unclear whether the use of blockchain can actually contribute to making supply chains more sustainable. While Köhler et al. (2021) identify several pathways of how blockchain technology in supply chains can create positive impacts on sustainability based on interviews with experts, it remains unclear if this potential can be fulfilled in the long- term, thus requiring a more extensive investigation of the use of blockchain technology in sustainable supply chains.

While these studies provide initial insights on the implementation of blockchain in supply chains, given that it may take between five and ten years to fully adopt BBT applications in supply chains (van Hoek, 2020), the understanding of how to address these problems is still incomplete and rapidly evolving (Köhler et al., 2021).

While the use of blockchain technology in agro-food supply chains is a recent phenomenon, the principal private governance mechanism for agro-food supply chain sustainability for at least two decades has been the adoption of voluntary sustainability standards (VSS). VSS govern different aspects of sustainability (social, economic, environmental) and the commodity production process including assurance of product quality and attributes, transportation, and production and processing methods (Lambin and Thorlakson, 2018; Potts et al., 2014). Most VSS are governed by non-state actors, mainly NGOs, though some industry associations and companies have also developed their own standards (e.g. 4C, 2021). Among the more well-known VSS are Fairtrade International and Rainforest Alliance (run by NGOs), and various organic standards, usually public sector-led (EC, 2021; Fairtrade International, 2021a; Rainforest Alliance, 2021). Finally, some multi-stakeholder initiatives have developed VSS, such as the Roundtable on Responsible Soy (RTRS) and the Roundtable on Sustainable Palm Oil (RSPO) standards (RSPO, 2021; RTRS, 2021).

VSS establish a governance structure allowing producers and companies to signal specific commodity sustainability characteristics, even along fragmented supply chains, responding to increased consumer demand for sustainability-related information about their purchases (Meemken et al., 2021). Consequently, some VSS include certifications and eco-labels, facilitating information transfer on sustainability characteristics along the supply chain. The governance structure of VSS also specifies monitoring, usually classified as first, second and third party monitoring, defined by the relationship between the governing and the monitoring body (Lambin and Thorlakson, 2018). Generally, third party monitoring is considered more stringent and credible (Potts et al., 2014; Lambin and Thorlakson, 2018). However, the credibility and effectiveness of VSS is today questioned due to several reasons. The proliferation of standards, leading to situations where each different stakeholder group creates their own certification, has been shown to diminish the credibility of VSS (Lambin and Thorlakson, 2018). Recent research documents also situations where consumers expressed concerns about insufficient transparency and lack of compliance with sustainability criteria, thus questioning the ability of VSS to materialize the desired changes and leading to a lack of consumer trust in VSS (Dietz et al., 2021; Lernoud and Willer, 2017; Meemken, 2020). Furthermore, a limited uptake among supply chain participants has been flagged as an increasingly occurring problem of VSS (Bager and Lambin, 2020; Lernoud and Willer, 2017; Potts et al., 2014).

Even though both BBT and VSS are currently used to address sustainability governance in agro-food supply chains, little is known about the interaction between these two different sustainability governance mechanisms. Investigating how VSS and BBT interact can potentially bring new valuable insights on the management of agro-food supply chains, because using BBT can potentially solve some of the issues faced by many VSS, such as insufficient transparency. BBT aim at providing easily accessible information to consumers (e.g., scanning a QR code on the product packaging returns information stored on a blockchain on product provenance and characteristics) and some even have their own mechanisms to increase the sustainability of their supply chains. For example, FairChain Foundation aims at ensuring a living income for their farmers and workers. According to FairChain this objective is achieved by paying a premium to the farmers, similar to the Fairtrade premium, and supporting good agricultural practices (FairChain Foundation, 2019).[1] Other BBT implementations rely on certifications obtained from VSS instead of developing their own. For example, Blockchain Bean sells Fairtrade International and organic certified coffee, but also includes a QR code leading to product- and program-specific information and the blockchain data can be verified by other parties (Brooklyn Roasting Company, 2021).

While there is an increasing focus on research of blockchain technology in agro-food supply chains, little is known on how BBT change governance mechanisms of agro-food supply chain sustainability and how the technology interacts with existing mechanisms such as VSS. To the best of our knowledge, the closest research to this topic is the work by Balzarova (2020) and Balzarova and Cohen (2020) discussing how the use of blockchain technology could potentially affect eco-labelling schemes. According to these scholars, blockchain technology can potentially enhance the effectiveness of eco-labelling schemes by reducing negative environmental and social impacts, enhancing quality and safety standards, and increasing producer's trading power by decreasing information asymmetry (Balzarova, 2020). Balzarova also suggest that BBT could reduce some of the inefficiencies of eco-labelling

[1] There are however claims in the independent press that such premium might not reach the farmers, a criticism that is commonly aimed at Fair Trade in Africa. http://www.storiesbyeva.com/wp-content/uploads/2017/05/Global-Coffee-Report-novemberdecember-2016.pdf.

schemes such as lack of data, inconsistent record-keeping, and confidentiality issues that do not allow an assessment of a program's impact (Balzarova, 2020). However, Balzarova and Cohen (2020) mention limitations to the use of blockchain technology within eco-labelling schemes. Besides technical limits that still require solving, humans interacting with the blockchain can threaten the integrity of the data. For example, while the amount of certified coffee cannot not be changed on the blockchain by downstream actors, and until advanced technological solutions like DNA tracing are implemented (Lafargue et al., 2021), there is still the opportunity to physically replace the certified coffee with inferior coffee (Bager et al., 2022). Considered this seminal evidence, it is natural to raise the question of whether BBT are competing with VSS, if they are improving each other, or if they are simply co-existing.

Summing up, an analysis of the existing literature indicates that the interaction between BBT and VSS remains under-investigated and seems worth pursuing to better understand how these two management systems can support, co-exist, or antagonize each other, and to anticipate the potential implication for agro-food supply chain management. Since both BBT and VSS are now potentially implementable as mechanisms of supply chain sustainability governance, each with different advantages and disadvantages, it is important to address this research gap by anticipating the potential consequences of future interactions between BBT and VSS and provide qualified insights to ensure that these interactions improve sustainability in supply chains. The objective of this study is therefore to analyze the relationship between BBT and existing VSS by asking the following question: *How do blockchain-based technologies and voluntary sustainability standards interact within agro-food supply chain sustainability governance?* Since evidence shows that BBT cases have developed their own mechanisms and collaborated with existing VSS, we proceed by testing the hypothesis that the relationship between BBTs and voluntary sustainability standards can be synergistic, co-existing, or antagonistic.

The results of the study are expected to support actors and stakeholders working with VSS and BBT with a better understanding of how they affect each other, where they bring advantages to sustainability governance, and where they can learn from each other. Given that BBT cases are still in early-stages of development it is particularly interesting for researchers and stakeholders in this fast-growing space to better understand their interaction with VVS. Similarly, the study can provide established VSS and their stakeholders with useful insights on BBTs and their features, as well as their relation with the existing VSS. Overall, this study intends to support both BBT and VSS governance mechanisms to improve supply chain sustainability by improving our understanding of when and how they affect the sustainability impact of each other.

2. Material and methods

This study is based on the analysis of case studies. We selected multiple existing, real-world examples of VSS and BBT and performed a comparative analysis using twelve sustainability-related assessment criteria selected from a critical analysis of existing literature. Fig. 1 provides an overview of the research process.

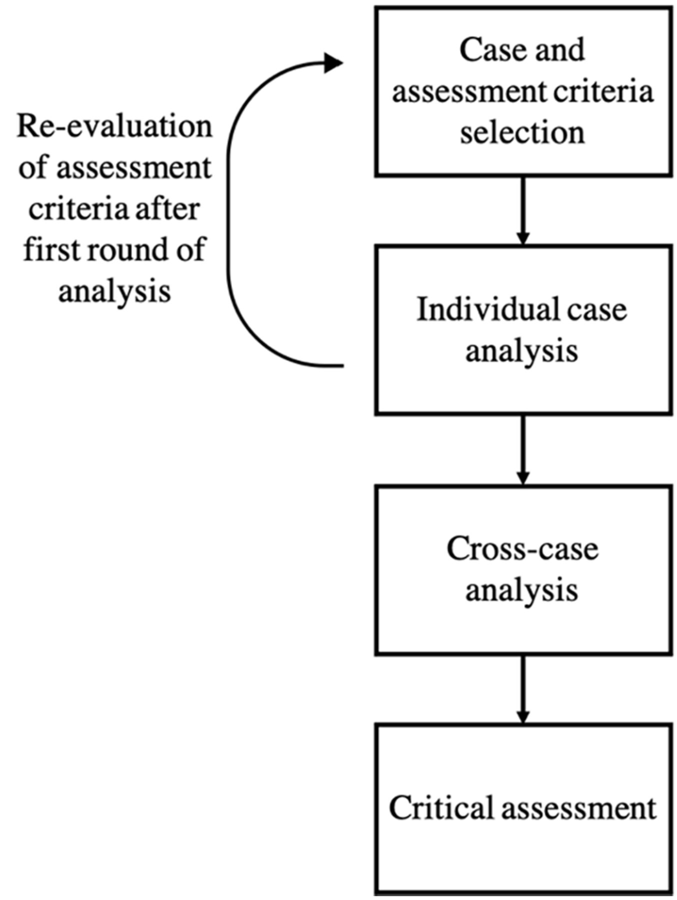

Fig. 1. Research process.

2.1. Selection of cases

The selection of cases was based on three pre-defined selection criteria. To be included in the analysis the case must: focus on the agro-food sector, be end-consumer facing, and address sustainability. By including selection criteria for choosing the included cases, we ensured that only cases that have a similar focus are analyzed, increasing overall comparability. To avoid including niche VSS – there are over 400 VSS across different sectors – we used the VSS defined as major in terms of area certified (minimum 1,000,000 ha) by *The State of Sustainability Markets 2020* report (ITC, 2020). After screening the VSS in the report using the selection criteria, eight VSS remained. In the present study, VSS cases refer thus to voluntary sustainability standards in the agro-food supply chain that are consumer-facing, meaning consumers can retrieve information about certified products through e.g. labels. We identify BBT cases from web-searches, blockchain-related newsletters, and the Positiveblockchain.io database (PositiveBlockchain, 2019). In total, we include eight BBT cases. Including the third selection criteria – *addressing sustainability* – meant that a specific sustainability focus was required for being considered for analysis and therefore we did not include the BBTs that only enable traceability for agro-food products. BBT cases refer to blockchain-based technologies that are applied in agro-food supply chains to increase sustainability. This includes BBT cases by start-ups, established companies, or in support of NGOs or governments. Table 1 lists the selected VSS and BBT cases.

2.2. Selection of assessment criteria

We used four recent publications describing the benefits of using BBT in supply chains to identify twelve sustainability-related assessment criteria for our analysis (Astill et al., 2019; Kamilaris et al., 2019; Katsikouli et al., 2021; Mahyuni et al., 2020). We include *social, environmental, and economic sustainability* as these are mentioned as the main benefits of BBT implementation (Astill et al., 2019; Kamilaris et al., 2019; Mahyuni et al., 2020). We added *equality* to these impact-related assessment criteria to highlight how the impacts affect different players in the supply chain. We added *efficiency* to cover frequently highlighted topics such as reduced transaction costs, digitization, automatization, and standardization (Astill et al., 2019; Katsikouli et al., 2021; Mahyuni et al., 2020). Further, literature often emphasizes *traceability* and *transparency* as main benefits of blockchain technology in supply chains (Astill et al., 2019; Kamilaris et al., 2019; Katsikouli et al., 2021;

Table 1
Overview of VSS and BBT cases considered in this study.

Case	Commodity	Type	Short description
4C Association	Coffee	VSS	4C is an "independent, stakeholder-driven, internationally recognized sustainability standard for the entire coffee sector" (4C, 2021).
BONSUCRO	Sugarcane	VSS	"Bonsucro is a global multi-stakeholder non-profit organization that exists to promote sustainable sugarcane production, processing and trade around the world" (Bonsucro, 2021).
Fairtrade International	Cocoa, coffee, sugarcane, tea	VSS	"Fairtrade International is a non-profit, multi-stakeholder association [that] works to share the benefits of trade more equally – through standards, certification, producer support, programs and advocacy" (Fairtrade International, 2021a).
Organic (example EU organic standard)	All kinds of commodities incl. tea, coffee, wine	VSS	"Organic farming is an agricultural method that aims to produce food using natural substances and processes. This means that organic farming tends to have a limited environmental impact." (EC, 2021)
ProTerra	Soybeans, sugarcane	VSS	ProTerra Foundation aims at "promoting sustainability in the food and feed supply chain and segregated non-GMO materials" (ProTerra Foundation, 2021).
Rainforest Alliance	Cocoa, coffee, tea, bananas, oil palm	VSS	"The Rainforest Alliance is an international non-profit organization working at the intersection of business, agriculture, and forests to make responsible business the new normal" (Rainforest Alliance, 2021).
RSPO	Oil palm	VSS	"The Roundtable on Sustainable Palm Oil is a non-profit organization that […] has developed a set of environmental and social criteria which companies must comply with in order to produce certified sustainable palm oil" (RSPO, 2021).
RTRS	Soybeans	VSS	The "Roundtable on Responsible Soy Association is a non-profit organization promoting the growth of production, trade, and use of responsible soy" (RTRS, 2021).
Bext360	Coffee, palm oil	Blockchain	"Bext360 provides comprehensive and measurable accountability for critical supply chains. The SaaS platform provides unsurpassed blockchain traceability and quantifiable measurements for sustainability" (Bext360, 2021).
Blockchain Bean	Coffee	Blockchain	Blockchain Bean is a collaboration between Brooklyn Roasting Company and IBM. It aims at sourcing and serving sustainable, ethically produced coffee (IBM, 2021).
Choco4Peace	Cocoa	Blockchain	"Choco4Peace enables vulnerable Colombian farmers to improve their lives by finding markets for their cacao, allowing them to escape poverty and conflict" (Choco4Peace, 2021).
Connecting Food		Blockchain	"Connecting Food offers digital transparency solutions which create value for agri-food players and restore consumer confidence in food" (Connecting Food, 2021).
FairChain	Coffee, cocoa	Blockchain	"The FairChain Foundation's mission is to stimulate and support business models that contribute to a truly fair distribution of wealth across all participants in the value chain" (FairChain Foundation, 2021b).
Fairfood	Coffee, coconut, tomato, cane sugar, pineapple, vanilla	Blockchain	"Fairfood accelerates the change towards a sustainable food system. [They] want everyone to benefit from truly good food, including the people at the very start of the value chains." (Fairfood, 2021)
Farmer Connect	Coffee	Blockchain	"Farmer Connect's vision is to 'Humanize consumption through technology.' [They] think tech should bring people together, make the world smaller, empower the individual and small business while reducing costs and inefficiencies for global enterprises" (Farmer Connect, 2021).
Provenance	All kinds of commodities incl. tomatoes, fish, and bacon	Blockchain	Provenance is "a platform and consultancy for transparency. [They] empower brands to make the sourcing and impact behind their products transparency and enable citizens to access and trust in business sustainability efforts beyond the marketing hype" (Provenance, 2021a).

Mahyuni et al., 2020). Finally, we chose *labelling* as an assessment criterion to cover the benefits related to consumer awareness, trust, and more informed purchasing decisions (Kamilaris et al., 2019).

We conducted a first round of case analysis using these assessment criteria (social impacts, environmental impacts, economic impacts, equality, efficiency, traceability, transparency, labelling). Based on a reflection on the results from the first analysis round, we included additional assessment criteria a posteriori: *verification, technological requirements, governance, process* and *outcome transparency*, to cover additional dimensions and allow for a more comprehensive analysis. We then organized the assessment criteria in three non-overlapping groups: impact, process, and communication. Table 2 provides an overview of the assessment criteria used in this study. More detailed definitions of the assessment criteria can be found in the Supplementary Information.

2.3. Comparative analysis of cases

We conducted the comparative analysis in three steps. Firstly, we analyzed the individual cases by qualitatively assessing each case against the assessment criteria. For this, we primarily used information for each case provided on their websites. Information on VSS was additionally cross-checked by data from standardsmaps.org, an in-depth database of over 300 VSS collected by the International Trade Center, a United Nations agency (ITC, 2022). It was more difficult to retrieve data for BBT cases, as limited information is directly available on the homepage of these companies. A few cases had examples of data shared with consumers via tutorials, mock-up consumer interfaces or real QR codes on their products (Blockchain Bean, FairChain, Fairfood, Provenance). In two cases, we used contextual information from personal communications had with the executing companies during the course of the research project, that helped clarifying the information obtained from the online documentation available from the same companies. Secondly, we performed a cross-case comparative analysis between VSS and BBT cases where we identified commonalities and differences between both types of cases. Finally, we carried out a critical assessment of the relationship between VSS and BBT cases that allowed us to characterize VSS and BBT approaches and their relationships to understand the conditions affecting them.

We started from the hypothesis that interactions between BBTs and VSS can be synergistic, antagonistic, or co-existing. A similar analytical framework was proposed by Lambin et al. (2014) to analyze potential interactions between instruments that regulate land use. This framework was useful for understanding how a combination of governance mechanisms facilitates the fulfilment of the functions required for effective governance (Lambin et al., 2014). Similarly, the proposed framework for this study intends to support the understanding of how different implementations of BBT interact with VSS as existing supply chain sustainability governance mechanisms, and specifically which assessment criteria are central for different relationships. Synergistic interaction describes a relationship where VSS and BBT complement and reinforce each other. For instance, while existing VSS provide measures to govern sustainability in agro-food supply chains, BBT may be used to bring transparency to the measures implemented by the VSS. The antagonistic relationship describes cases where BBT and VSS oppose each other and potentially make each other worse off. This is the case when BBT and VSS compete over the same customers or the measures of one governing mechanism counteract those of the other. The co-existing relationship occurs when BBT and VSS exist side-by-side, but do not interfere with each other. This is the case when the BBT and VSS focus on different products and customers. For example, BBT may be implemented in niche markets and specialty products, while VSS may contribute to the mainstream market.

3. Results

3.1. Individual case analysis

The individual case analysis can be found in detail in the Supplementary Information. It shows for each of the 16 cases how they perform against the twelve assessment criteria. The information is illustrated in a matrix with the rows showing information on the cases and the columns providing the analysis of the assessment criteria.

3.2. Cross-case analysis

Table 3 shows an overview of the results from the cross-case analysis, summarizing for each assessment criterion the cross-cutting differences and similarities between BBT and VSS. The results are further illustrated in the following using specific examples.

Blockchain-based technologies in the supply chain that aim at having positive *social and environmental impacts* either rely on voluntary sustainability standards themselves or have their own measures similar to

Table 2
Overview of assessment criteria used for the analysis including a short description.

Impact		Process		Communication	
Social	The impact on producers and workers, as well as their local communities.	Efficiency	Efficiency gains through e.g. faster information sharing, faster entry to countries, reduced costs of running the system, reduced bureaucracy, automation of processes, etc.	Outcome transparency	Transparency on social, environmental, and economic impacts, as well as equality and traceability.
Environmental	Reducing the impact on the environment within the supply chain.	Verification	How the information provided by the VSS or BBT case is verified	Process transparency	Transparency on how one can participate in a VSS or BBT case, what kind of criteria are important, how the criteria are changed over time, etc.
Economic	The economic impact on producers and workers. It mainly addresses how their livelihoods are ensured, but also includes access to credit and financial services.	Traceability	Knowing where a product has been produced, processed, etc./visibility of product journey and included actors, chain-of-custody	Labelling	Product-specific information for consumers, e.g. through labels, QR codes or NFC tags, etc.
Equality	Equality between different actors in the supply chain. It relates to fairer pricing, access to markets and financial services, access to technology and information, etc. Issues of data access and data ownership are also relevant here.	Technological requirements	Level of digitization, electricity and/or cell service access, technology in place, use of technology, etc.		
		Governance	Who governs a system and who can participate in decision making processes.		

Table 3
Summary of cross-cutting differences and similarities between BBT and VSS cases identified in the cross-case analysis.

Impact		Process		Communication	
Social	- VSS have their own measures such as strict requirements on no human rights abuses or access to health care (except the organic standard) - BBT either rely on measures from VSS or have their own	Efficiency	- VSS have established processes in place. Experiences from the past can lead to more efficient implementations compared to new BBT implementations. - BBT claim to be cheaper over time. BBT can connect data that was previously stored in silos and facilitate the collection of additional data. This data can be used to identify supply chain efficiencies and sustainability improvement opportunities. Automated payments and process can further lead to cost savings.	Outcome transparency	- VSS share outcomes typically online and in impact reports. They share the volumes of products certified in a given period, the amount of people impacted, etc. These are program-wide outcomes. - BBT provide batch- or even product-specific information. Blockchain Bean, FairChain, and Fairfood additionally report program-wide information.
Environmental	- VSS have their own measures such as agroforestry or limited use of pesticides - BBT either rely on measures from VSS or have their own	Verification	- VSS rely on third-party audits. - BBT may use third-party on-site audits, conduct their own, or have no on-site audits. - BBT can additionally be used to do data audits on the blockchain – if publicly accessible also by third parties and the public.	Process transparency	- VSS have clearly defined processes of how a certification can be obtained. These are regularly reviewed. About half the standards are members of the ISEAL alliance for ambitious, collaborative, and transparent sustainability systems. - BBT do not have such defined processes.
Economic	- VSS have their own measures such as premiums or trainings (except the organic standard) - BBT either rely on measures from VSS or have their own; some BBT particularly provide access to financial services, and automate payments	Traceability	- VSS have different level of traceability ranging from knowing which farm products came from (e.g. Rainforest Alliance, RSPO) to mass-balance traceability (e.g. Bonsucro). - BBT is in most cases used for providing information about the entire provenance of a product but can also improve mass-balance traceability as no certificates can be duplicated.	Labelling	- VSS in this study provide a label based on which consumers can trust that the product has been produced sustainably. - BBT include QR codes or NFC marks on products that show product-, batch- or program-specific information.
Equality	- VSS have their own measures (except the organic standard) - BBT either rely on measures from VSS or have their own. BBT further bring visibility of the supply chain to all actors (= access to supply chain data) and access to financial services. This can increase equality.	Technological requirements	- Levels of technological requirements for VSS vary. - BBT require the supply chain to be digitized and further rely on other technologies such as tracking devices or AI.		
		Governance	- VSS in this study have different governance models: governed by industry associations (4C), NGOs (Rainforest Alliance, Fairtrade International), public sector (organic). - BBT are privately held companies or foundations.		

those found in VSS. For example, FairChain pays their farmers a premium, similar to the Fairtrade premium (FairChain Foundation, 2019). Other BBT cases such as Blockchain Bean or Provenance are certified by VSS (IBM, 2021; Provenance, 2021b). Thus, for the impact indicators, standards and project-specific measures drive positive impact. Implementing blockchain technology can, however, make more data transparently available for consumers and third parties by 1) collecting more sustainability-related data, and by 2) granting access to this data to outside parties (e.g. Connecting Food, Choco4Peace). While blockchain is typically associated with stakeholders maintaining ownership of their data, the analyzed BBT cases do not specifically highlight this issue. This could mean that it is either not implemented or not advertised. Only Farmer Connect mentions that their farmers are in control of their data (Farmer Connect, 2021). With respect to *economic impacts*, BBT can automate payments (e.g. bext360). Blockchain technology can further be used to provide financial services to unbanked actors in the supply chain. For example, Farmer Connect farmers get a digital ID, with which they can get access to loans and keep a proof of their sales and income (Farmer Connect, 2021).

Efficiency is often highlighted as one of the main benefits of using blockchain technology. This refers largely to setting up a system where data is stored or connected on one ledger. This allows for several efficiency improvements such as providing access to data for all relevant stakeholders, analyzing the data and identifying improvement potentials, and automating processes and payments. However, this is dependent on the digitalization of processes along the entire supply chain and on the participation of relevant actors, and thus requires significant investments of both time and money. Even so, several BBT projects promise significant reductions in (transaction) costs over time (e.g. FairChain, Farmer Connect).

Regarding *verification*, on-site third-party audits are common practice for VSS. Such audits do not seem to be common practice for most BBT cases. While in some cases it is simply not clear from the material available if on-site audits are conducted in BBT cases, some BBT cases strongly imply that they do not conduct on-site audits such as Connecting Food with their “fully digitalized auditing module” that provides real-time traceability of products (Connecting Food, 2021). Such audits of blockchain data are interesting additions to on-site audits. Moreover, if the blockchain data is publicly accessible, outside parties such as NGOs or interested people can verify it, increasing transparency and potentially trust in the audits and programs – this can be considered as an indirect, external auditing. However, while this type of auditing may be planned by some BBT cases (e.g. FairChain), we observed no implementations of this.

The degree of *traceability* differs within the selected VSS and BBT cases and across the VSS cases. All BBT cases aspire to provide identity preservation traceability, which means the products are not mixed with others and can therefore be traced all the way back to the farmer, including all intermediary steps. In addition to blockchain technology, this requires a variety of other technologies, such as radio frequency identification (RFID) tags to provide real-time data on the individual product items (Rogerson and Parry, 2020), and – again – a fully digitized supply chain where available data is captured digitally at all levels (from the farm to the consumer) so that it can be used by BBT. Most VSS, in contrast, only physically separate the products from non-certified products (e.g. organic standard, 4C, RTRS), and some use mass-balance (e.g. Bonsucro). This means that the product cannot be traced back to the farmer, but it can be guaranteed that the product is a certified one. Therefore, VSS that use mass-balance do not allow for product specific traceability, although buying, for example, their certified sugar cane means that this or another sugar cane has been produced under the requirements of the certification. Thus, the product is not traceable, but the consumer may – if the VSS is effective – increase overall sustainability of the product's supply chain. However, some VVS cases claim to also provide identity preservation traceability, where the product can be traced back to a single source (e.g., Rainforest Alliance, RSPO). The method of traceability for VSS can further vary within a single standard depending on the kind of product. For example, Fairtrade International can identify the origin farmer for certified bananas, but uses mass-balance for certified oranges juice, where oranges from different farms may have been mixed.

The VSSs selected for this study provide a *label* based on which consumers can trust that the product has been produced sustainably. The BBT cases included in this study put a QR code or NFC mark on the product that leads to product-, batch-, or program-specific information. The FairChain chocolate, for example, includes a QR code that allows consumers to access data on the product's journey including some impact data such as what the actors' share of the payments are – in contrast to traditional chocolate businesses (FairChain Foundation, 2021a).

The VSS considered in this study have different *governance* models. Some are multi-stakeholder organizations, enabling multiple stakeholders to influence standard-setting, e.g. RSPO. Stakeholder inclusion also feature in seemingly unipolar governance arrangements, where one entity governs the process. For example, Fairtrade International includes representatives of different stakeholder groups, such as members selected by producers, in their Board of Directors (Fairtrade International, 2021b). The organizations behind these VSS are accountable towards their members and stakeholders including farmers and workers. Blockchain-based technologies, in contrast, are privately held companies or foundations with lower public accountability. The *processes* for obtaining a certification for a VSS are clearly defined, transparent, and reviewed regularly. BBT cases, in contrast, do not have such defined processes and some of these projects (e.g. Provenance, Choco4Peace) ask interested brands to contact them to discuss possible implementation. It is unclear to outsiders if internal rules that govern participation exist and what these entail.

3.3. Critical assessment of relation between BBT and VSS

Table 4 provides an overview of characteristics of the co-existing, synergistic, and antagonistic relationships as identified here.

3.3.1. Co-existing relationships

The co-existing relationship is characterized by BBT cases that exist independently of VSS and do not have a large enough market share to be competitors. Main mechanisms to bring positive impacts to supply chains by the co-existing BBT cases are increased transparency through data collection and sharing and providing access to financial services using blockchain technology. The BBT projects are typically in early stages of development, are technology-driven solutions and the existence of these BBT projects do not change VSS.

Table 4
Characteristics of the relationship between BBT and VSS cases.

Co-existing	Synergistic	Antagonistic
- Collecting data on impacts and bringing transparency is the main mechanism BBT cases use to create impact - Access to financial services using blockchain technology is the only additional measure BBT cases add - Data on the blockchain is used to conduct audits - VSS cases are unchanged	- BBT cases implement the measures from VSS - Blockchain companies and standards collaborate. E.g. audits of the blockchain data in addition to on-site audits - VSS labels can be interacted with to get access to more product-information	- BBT cases implement their own measures – both measures using blockchain technology (e.g. access to financial services) and not using blockchain technology - Blockchain data can be accessed and audited by anyone (the public, NGOs, etc.) - VSS cases are unchanged

Most BBT cases (four out of eight) currently *co-exist* with VSS. Farmer Connect, for example, allows farmers to obtain proof of identity and income, which in turn allows them to obtain loans. Consumers can further support the farmers through an app, for instance by donating to sustainability projects. When consumers buy a Farmer Connect product, they can access information about that product through scanning the QR code. While the Farmer Connect directly address the economic impact criterium and indirectly support other sustainability projects, it does not interfere with existing VSS.

3.3.2. Synergistic relationships

The synergistic relationship is characterized by a combination of BBT and VSS that improves the governance of agro-food supply chain sustainability. While VSS provide tested measures of positive impact and an established governance framework, a trusted label, multi-stakeholder governance structures, and defined processes for joining and auditing, BBTs are innovative in ensuring transparency and increasing data connectivity. The projects combine a technology-driven solution with existing sustainability governing structures.

Several of the BBT cases in this category, including Provenance, Blockchain Bean, and Fairfood are certified by existing standards and exist in a *synergistic* relationship with VSS. For example, Provenance works with the Soil Association, a British certification body for organic standards (Provenance, 2021b), to limit the environmental impact of the products. Blockchain technology is then used to create efficiencies by connecting data that was previously only available in silos, which can be used to identify data gaps and ensure data consistency along the supply chain. The synergistic relationship becomes clear concerning labelling. While most organically certified products simply contain a label (that consumers have to trust), Provenance's products include an NFC-tag, a more secure alternative to QR codes, which allows consumers to access information about the product collected throughout its journey. Consumers still make purchasing decisions based on the knowledge of the Soil Association label, but can, additionally, obtain specific information about the product. The BBT project thus complements the standard and together they improve the labelling process and increase transparency.

3.3.3. Antagonistic relationships

The *antagonistic* relationships are generally characterized by BBT cases that not only provide a technology solution (as in the co-existing relationship), but also implement their own sustainability governance mechanisms, such as measures for creating positive impacts. In this situation, the BBT cases compete with existing VSS over customers. The BBT projects that have an antagonistic relationship with VSS are typically still in early stages and their ambition and implementation do not yet fully match.

These BBT cases aim at building an alternative to traditional VSS. For example, FairChain Foundation claims to go "beyond certification" (FairChain Foundation, 2021c) and thereby states their intention to compete with existing VSS. FairChain implements their own mechanisms to foster sustainability. For instance, the foundation built a roasting factory in Ethiopia, a coffee exporting country, to create jobs and pays a 20 % premium on top of the coffee market price to their farmers (FairChain Foundation, 2019). With the help of blockchain technology, they further test new mechanisms, for example, providing farmers access to financial services, such as micro-loans (FairChain Foundation, 2021a). In contrast to VSS, FairChain relies on blockchain technology for verification of sustainability claims, as the technology, when implemented, will make data publicly accessible and auditable. Blockchain technology is used to provide a reliable and transparent tracking system for all transactions (FairChain Foundation, 2021c). Consumers do not find a VSS's label on the product, but a QR code that can be scanned to view a product's story. As a foundation, FairChain does not have the same accountability as, for example, Fairtrade International, although some of their projects are funded by public money, which comes with some accountability. Additionally, the participation process is unclear. However, FairChain does report that they are not ready to add new projects just yet, but will inform interested parties if they open up for applications (FairChain Foundation, 2021d). FairChain creates a sustainability governance mechanism outside of traditional VSS, competes with them, and, thus, has an antagonistic relationship to those standards. VSS currently remain unchanged under this relationship type.

4. Discussion

We answer the question of *how BBT and VSS interact within agro-food supply chain sustainability governance* by firstly positing that there can be three types of interactions, namely synergistic, co-existing, or antagonistic, and secondly by observing, based on a sample of 16 cases, that most of the assessed BBT and VSS cases co-exist. However, there are cases where the two have synergistic or antagonistic relationships as well. The nature of the relationship depends on how the BBT is designed. For example, Blockchain Bean collaborates with Fairtrade and organic certified coffee in their project, incorporating the impact measures that those VSS include. FairChain, in contrast, has specifically designed a system that competes with existing VSS, as it employs its own impact measures and aims at bringing more transparency than existing governance mechanisms with the help of blockchain technology. This emphasizes that BBT system design – including technology architecture, data collection, inclusion of existing governance measures, etc. – is ultimately crucial for determining the kind of relationship BBT cases will have with existing VSS. System design is further important if the BBT case will bring sustainability to agro-food supply chains. We can further reflect on whether a tool like blockchain technology can improve the welfare and wellbeing of the individuals and communities that are involved in the supply chains governed by BBT systems – what could be referred to as delivering "social innovation". The answer depends on the goal of the implementation of blockchain technology and on its design. The cases we have analyzed show that both goal and design affect the relationship between BBT and existing VSS and the impact the BBT can have, as also highlighted in previous research (Köhler et al., 2021). The cases investigated in this study show that, so far, blockchain has not led to radically transformed supply chain governance. Yet, the technology is still in its nascent phases leaving room for technological development. Empirical case studies further point to both technological and governance challenges when implementing BBT as an alternative or in addition to VVS systems (Bager et al., 2022; Singh et al., 2022). Such challenges must be reduced before the social innovation potential of BBT can be realized across agro-food supply chains.

The co-existing relationship was hard to distinguish from the other two, as many of the BBT cases are still in early stages, and it is unclear if they will compete with existing VSS, eventually collaborate with them when reaching maturity and operating on a larger scale, or focus on a specialty sector and continue to co-exist with VSS. This suggests that, particularly, early-stage BBT cases fall under the co-existing relationship, as they are focused on implementing their solution on a small-scale without interacting with VSS but may broaden their scope later on and redefine their relationship. Further, some BBT cases operate in niche markets or high-end segments (e.g. specialty coffee) where margins are higher, supply chains more segregated, and development more advanced. In contrast, many VSS are becoming "mainstreamed" across supply chains, moving from occupying niche markets to contributing a significant portion of the total market (Bager and Lambin, 2020; Raynolds, 2009). If BBT cases also become mainstream, this increases the risk that relationships might become antagonistic. Additionally, it may be that cases that compete with each other over consumers leading to market or supply chain fragmentation, as too many competing sustainability governance mechanisms exist. This, in turn, could further reduce the effectiveness of all governance mechanisms since this can make it more difficult to understand and distinguish different mechanisms.

4.1. *Sustainability governance of supply chains*

One particular reason why BBT are proposed as an improvement to existing VSS is that VSS have shown mixed results in terms of effectiveness as a sustainability governance mechanism for supply chains (Bager, 2021). Recent reviews and meta-analyses suggest that while certified farmers often earn higher incomes, results are mixed and vary across standards. Further, while standards can improve environmental conditions, they currently do not deliver sustainability improvements at system level (Meemken, 2020; Meemken et al., 2021; DeFries et al., 2017). The question is if BBT – by themselves or in collaboration with VSS – can achieve better results and facilitate a clearer assessment of the effectiveness of the sustainability governance mechanisms employed. BBT projects can be built to specifically collect data on sustainability outcomes and impacts. For example, Choco4Peace measure socioeconomic and environmental benefits of and investment based on data registered on the blockchain (Choco4Peace, 2021). BBT can also be built in such a way that outside parties such as consumers or NGOs can audit their data and check sustainability claims on products. This, however, requires publicly available data. A tentative hypothesis is that using BBT would allow for a better assessment of existing measures, as more data is available for analysis than in the VSS cases. This analysis could be carried out by the specific BBT case, but also third parties like auditing bodies or even the public. Further and long-term research is needed to investigate the effectiveness of BBT to measure impact of sustainability measures.

Additionally to the effectiveness of sustainability governance through VSS criticism was expressed in how VSS set standards that assign responsibility to actors in the Global South that are typically less-resourced, while more powerful actors in the Global North are ignored under these schemes (MSI Integrity, 2020). Particularly when certification costs and burdens are put on producers, economic inequality is exacerbated (MSI Integrity, 2020). These structural shortcomings are currently copied by BBT cases, although better tools for economic support can be put in place via blockchain. Yet, it remains questionable if BBT will be able to adequately address these issues or in fact copy them.

An assumption about the use of eco-labels and blockchain-enabled QR codes alike is that this information will allow consumers to make more informed decisions and increase purchases of sustainably produced products (Gardner et al., 2019). However, the question remains how this information needs to be designed, as simply providing more information has limited impact on changing consumer behavior (O'Rourke and Ringer, 2016). A label is easy to understand and facilitates consumer decision-making without extensive research requirements. BBT cases may lead to information overload that impedes consumer decision-making. Furthermore, eco-labels are based on trust and reputation as well as the process of verification (typically by third parties). BBT cases claim to improve on this using blockchain technology and providing more detailed information to the consumers. However, this is problematic as bridging information from the physical world to the blockchain is still a challenge. When wrong data is put on the blockchain, the whole system could become useless. While using technology to measure data and store it directly on the blockchain could be a solution for some cases where the physical world needs to be linked with the digital, it is expensive and cumbersome to implement. BBT can further improve upon existing VSS when it comes to creating economic impact. There are examples of BBT cases providing a way for farmers and workers to record their incomes and allow them to access financial services, including micro-loans and insurances (e.g. FairChain, Farmer Connect). In the future, tokens can also play an important role, as they could incentivize good behavior. For example, FairChain has been testing ideas such as providing tokens to consumers that they can either donate to plant trees or use to buy new products cheaper. Other potentially interesting ideas – that have not yet been implemented in real life – could be tracking specific behavior and tokenizing it. For example, farmers could collect tokens for producing their goods under certain circumstances – e.g. non-GMO or organically produced – and reaching a certain amount of tokens could bring benefits to the farmers. For instance, a brand could provide favorable terms for suppliers that have collected a specific minimum amount of tokens showing their positive impacts on the community or environment (e.g. tokens for implementing additional measures to reduce pesticides or protect local biodiversity). However, this may carry a risk of self-selection bias rewarding already well-off producers (at the expense of marginalized smallholders), which reduces the additional impact of implementation. There are also challenges to real-life verification of many of the sustainability practices conducted upstream (Bager et al., 2022).

Our analysis shows that BBT are usually governed by companies – often startups – while VSS have typically more structured and bureaucratic governing forms such as industry organizations and NGOs (cf. Table 3 and SI; assessment criteria *governance*). Thus, this lighter governance allows BBT to quickly test new ideas and iterate without relying on slow approval processes. However, this also means they have less accountability to the public. This raises the question if privately held companies are better suited to innovate existing agro-food supply chains than the organizations behind VSS, as they are more flexible and independent. Studying this dynamic could be an interesting addition to the literature.

There have been media reports of VSS organizations exploring the use of blockchain technology. For example, Rainforest Alliance partnered with Nestlé and the IBM Food Trust to trace coffee (CoinDesk, 2020). According to Fairtrade International, the company is excited about the range of blockchain projects, but has not found a project that will deliver long-term value, as the projects neither consider the context of Fairtrade farmers nor offer a safety net in case their implementation fails (Fairtrade International, 2021c). This shows mixed assessments from VSSs of the potential of BBT to create positive social and environmental impact. Measuring their own impacts is therefore crucial for BBT projects.

4.2. Relevance to literature

Most existing literature investigates VSS and BBT cases separately (DeFries et al., 2017; Kamilaris et al., 2019; Meemken, 2020; Zhao et al., 2019). Only few studies look at the link between blockchain technology and eco-labelling schemes (Balzarova, 2020; Balzarova and Cohen, 2020). By analyzing how VSS and BBT interact with respect to governing sustainability in agro-food supply chains, our study moves beyond previous research: taking a point of departure in real-world cases of BBT and VVS we elucidate the interplay of BBT and VSS operating in the same space and describe BBT and VVS across a broad spectrum of assessment criteria on sustainability governance.

Our findings confirm that that there can be synergetic overlaps between VSS and BBT cases, particularly regarding transparency and labelling (Balzarova and Cohen, 2020). The fact that some BBT cases use blockchain technology to increase traceability and provide provenance data aligns with findings form previous literature highlighting the benefit of blockchain technology to enable product traceability (Wang et al., 2019). Companies can market their products based on traceability data (Lim et al., 2021) and allow consumers to make more informed purchasing decisions as suggested by Kouhizadeh and Sarkis (2018). The study also confirms that the data on the blockchain is intended to serve auditing, which was previously proposed by Kamilaris et al. (2019).

Blockchain technology may further be used as a tool to overcome bottlenecks of insufficient data and inconsistent record-keeping of existing VSS, which makes it difficult to assess the VSS' impact (Balzarova and Cohen, 2020). Using blockchain technology to increase traceability and make this data available for relevant parties can allow additional auditing of digital information thereby complementing the use of on-site audits and improving monitoring possibilities.

Beyond investigating synergistic interactions between BBT and VSS, we also identify cases where the relationships between the two governing mechanisms are co-existing or antagonistic. This was previously not discussed in literature as BBT are either assumed to be independent solutions or collaborate with existing VSS (Lim et al., 2021).

Our findings also address an important research gap, namely that while both BBT and VSS are today employed as mechanisms for supply chain sustainability governance, it has not yet been investigated how they interact with each other. It is important to address this gap because not understanding their interactions could have adverse effects on supply chain sustainability. Thus, we hope to initiate a discussion on the relationship between BBT and VSS and how this relationship effects the governance of supply chain sustainability. Further research is encouraged to build on our initial findings by conducting monitoring and long-term observational and empirical studies for an improved understanding of this relationship and its consequences.

4.3. Limitations and uncertainties of the study

Limitations regarding the choice of the VSS and BBT cases deserve to be discussed. While selecting cases can be a challenge (Seawright and Gerring, 2008) – particularly regarding BBT cases that have a low level of maturity – the selected cases do represent a wide range of BBT and VSS cases in the agro-food supply chain. Selecting different cases may have led to divergent findings. Thus, the selected cases do not reflect every possible case, but instead provide insights on a wide range of cases. Furthermore, there are limits regarding the information available for assessing the cases. Particularly for BBT cases, the analysis is based on the limited information provided by the cases themselves (e.g. through their homepages). For specific cases, we were able to obtain additional information through conversations with the company or scanning QR codes on available products. Nevertheless, lack of empirical data on BBT cases is a limitation that further research should address.

The findings of the study may hold true beyond applications in the agro-food supply chain. For example, OpenSC is a BBT case that initially implemented blockchain technology for tracking Patagonian Toothfish from bait to plate (OpenSC, 2021). Their fish are MSC certified, and a synergistic relationship can be observed regarding the impact categories. The case also shows that OpenSC is able to provide more data on the legality of the fish and increase visibility of such information. Audits still take place as is the case with MSC-certified products, but additionally the data on the blockchain can be audited. Finally, consumers can scan a QR code on the product and are able to learn about the journey of the fish and see additional information such as that the vessel that caught the fish sets off their carbon footprint. However, with respect to technology requirements, governance, and process transparency, an antagonistic relationship can be identified. OpenSC requires the implementation of a machine learning model, which uses data from the vessels, such as GPS data, weather, and boat speed, next to tracking technologies and blockchain technology. OpenSC too is a privately held company, and the process of becoming an OpenSC fisher or company is unclear. While this example shows that although the results of the study may be applicable outside of the agro-food sector, we cannot ensure validity for other sectors. However, some of the results can likely be transferred. For example, BBT that implement VSS will likely have a synergistic relationship. Other results may not be transferable. For example, the automobile industry employs blockchain technology to trace components of the battery for electric vehicles. Labelling and outcome transparency cannot be addressed in these cases in the same way as is done for agro-food products, as the battery is only one component of the entire vehicle.

Another limitation of this study is that it cannot validate long-term effects of BBT in agro-food supply chains. Given the data available and the early stages of implementation of most BBT cases, we could not demonstrate whether the proposed BBT solutions will in a definite way address (some of) the limitations of existing VSS and how this would occur. We thus insist on the need for more long-term research on the impact of BBT in supply chains (Köhler et al., 2021). Given the variety and complexity of the social and institutional settings of the cases considered in thus study, a suggested direction for future analysis would be to carry out a more systematic classification and critical assessment of the currently existing and emerging institutional settings for BBT.

Notwithstanding, it should be kept in mind that blockchain technology is still in its early stages of development. It is impossible to know how the technology will develop over time, which features will be added, which weaknesses will be discovered, and if it will be adopted as a governance mechanism of supply chain sustainability on a large scale or whether voluntary sustainability standards will remain the dominant mechanisms. The results of this study should be understood with this in mind.

5. Conclusions

We described in detail 16 VSS and BBT according to twelve sustainability-related assessment criteria and analyzed how the relationship between BBT and VSS can be synergistic, co-existing, and antagonistic. While most of the cases under analysis showed a co-existing relationship between BBT and VSS, we identified a few cases of synergy when BBT cases integrate VSS, and one case of antagonism occurring when a BBT becomes an alternative to existing VSS. We further identified specific characteristics of each relationship type. BBT cases that co-exist with VSS typically focus on making supply chain data available. Some also provide access to financial services to upstream actors in the supply chain. In cases where BBT and VSS have a synergistic relationship, VSS provide measures for positive impact, established structures, and a trusted label, while BBT increase transparency and make the existing label interactive providing access to additional product information. BBT cases that are antagonistic to existing VSS set up their own sustainability measures, make the outcome data transparent, and ultimately build an alternative to VSS. While VSS have shown mixed results in terms of effectiveness of their sustainability governance, BBT have been suggested as a solution to those shortcomings. However, it is doubtful if BBT can adequately fill all these gaps as the technology brings its own challenges and does copy some existing structural issues of VSS.

Our findings provide a better understanding on how BBT and VSS interact. We show what advantages and drawbacks to sustainability governance in agro-food supply chains BBT can bring compared to VSS. This can inform stakeholders of the possibilities to cooperate constructively and ultimately bring positive social and environmental impacts to agro-food supply chains. With this study, we also intend to initiate a discussion on the relationship between BBT and VSS and its effects on governance of supply chain sustainability.

To verify that BBT and VSS can have synergistic, co-existing, and antagonist relationships requires additional long-term research with larger sample sizes and additional empirical data. Research should also confirm that the additional and more transparent data that BBT provide to actors within the supply chain, such as brands and consumers, will in fact lead to positive impacts. Furthermore, research should investigate if consumers having access to more product-specific data foster more informed decisions leading to more sustainable consumption. Finally, research should analyze if private companies are better at innovating than more bureaucratic organizations such as VSS.

CRediT authorship contribution statement

Susanne Köhler: conceptualization, conducting case studies, data analysis, writing – original draft preparation; **Simon Bager**: conceptualization, feedback on analysis, writing – review and editing; **Massimo Pizzol**: conceptualization, feedback on analysis, writing – review and editing.

Data availability

We have shared the data as a Supplementary File.

Acknowledgements

SK and MP contribution has been funded by the grant 7015-00006A of the Independent Research Fund Denmark – Social Sciences. SB acknowledges funding from the H2020 Marie Skłodowska-Curie Actions Grant Number: 765408.

Appendix A. Supplementary data

The case study database is appended as a supplementary file. Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2022.122094.

References

4 4C, 2021. 4C serives [WWW document]. URL. https://www.4c-services.org/.
Astill, J., Dara, R.A., Campbell, M., Farber, J.M., Fraser, E.D.G., Sharif, S., Yada, R.Y., 2019. Transparency in food supply chains: a review of enabling technology solutions. Trends Food Sci. Technol. 91, 240–247. https://doi.org/10.1016/j.tifs.2019.07.024.
Bager, S.L., Lambin, E.F., 2020. Sustainability strategies by companies in the global coffee sector. Bus. Strateg. Environ. 29, 3555–3570. https://doi.org/10.1002/bse.2596.
Bager, S.L., 2021. Delivering zero deforestation: how governance interventions in agro-food commodity supply chains can foster sustainable land use. Universite catholique de Louvain, Earth and Life Institute. https://dial.uclouvain.be/pr/boreal/object/boreal:254482.
Bager, S.L., Singh, C., Persson, U.M., 2022. Blockchain is not a silver bullet for supply chain sustainability: insights from a coffee case study. Curr. Res. Environ. Sustain. 4, 100163 https://doi.org/10.1016/j.crsust.2022.100163.
Balzarova, M.A., 2020. Blockchain technology – a new era of ecolabelling schemes? Corp. Gov. 21, 159–174. https://doi.org/10.1108/CG-08-2020-0328.
Balzarova, M.A., Cohen, D.A., 2020. The blockchain technology conundrum: quis custodiet ipsos custodes? Curr. Opin. Environ. Sustain. 45, 42–48. https://doi.org/10.1016/j.cosust.2020.08.016.
Bext360, 2021. About us [WWW document]. URL. https://www.bext360.com/.
Bonsucro, 2021. About Bonsucro [WWW document]. URL. https://www.bonsucro.com/what-is-bonsucro/.
Brooklyn Roasting Company, 2021. Adweek: Brooklyn Roasting Co. and IBM are letting you track your coffee on the blockchain [WWW document]. URL. https://brooklynroasting.com/ibm-blockchain-adweek/.
Choco4Peace, 2021. Home [WWW document]. URL. https://choco4peace.org/.
CoinDesk, 2020. Nestlé partners with rainforest alliance to trace coffee beans [WWW document]. URL. https://www.coindesk.com/nestle-partners-with-rainforest-alliance-to-trace-coffee-beans.
Cole, R., Stevenson, M., Aitken, J., 2019. Blockchain technology: implications for operations and supply chain management. Supply Chain Manag. 24 (4), 469–483. https://doi.org/10.1108/SCM-09-2018-0309.
Connecting Food, 2021. Reconnecting all consumers with their food [WWW document]. URL. https://connecting-food.com/en/.

DeFries, R.S., Fanzo, J., Mondal, P., Remans, R., Wood, S.A., 2017. Is voluntary certification of tropical agricultural commodities achieving sustainability goals for small-scale producers? A review of the evidence. Environ. Res. Lett. 12 https://doi.org/10.1088/1748-9326/aa625e.

Dietz, T., Grabs, J., Chong, A.E., 2021. Mainstreamed voluntary sustainabilty standarrds and their effectiveness: evidence from the honduran coffee sector. Regul. Gov. 15, 333–355. https://doi.org/10.1111/rego.12239.

EC, 2021. Organics at a glance [WWW document]. URL. https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organics-glance_en.

FairChain Foundation, 2021a. The other bar [WWW document]. URL. https://www.theother.bar/.

FairChain Foundation, 2021b. Our story [WWW document]. URL. https://fairchain.org/our-story/.

FairChain Foundation, 2021c. Posterior tech [WWW document]. URL. https://fairchain.org/posterior-tech/.

FairChain Foundation, 2021d. Join us [WWW document]. URL. https://fairchain.org/join-us/.

FairChain Foundation, 2019. FairChain Farming Whitepaper.

Fairfood, 2021. Working on fair food [WWW document]. URL. https://fairfood.nl/en/.

Fairtrade International, 2021a. Fairtrade International [WWW document]. https://www.fairtrade.net/about/fairtrade-international.

Fairtrade International, 2021b. Our general assembly and board [WWW document]. URL. https://www.fairtrade.net/about/ga-and-board.

Fairtrade International, 2021c. Blockchain: the answer to everything? [WWW document]. URL. https://www.fairtrade.org.uk/media-centre/blog/blockchain-the-answer-to-everything/.

Farmer Connect, 2021. A new horizon for farmers, consumers, and everyone in between [WWW document]. URL. https://www.farmerconnect.com/.

Gardner, T.A., Benzie, M., Börner, J., Dawkins, E., Fick, S., Garrett, R., Godar, J., Grimard, A., Lake, S., Larsen, R.K., Mardas, N., McDermott, C.L., Meyfroidt, P., Osbeck, M., Persson, M., Sembres, T., Suavet, C., Strassburg, B., Trevisan, A., West, C., Wolvekamp, P., 2019. Transparency and sustainability in global commodity supply chains. World Dev. 121, 163–177. https://doi.org/10.1016/j.worlddev.2018.05.025.

Gurtu, A., Johny, J., 2019. Potential of blockchain technology in supply chain management: a literature review. Int. J. Phys. Distrib. Logist. Manag. 49, 881–900. https://doi.org/10.1108/IJPDLM-11-2018-0371.

IBM, 2021. The blockchain bean [WWW document]. URL. https://www.ibm.com/thought-leadership/blockchainbean/.

ITC, 2020. The State of Sustainable Markets 2020 – By Commodity.

ITC, 2022. Standards map [WWW document]. URL. https://resources.standardsmap.org/why/.

Kamilaris, A., Fonts, A., Prenafeta-Boldú, F.X., 2019. The rise of blockchain technology in agriculture and food supply chains. Trends Food Sci. Technol. 91, 640–652. https://doi.org/10.1016/j.tifs.2019.07.034.

Katsikouli, P., Wilde, A.S., Dragoni, N., Høgh-Jensen, H., 2021. On the benefits and challenges of blockchains for managing food supply chains. J. Sci. Food Agric. 101, 2175–2181. https://doi.org/10.1002/jsfa.10883.

Köhler, S., Pizzol, M., 2020. Technology assessment of blockchain-based technologies in the food supply chain. J. Clean. Prod. 269 https://doi.org/10.1016/j.jclepro.2020.122193.

Köhler, S., Pizzol, M., Sarkis, J., 2021. Unfinished paths – from blockchain to sustainability in supply chains. Front. Blockchain. https://doi.org/10.3389/fbloc.2021.720347.

Kouhizadeh, M., Sarkis, J., 2018. Blockchain practices, potentials, and perspectives in greening supply chains. Sustainability 10, 3652. https://doi.org/10.3390/su10103652.

Kshetri, N., 2018. 1 Blockchain's roles in meeting key supply chain management objectives. Int. J. Inf. Manag. 39, 80–89. https://doi.org/10.1016/j.ijinfomgt.2017.12.005.

Lafargue, P., Rogerson, M., Parry, G.C., Allainguillaume, J., 2021. Broken chocolate : biomarkers as a method for delivering cocoa supply chain visibility. Supply Chain Manag. https://doi.org/10.1108/SCM-11-2020-0583.

Lambin, E.F., Meyfroidt, P., Rueda, X., Blackman, A., Börner, J., Cerutti, P.O., Dietsch, T., Jungmann, L., Lamarque, P., Lister, J., Walker, N.F., Wunder, S., 2014. Effectiveness and synergies of policy instruments for land use governance in tropical regions. Glob. Environ. Chang. 28, 129–140. https://doi.org/10.1016/j.gloenvcha.2014.06.007.

Lambin, E.F., Thorlakson, T., 2018. Sustainability standards: interactions between private actors, civil society, and governments. Annu. Rev. Environ. Resour. 43, 369–393. https://doi.org/10.1146/annurev-environ-102017-025931.

Lernoud, J., Willer, H., 2017. Global Survey on Voluntary Sustainability Standards (VSS) Key Figures 1–17.

Lim, M.K., Li, Y., Wang, C., Tseng, M.L., 2021. A literature review of blockchain technology applications in supply chains: a comprehensive analysis of themes, methodologies and industries. Comput. Ind. Eng. 154, 107133 https://doi.org/10.1016/j.cie.2021.107133.

Mahyuni, L.P., Adrian, R., Darma, G.S., Krisnawijaya, N.N.K., Dewi, I.G.A.A.P., Permana, G.P.L., 2020. Mapping the potentials of blockchain in improving supply chain performance. Cogent Bus. Manag. 7 https://doi.org/10.1080/23311975.2020.1788329.

Meemken, E.M., 2020. Do smallholder farmers benefit from sustainability standards? A systematic review and meta-analysis. Glob. Food Sec. 26, 100373 https://doi.org/10.1016/j.gfs.2020.100373.

Meemken, E.-M., Barrett, C.B., Michelson, H.C., Qaim, M., Reardon, T., Sellare, J., 2021. Sustainability standards in global agrifood supply chains. Nat. Food 2, 758–765. https://doi.org/10.1038/s43016-021-00360-3.

Mol, A.P.J., 2015. Transparency and value chain sustainability. J. Clean. Prod. 107, 154–161. https://doi.org/10.1016/j.jclepro.2013.11.012.

MSI Integrity, 2020. Not Fit-for-Purpose: The Grand Experiment of Multi-Stakeholder Initiatives in Corporate Accountability, Human Rights and Global Governance [WWW Document]. URL MSI_Not_Fit_For_Purpose_FORWEBSITE.FINAL_.pdf (msi-integrity.org).

Nakamoto, S., 2008. Bitcoin: A Peer-to-Peer Electronic Cash System.

O'Rourke, D., Ringer, A., 2016. The impact of sustainability information on consumer decision making. J. Ind. Ecol. 20, 882–892. https://doi.org/10.1111/jiec.12310.

OpenSC, 2021. Your Patagonian toothfish [WWW document]. https://opensc.org/product-example. Accepted for publication.

PositiveBlockchain, 2019. Real impact. Real use cases. [WWW document]. URL. https://positiveblockchain.io.

Potts, J., Lynch, M., Wilkings, A., Huppe, G., Cuningham, M., Voora, V., 2014. State of Sustainability Initiatives Review 2014: Standards and the Green Economy.

ProTerra Foundation, 2021. The ProTerra standard [WWW document]. URL. https://www.proterrafoundation.org/the-proterra-standard/.

Provenance, 2021a. About [WWW document]. URL. https://www.provenance.org/about.

Provenance, 2021b. Reinforcing organic certifications in the digital age [WWW document]. URL. https://www.provenance.org/case-studies/soil-association.

Queiroz, M.M., Telles, R., Bonilla, S.H., 2020. Blockchain and supply chain management integration: a systematic review of the literature. Supply chain management. Supply Chain Manag. 25 (2), 241–254. https://doi.org/10.1108/SCM-03-2018-0143.

Rainforest Alliance, 2021. Who we are [WWW document]. URL. https://www.rainforest-alliance.org/about.

Raynolds, L.T., 2009. Mainstreaming fair trade coffee: from partnership to traceability. World Dev. 37, 1083–1093. https://doi.org/10.1016/j.worlddev.2008.10.001.

Rogerson, M., Parry, G.C., 2020. Blockchain: case studies in food supply chain visibility. Supply Chain Manag. 25 (5), 601–614. https://doi.org/10.1108/SCM-08-2019-0300.

RSPO, 2021. About us [WWW document]. URL. https://rspo.org/about.

RTRS, 2021. What is the round table on responsible soy association? [WWW document]. https://responsiblesoy.org/sobre-la-rtrs?lang=en. Accepted for publication.

Seawright, J., Gerring, J., 2008. Case selection techniques in case study research: a menu of qualitative and quantitative options. Polit. Res. Q. 61, 294–308. https://doi.org/10.1177/1065912907313077.

Singh, C., Wojewska, A.N., Persson, U.M., Bager, S., 2022. Coffee producers' perspectives on blockchain technology in the context of sustainable global value chains. Front. Blockchain. Accepted for publication.

van Hoek, R., 2020. Developing a framework for considering blockchain pilots in the supply chain – lessons from early industry adopters. Supply Chain Manag. 25 (1), 115–121. https://doi.org/10.1108/SCM-05-2019-0206.

Wang, Y., Han, J.H., Beynon-Davies, P., 2019. Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. Supply Chain Manag. 24, 62–84. https://doi.org/10.1108/SCM-03-2018-0148.

Zhao, G., Liu, S., Lopez, C., Lu, H., Elgueta, S., Chen, H., Boshkoska, B.M., 2019. Blockchain technology in Agri-food value chain management: a synthesis of applications, challenges and future research directions. Comput. Ind. 109, 83–99. https://doi.org/10.1016/j.compind.2019.04.002.

Susanne Köhler is a Ph.D. Fellow at the Danish Centre for Environmental Assessment at Aalborg University. Her research interests are in the fields of sustainability, life cycle assessment, and blockchain technology. She is currently working on the Sustainable Blockchain Technology's project, which aims at investigating what environmental and social impacts blockchain technology will have beyond the hype and with a solid scientific basis.

Simon Bager is a Ph.D. Fellow at the Earth and Life Institute at Université catholique de Louvain in Belgium. His research interests revolve around sustainability in the agro-food sector, focusing particularly on governance of global agro-food supply chains. His thesis work focused on how governance interventions can address issues related to deforestation and land use change.

Massimo Pizzol is an Associate Professor at the Danish Centre for Environmental Assessment at Aalborg University. His teaching and research interests are in the fields of sustainability, industrial ecology, and life cycle assessment and has published several scientific articles in these domains. His current research focus is the assessment of the sustainability of emerging technologies, especially digital technologies and technologies for the circular blue and green bioeconomy - this is investigated using interdisciplinary and mixed-methods approaches and tools, from stochastic models to interview, and with an explicit attention to uncertainty and scenario analysis.