Graduation project

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Traceability for sustainability – challenges and opportunities of blockchain technology in apparel supply chains

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Preface - Acknowledgements

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Abstract

Although efforts addressing the industry’s negative are gaining momentum, apparel supply chains are still far from being sustainable. An important factor hereby is the lack of traceability inherent to the sector. In order to verify sustainability claims, identify and address key pain-points, the tracing of data concerning the entire supply chain impact is seen as a key requirement recognized as a priority to enable sustainable development (UNGC 2015; GFA and BCG 2019).

The current state of traceability in apparel, however, is still deficient. Only around a third of the industry tracks and traces the supply chain and these efforts are mainly limited to the second tier – while a great part of the environmental breaches happens further down the chain. Main barriers for traceability implementation are the complexity and fragmentation of the supply chain as well as involved cost, resources and lacking capabilities of all supply chain actors. On the other hand, growing stakeholder pressure, operational efficiencies as well as better risk management are key incentives. To harness its full potential, a standardized traceability system would be a precondition to ensure integrity and comparability. Constraints for the implementation of a functional system are a lack of consensus which technology, system and metrics would be required. Therefore, a key enabler would be a regulatory framework for the industry. In the meantime, the question remains which system and technology would be best suited for the apparel supply chain in order to enhance traceability, accountability and more sustainable practices.

An increasing interest around the application of Blockchain technology within supply chains and especially for traceability could be noticed in media and scholarly research. Features such as immutability, decentralized information sharing as well as time-stamped integration of data and Internet of Things, are potentially interesting for apparel supply chains.

In this context, by using various information sources including recognized literature, case studies as well as interviews, this study aims to give a holistic picture of the concept of traceability and related systems within apparel and its implications for environmental sustainability including an exploratory, critical evaluation of potentials and challenges of blockchain technology in this same context.
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Abbreviations and term-explanation

SC – Supply chain – all processes involved in the creation and distribution of a product
BC – Blockchain
BCT – Blockchain technology
DLT – Distributed ledger technology
PLM – Product lifecycle management
Negative externalities – Environmental and social costs that businesses impose on society
MNC’s – Multinational companies
PoA – Proof of authenticity
TRU – Traceable Resource Unit
IoT – Internet of things
RFID – Radio frequency identification
GHG emissions – Green house gas emissions
LCA – Life-cycle-assessment
UNECE – United Nations Economic Commission for Europe
OECD – Organisation for Economic Cooperation and Development
SDG – Sustainable Development Goal
PoC – Proof of Concept
3. Introduction

3.1. Rationale

Although promising developments towards more sustainable practices have been observed in recent years, the apparel industry remains a challenging sector regarding sustainable development. Textile supply chains continue to compromise numerous social and environmental issues with water and air pollution, intensive water and energy use as well as inhumane working conditions being only the most striking examples (de Brito et al. 2008) and progress does not take place on the pace and scale needed (BBG and GFA 2019).

While all of these aspects do have a tangible, negative impact on livelihoods and the environment, a great part of the harm the apparel industry causes in this sense remains widely unaddressed due to the lack of traceability and accountability within the sector. This can be attributed to several factors inherent to textile supply chains hindering the effective collection and tracing of data that would fully evidence the industry’s negative externalities and, in the next step, enable measures to reduce its negative impact.

One of these factors is that the textile industry operates in a complex network of global, fragmented supply chains including many tiers and stakeholders ranging from raw material providers, fabric mills to finishing and manufacturing - with each tier carrying potential risks for negative externalities. Geographical distance, cultural and regulatory differences (Busse et al. 2017) as well as the fact that companies often do not own their upstream suppliers, increases information asymmetry among all supply chain actors leaving the majority of firms with limited knowledge and control about all activities of suppliers beyond the first tier.

Other crucial aspects are the authenticity, verifiability and comparability of information collected at different stages in the supply chain. An essential, problematic aspect hereby is the accurate and standardized gathering, recording and sharing of data throughout the value chain. Furthermore, emphasized by its fragmented nature and the weak state of digitalization of textile supply chains, relevant data is still being stored in silos in form of unconnected databases using different tools, methods and standards (Galvez et al. 2018). Additionally, there is an increasing variety of used certificates referring only to single parts of the supply chain which further increases complexity, confuses stakeholders and decreases comparability. Lastly, often due to trade secrecy, many suppliers are hesitant to share certain information for competitive reasons or simply because they do not have resources nor incentives to record it (Pisani 2017).

MNC’s of all industries including apparel have been operating within this setting for many years more or less intentionally, avoiding accountability for environmental and social breaches.
More recently however, several scandals revealed the catastrophic effects of lacking traceability at all supply chain stages as well as the negative impact and role the textile industry has in the context of the global environmental crisis we are facing. Therefore, the missing insight into the complexity and implications of apparel supply chains of increasingly demanding stakeholders lead to great mistrust and a call for more authentic information disclosure (Fashion Revolution 2019). Consequently, corporations are expected to face increasing obligations from governments, NGO’s and consumers to enhance full supply chain traceability revealing the real impact of their products and processes (Rusinek et al. 2018).

However, the current state of traceability in textile supply chains is still deficient. Many initiatives illustrate how much information related to environmental and social impact is traced and publicly shared about fashion brand’s supply chains, one of them being the Transparency Index by the Fashion Revolution organization, which is an assessment of 200 fashion brands on five categories - among which traceability makes up the highest evaluation percentage. It clearly states that, although it has seen a slow increase, this category has the lowest scores since its first measurement in 2017. Although the report confirms that there is definitely a trend among brands and retailers to trace and publicly share more information around their supply chain impact, it also points out that most crucial information further down the chain, concerning one of the most critical areas of raw material sourcing for example, still remains hidden and concealed by vague statements. Progress seems to happen on a slow pace, mostly limited to individual, selective initiatives and loose commitments.

Hence, in order to achieve traceability and accountability driving systemic change and sustainable development in the apparel sector, an industry-wide traceability scheme and system would be a basic requirement and frame in order to provide reliable, standardized and quantifiable information about the environmental as well as social impact of textile supply chains (BSR and UNGC 2014).

In the process of the rapidly ongoing digital transformation under the framework of industry 4.0., supply chain structures are expected to change profoundly within the next years. Experts at leading consultancies forecast that evolving technologies summarized as DARQ (Distributed ledger technology, Artificial intelligence, extended Reality, and Quantum computing) will shape the future in many ways across industries (Accenture 2019).

The application of these enabling technologies could pose potential solutions to the current transparency, traceability and sustainability issues in fashion. While all of these innovations start to and will continue to touch upon apparel supply chains in different ways, Blockchain, or more precisely: Distributed Ledger Technology, is an emerging technology that seems
especially interesting in the context of traceability as it is claimed to have the ability to securely record data and in this way eventually enable more effective measures to increase accountability in the apparel supply chains. BCT, being an immutable and peer-to-peer verified transaction ledger, could potentially play the role of making supply chain information available in one place by breaking down the currently existing data silos in order to store reliable information in a shared, decentralized database (Jordan 2018). Furthermore, it could be implemented across borders and supply chain stages, therefore also addressing the issues at the bottom of the chain. In this sense, BCT could also serve as a tool for external regulators such as NGO’s and governments to track supply chains in a more effective manner, hold supply chain actors accountable for their actions and in this way enforce more sustainable practices (Jordan 2018).

Many studies examine interesting use cases of BCT enhancing supply chain traceability and accountability in industries ranging from food tracking, logistics, pharmaceuticals, and automotive supply chains (Deloitte 2017; Francisconi 2017) and also in the textile industry numerous studies and pilots have been and continue to be conducted in this context. Recently, the agricultural blockchain startup Bext360 collaborated with the C&A Foundation for a pilot project tracing the supply chain of organic cotton, which is in many aspects less harmful than conventional cotton, to prove that the same cotton collected at the farm is still the same when arriving in the fabric mill - as it is often secretly mixed with conventional cotton while still charging a premium price. Using DNA samples as additional proof of authenticity (PoA), this step could be successfully traced and raises hope that in the same manner similar processes will be possible to be traced (Knapp 2019). However, scalability as well as several other constraints of the technology itself still remain challenging.

Considering the above, the rationale of this research report is to examine the current state and challenges of traceability in the textile industry as well as a critical analysis of barriers and incentives of BCT as an emerging technology to enhance current textile supply chain traceability systems leading to increased accountability and eventually more sustainable practices.

3.2. Aim

The goal of this research is to examine the implications and state of traceability in apparel supply chains and to critically analyze the current trend of emerging proposals using blockchain aided solutions to increase accountability and eventually the adoption of more sustainable practices. This will lead to the identification of challenges regarding effective traceability systems and further to an examination on if and how the capabilities of blockchain technology can solve some of these issues in apparel supply chains, based on literature and case study
analysis. The outcome in terms of a final product is focused on the supply side of the industry and will be an article about the pro and contra as well as applicability and scalability of BCT for traceability in apparel.

**Research question:**

1. **Main research question:**
   Can blockchain technology potentially disrupt current traceability systems in order to hold supply chain actors accountable for negative externalities and in this way advance sustainable development?

**Sub-questions:**

1.1. What exactly does complete traceability entail, especially regarding sustainable development and accountability in apparel?
1.2. What are the most pressing issues in apparel supply chains regarding environmental impact, its traceability and related systems?
1.3. What are the capabilities, challenges and opportunities of BCT applied in traceability systems to solve the detected prevailing challenges?

**3.3. Methodology**

The methodology applied for this research will consist of:

1. **Thematic literature review** Secondary research in form of a thematic literature review of relevant reports and academic articles in the same field found in google scholar will be conducted to examine the current state, relevance and trends around the mentioned topic. Used keywords to find suitable articles will include *apparel supply chain traceability, traceability systems, supply chain digitization and blockchain for (apparel) supply chain traceability.*

2. **Case study analysis:** Further, companies that are using blockchain technologies for apparel supply chains will be analyzed and evaluated by conducting case studies of firms such as Provenance, Bext360, Sourcemap and TrustTrace in order to detects challenges and opportunities of BC application in apparel supply chains.
3. **Primary data**: Qualitative data will be collected by conducting semi-structured interviews with approximately five industry professionals from different, topic specific backgrounds - such as apparel supply chains, sustainable fashion and (blockchain) technology to gain a secondary, professional opinion on the research results.

3.4. **Structure**: The structure applied in this research will be as follows:

1. A literature review will be conducted analyzing the state of traceability and related systems as well as prevailing issues in fashion supply chains linked to traceability and the industry’s environmental impact. Further, blockchain as an emerging technology will be analyzed regarding its potential to gather environmental metrics throughout the supply chain and in this way improve the visibility and accountability for negative externalities in textile supply chains. This will include a brief explanation of the technology as well as related challenges and opportunities.

2. Four case studies exemplifying the business models of start-ups using blockchain for traceability and sustainability in apparel supply chains will give an insight into current approaches, its applicability in the industry and the identification of challenges and opportunities.

3. Finally, approximately five semi-structured interviews with professionals within apparel, sustainability and IT will give an insight into opinions and attitudes of people working in the relevant fields on how they evaluate the mentioned topics in order to compare them with the research results leading to final conclusions.

3.5. **Scope**

Due to the complexity of the concept of sustainability in the textile industry, this study will focus on environmental aspects, still bearing in mind that implications of social and environmental sustainability are often intrinsically linked.

Accordingly, the selected case studies of firms using blockchain technology in apparel supply chains will be focused on those solutions that are emphasizing accountability for environmental sustainability issues.
Moreover, the study will focus on only one emerging technology, namely blockchain technology, bearing in mind that its full potential is often unleashed by integrating other innovative technologies.
Lastly, the study is focused on the garment sector while textile and footwear sector are not separately addressed due to limited data availability that differentiates between these areas.
4. Conceptual background

Traceability

The lack of traceability as a prerequisite of transparency and accountability remains a key challenge in industries including apparel, in particular regarding sustainable development. In order to understand how or if emerging technologies such as BC can contribute to solve the related issues, it is important to fully comprehend the concept of traceability and what it entails. Therefore, this chapter outlines the term’s most widespread definition as well as implications for sustainable development and accountability.

4.1. Definition

While different organizations use varying definitions for traceability, all of them equally refer to the process by which a product moves from its original raw material state and production phase to the final consumer (UN guide for traceability 2014). The most widespread definition of traceability by the International Organization for Standardization, defines traceability as the ability to trace the history, application or location of a product in relation to the origin of its materials and parts; the processing history; and the distribution and location after delivery. (ISO 9000/BS 5750, 2014).

Recognizing the link to sustainability and the significant, supporting role of supply chain traceability in achieving the Sustainable Development Goals (SDG’s) set for 2030 at the UN General Assembly in 2015, the United Nation’s Global Compact suggests a sustainability orientation of the ISO’s definition, which will be the point of departure of this research report. It describes traceability as: The ability to identify and trace the history, distribution, location and application of products, parts and materials, to ensure the reliability of sustainability claims, in the areas of human rights, labor (including health and safety), the environment and anti-corruption (United Nations Global Compact Office 2014).

4.2. Implications for sustainable development

The relevance of supply chain traceability is often linked to the effects of globalization and the shift of manufacturing to suppliers in countries with inexpensive labor, better raw material availability and less stringent regulations (Kumar et al. 2017) and has traditionally been focused on quality assurance, risk management and lean manufacturing. Obviously, these significant
financial gains haven’t come without a price. More recently, several scandals revealed the negative environmental and social implications, especially in relation to the absence or inefficiency of traceability in various industries including apparel, giving rise to efforts aiming to turn global supply chains into more accountable and sustainable networks (Closset et al. 2011). In this context, the term of *Traceability for sustainability* has been coined as a key enabler for sustainable supply chain management being defined as the *ability to combine SC information-sharing and visibility in such a way that actors within the chain have access to information that is accurate, trusted, timely and useful for operational reasons and to ensure the reliability of sustainability claims* (Garcia-Torres et al. 2019).

In the same vein, the UN sustainable development goals make reference to the relevance of traceability for sustainable development, in particular in goal number 12, sustainable consumption and production, which includes the advice for businesses to trace their supply chains (United Nations Global Compact Office 2014). Facing increasing demands for product transparency and traceability, approaches to sustainability in the corporate realm of industries including apparel have evolved to a point where vaguely expressed sustainability commitments and objectives are not sufficient (WALDB 2014). Sustainability initiatives and claims must be based on and backed by the firm’s core sustainability issues which requires the tracing and assessment of information across the entire value chain (WALDB 2014). The data collected from this process can then on the one hand be used to identify, address and tackle critical business-intern sustainability issues and on the other hand communicate more credibly about sustainability (Quantis, 2019). Recognizing that this goal cannot be reached on a large scale by individual initiatives, increasing efforts are taken by companies and stakeholders in industries with more complex supply chains such as agriculture, food and apparel, to join forces with global, multi-stakeholder initiatives in order to trace materials, products and processes in a more collaborative and effective manner (UNGC and BSR 2014). Global traceability schemes in industries including apparel, such as the Better Cotton Initiative (BCI), have advanced collaboration and engagement with all stakeholders along the entire value chain in order to develop more credible and reliable chain of custody standards and certification for end-to-end traceable products (BCI 2014). Promising results of these initiatives leave no doubt that traceability schemes have become an important enabler for sustainable development and are further growing in impact and credibility (UNGC and BSR 2014).
4.3. Implication for accountability

It is important to point out the implications of traceability for accountability backed by the aforementioned standards, certifications as well as regulations whereby the validation of information acts as a key prerequisite. Generally, traceability can be seen as an enabler for greater accountability of global value chains but requires the reliability of systems collecting verified information as well as measures to enforce legal consequences in the case of breaches with regulations. Although laws, regulations, as well as private and international voluntary standards have evolved to advance accountability and sustainability in global value chains in the course of the last years (Rusinek et al, 2017), this same development of hard and soft laws has also further increased global complexity and fragmentation - both for consumers and businesses (Nikolakis et al. 2018). Moreover, there is a wide-spread perception that government involvements have not gone far enough in advancing sustainability, especially in developing countries, and private actors have stepped in with to fill this gap by creating voluntary standards and certifications for firms to enhance sustainability – with different objectives, as well as levels of authenticity and effectiveness. Companies frequently make various sustainability statements about their supply chain and products such as being organic or fair-trade certified, and these claims are usually backed by audits and certifications, but they often only validate a part of the supply chain (Bonanni 2019). However, changing legislation will require businesses to ensure accountability for end-to-end traceability whereby verification and validation of traced data remains a key challenge to tackle (Bonanni 2019).

4.4. Conclusion

While there are numerous definitions for traceability, in any case it entails tracing a product from raw material to consumption state. Due to various scandals in the past years, illustrating the lack of supply chain traceability and the negative impact of global value chains, sustainable supply chain management starts to integrate traceability as a prerequisite and key enabler for better practices and the link of traceability and sustainability is recognized by various respected institutions. There has been an increase in multi-stakeholder initiatives in the last years to tackle these issues which point out that collaboration is a critical aspect that is starting to be addressed by the industry. On the other hand, this same development has further increased the complexity of traceability in global value chains due to different regulations and standards. A key point
enabling accountability remains data quality and reliability as well as a lack of hard laws backing end-to-end traceability.

5. Traceability implications within global apparel supply chains

After introducing the general relevance and implications of traceability, this chapter focuses on its role within the apparel industry in particular. First, in order to grasp the relevance of apparel on a global scale, the overall environmental impact per supply chain stage is visualized which enables the identification of pain-points of the industry that need to be traced and addressed. Further, the current state of traceability and the factors hindering effective tracing on all supply chain levels is summarized in order to conclude where key areas of improvements lie that BCT could eventually pose solutions for.

5.1. Environmental impact per supply chain stage

As outlined in figure 1, each tier in the life-cycle of apparel holds the potential for negative externalities for the environment (Quantis 2018). For the following analysis, it is important to consider that the use-phase of apparel is not fully considered as the focus is on the apparel value chain and production processes. The most severe environmental impact of textile production can be divided into two main areas (UNEP 2014). First, the discharge of pollutants and secondly the consumption of water and energy. Regarding the first aspect, key areas of impact are air, water and land pollution which are mostly linked to the use of chemicals. Hereby, emissions to the air are a rather minor but not negligible source of pollution while most of the chemicals are released to waste water making water pollution the predominant impact factor (OECD 2004). With regard to energy
consumption, it is widely recognized that the apparel industry plays a notable role in climate change (Quantis 2018). In order to meet the industry’s high energy demand, apparel uses mainly two types of energy sources namely electricity as an indirect emission source and natural gas, cogeneration and diesel fuel as direct emission sources (UNEP 2014). In this way, the apparel and footwear sector generate an estimated 8% of the global GHG emissions while apparel alone makes up 6.7% (Quantis 2018). Concerning water consumption, key stages of freshwater withdrawal and usage are fiber production – especially for water intensive materials such as cotton, followed by dyeing and finishing and wet spinning in yarn preparation.

Therefore, as pictured in Figure 2, 3 and 4, within the apparel sector in particular, the dyeing and finishing stages, namely tier 2, are the biggest contributors to climate impacts due to high levels of freshwater withdrawal as well as energy intensive processes in countries that largely rely on coal and natural gas for electricity and heat production, especially in China, India and Bangladesh which are the sectors largest manufacturers but heavily rely on fossil fuels (OECD 2019). Both processes are main contributors to the aforementioned emissions.
Additional factors are the use of grasslands and rainforest for rubber or bamboo plantations as well as cattle farms for leather, which are just two examples of how the fashion sector also contributes to increased emissions through land-use change, deforestation, and livestock supply chain emissions (OECD 2019). The considerable waste generated with the disposal of used or even unused garments, is also contributing to the climate footprint of the sector as well as the release of micro-plastics shedding from synthetic garments into waterways.

It can be concluded that, concerning the different tiers of the textile production, tier 2, 3 and 4 are the main contributors to climate change.
5.2. The current state of traceability in apparel

An initial observation regarding the state of traceability in global supply chains is that the great majority of references, especially to cases of more effective traceability implementation, are related to examples from industries with higher levels of regulatory enforcement due to increased health risks for the end consumer such as pharmaceuticals or food (Moe, 1998; Zhou and Piramuthu 2015) and the link to the social and environmental dimensions of sustainability is mainly reduced to perceived product health and safety concerns.

Recognizing the aforementioned impact of the textile industry, improving traceability should be a priority for the industry, in order to increase the ability to manage supply chains both more efficiently and sustainably (UNECE 2017). However, the current state of traceability is weak and shows slow progress. Several attempts have been made to shed light on the current efforts and deficits regarding the implementation of traceability in apparel. One of them is the Fashion transparency index by the Fashion Revolution Organization, which is an assessment of 200 fashion brands on five categories - among which traceability makes up the highest evaluation percentage. The category is focused on whether brands are publishing lists of their suppliers and what level of detail brands are disclosing about these. According to the Index of 2019, no brand or retailer is scoring above 66% of the total 250 possible points and only 11% in the category traceability, which means that 70 brands are publishing tier 1 suppliers, 38 are publishing their processing facilities and just ten enclosed the source of raw materials (Fashion Revolution 2019). There is an overall increase in the traceability category of 7% since the first index in 2017 but at the same time it remains the category with the lowest average score.
Further, the UNECE surveyed a sample of 100 apparel businesses in 2018 coming to the conclusion that only around a third (34%) was tracing their supply chains at all and the majority of this part only until the second tier. The consensus of all of these statistics is clear: although there is a trend to enclose more supply chain information, the majority of brands does realize this yet and traceability mostly ends with the second tier.
However, disclosing information about the tier-one and two suppliers is not enough. According to the previously mentioned statistics and backed by other recognized industry reports such as the Pulse of the Fashion Industry 2018 report, 2/3 of negative sustainability impact occurs at the raw materials stage (GFA and BCG 2018). Therefore, complete traceability systems in apparel must integrate all supply chain tiers.

5.3. Barriers and incentives for end-to-end traceability in apparel supply chains

5.3.1. Barriers

**Complexity and fragmentation**

The global, geographic as well as cultural and regulatory complexity of the apparel industry as well as the lack of commonly accepted standards complicates tracking and tracing processes significantly (Boström et al. 2012). Further, supply chains of other consumer goods tend to have a simpler outline as they regularly just refer to a single product category undergoing little to no transformation before reaching the end-consumer. In the case of apparel products, however, various types of materials, textiles and garments are subjects to numerous processes that all come with a difficulty to trace related metrics. As complete supply chain traceability requires recording various types of information at different stages of the product transformation, starting from raw material production to logistics, this aspect is even more difficult to realize in the fragmented, globally operating apparel industry where textiles often travel through many different countries before reaching the destined country of consumption, causing complications in gathering data on each step of the supply chain (see figure 7).
Costs, resources & capabilities

Another crucial factor remains the economic and organizational burden of traceability (Stranieri et al. 2017). Effective traceability requires substantial investments in rather advanced technologies and processes of data verification on products, parts and components at all stages of the value chain (UNECE & CEFACT 2019). Moreover, the lack of resources and capabilities among supply chain actors, especially further down the chain, is another inhibiting factor (Boström et al. 2012) for traceability implementation as data is not recorded or just on simple paper sheets or excel files. Obtaining accurate, timely and reliable data from each step of the supply chain is, however, crucial in order to obtain an authentic picture of the environmental impact of the supply chain. This requires a mutual effort from all involved supply chain actors and especially of those in upstream, product transforming positions, which often lack the incentives, tools and capabilities to fulfill this responsibility (Kumar et al. 2017).

Technological barriers:

Lack of digitalization

Using technologies for traceability such as platforms, bar codes or chips is a challenge for many supply chain actors, especially those located in developing countries and remote areas without even access to the internet. There are language, skill and access barriers to using these technologies.

Data reliability, falsification and verifiability
Although there are several traceability standards, verifiability and authenticity of the collected data is a difficult issue and is emphasized by the lack of resources among supply chains actors as some suppliers are not equipped with the right technology to collect data in an effective and verifiable way. Also, some actors falsify information on purpose claiming products to be *organic* without backing these statements with validated data.

**Sensitive data and supplier resistance**

As supply chain actors, especially in manufacturing, are often bound to trade secrecy, supply chain information remains concealed due to competitive reasons. Privacy of data and data security are of concern particularly for brands, traders, and companies in the high value segment of the market and they are often reluctant to share information about specialized providers.

**Lack of consensus and regarding standards and legislation**

The lack of a common definition of traceability to the non-existence of a supporting technological tool and language poses a significant barrier for traceability (Marshall et al. 2016). In addition, coordination between different supply chain actors requires time and willingness on all sides.

**5.3.1.Incentives**

**Increasing stakeholder pressure:**

*Legal compliance and proof of provenance*

The first group are consumers and their increasing interest in sustainable products includes a growing interest in product provenance (Joy et al, 2015). This trend provides an incentive for implementing measures for more insights into supply chains as traceability implementation has been proven to restore consumer confidence in product quality and safety by providing more information beyond standard facts such as product origin, composition or quality (Aung et al. 2014; UNGC&BSR 2014). Companies that invest in increased traceability and measurements of sustainability data in the value chain will have a competitive advantage in meeting this consumer demand (UN BSR guide 2014).

More direct incentives for companies to be more transparent about their supply chains practices are first of all, growing pressure from governmental regulations and other external entities which are expected to increase in the future (UNGC&BSR 2014). Governments are increasingly focused on the role of companies in addressing sustainability issues and environmental risks in supply chains. This has already resulted in a rise of disclosure legislation
in countries including California, France, the United Kingdom, the Netherlands, and Australia (OECD 2019).

From the side of civil society benchmarks, the past years has seen an increase in third-party sustainability and due diligence efforts to measure company performance related to their supply chains (OECD 2019).

**Risk management**

Another benefit that can be achieved by traceability implementation is better supply chain risk management. Apart from reputational and logistic risks linked to traceability measures, the ability to identify and eliminate potential social and environmental risks, will become even more relevant due to expected raw material shortages and environmental changes. Moreover, savings generated by more efficient water and energy use as a result of better traceability can bear significant financial benefits (Pisani et al. 2017).

**Increased operational efficiencies**

Traceability system implemented at different stages of the supply chain can reveal processes that are effective or not. Exchange of data and documentation can open the dialogue about process improvements and can contribute to integrating best practices throughout supply chain actors leading to cost reductions and increased productivity (UNGC&BSR 2014).

**Collaboration and alignment**

Consensus around traceability and tools can help reduce costs to individual actors on the long-run. When collaboration is widespread, there is greater incentive for actors to work together, which lowers cost overall (UNGC&BSR 2014). Standardization of processes and systems regarding traceability can make sustainability requirements a norm in the industry.

**5.4. Conclusions**

As the statistics indicate, the global environmental impact of apparel is mainly centered around energy and water use and emissions to water while most of these impacts occur in the second, third and fourth supply chain tier. On the other hand, several reports confirm that the majority of apparel businesses does not track and trace its environmental and social supply chain impact at all and if mostly and only to the second tier which does not integrate all significant stages of negative impact. Therefore, it should be a core priority to tackle these deficits and extend
traceability schemes to all involved stages. However, although consensus has been reached that traceability is an indispensable aspect of sustainable supply chains, its implementation remains a complex due to several significant barriers. The most challenging constraint remains the global complexity and fragmentation of apparel supply chains. Further, the lack of consensus about commonly accepted standards, missing willingness and abilities to invest in measures to collect and share all information along the value chain as well as the organizational and economic costs aggravate the problem. On the other hand, increasing stakeholder pressure, potentially better risk and resource management remain some of the main drivers of traceability implementation. An industry-wide, standardized traceability system would be indispensable to drive change and sustainable development. Traceability system requirements and examples will be further discussed in the following chapter.

6. Traceability systems

This chapter will give an insight into the current state of traceability system implementation with focus on system requirements and relevant sustainability metrics that should be recorded in order to conclude which challenges are still prevailing that BCT might have a solution to offer for.

6.1. System requirements

Generally, a precondition for any traceability system is the ability to access, record and share information related to all involved actors, activities, and products including raw materials, processing conditions, logistics movements or carbon footprint. (Agarwal 2019). Considering the detected challenges and the lack of a common approach, implementation factors and requirements found in the literature that acts as precondition for a functional traceability system are summarized in the following. Hereby, the frameworks used by Kumar, Hallquvist and Ekwall for traceability implementation in apparel as well as Olsen’s and Borit’s framework for components for traceability systems in the food industry are summarized and combined. First and foremost, traceability system implementation has to be approached based on strategies for data management. (Thakur et al. 2007). In this sense, any functional traceability system has some core requirements for implementation (Khabbazi et al. 2009). Broadly, the components and essential steps for the development and implementation of any functional traceability system that could be identified in the literature are mechanisms for:
a) **Identifying Traceable Resource Units (TRUs)** - a product or batch  
b) **Documenting transformations of TRUs** – processes like dyeing and finishing  
c) **Recording the attributes of the TRUs** – stored, evaluated and shared in database  

### a) Identifying TRUs

In order to correctly identify any TRU, the structure and type of an identifier code has to be chosen, while also considering the granularity or preciseness as well as uniqueness of the code and a way to associate the identifier with the TRU in question.

*Identifier code type and structure*

A TRU identifier can be numeric or alphanumeric while the length can vary from a few characters, used for internal batch identification, to a couple of hundred used, for example, for electronic product identification where the code is read from a computer chip associated with the TRU (Olsen and Borit 2018). These identifiers can be printed in machine-readable formats, such as bar-codes.

*Uniqueness and granularity of identifier codes*

To ensure that the chosen identifier codes serve its purpose, the uniqueness within the context of use is crucial (Regattieri et al. 2007; Storøy et al. 2013). While TRU’s of a batch share several properties, they are effectively separate entities and could have different ways throughout the supply chain. Therefore, since longer codes and media able to carry these such as Radio-frequency identification (RFID) chips and sensors are becoming more common, one-to-one relationships between codes and TRUs are increasingly used (Dabbene et al. 2016) and make any traceability system more powerful but are also related to higher costs.

*Association of identifier to TRU*

The most common way is a physical marking directly on the TRU or on its label (Dabbene et al 2014) and can be in text, readable by humans, or by machine-readable codes such as barcodes or Quick Response (QR) codes. RFID technology is increasingly used in B2B solutions (Badia-Melis et al. 2015), where the chip is either physically attached to the TRU or to the packaging that the TRU is in. Hereby, we can distinguish passive RFID tags, which are less expensive and require no battery and active RFID tags use a battery and can also record environmental metrics such Global Positioning System (GPS) location - which are more expensive.
b) Documenting transformations

Once the type of identifier to use is selected and a way to associate the identifier to the TRU is found, the next step is the documentation of what occurs to the TRU throughout the supply chain. The supply chain for food and apparel products is often long and complex. States of TRUs do not necessarily last long and are subject to several modifications. Examples of transformations in apparel supply chains can be spinning of yarn from raw materials, dyeing and finishing processes or manufacturing which are some of the most important aspects to record.

c) Recording TRU attributes

This step includes the ability to record, store and share attributes associated to each TRU linked to their identifier and represents the most valuable aspect for most supply chain actors since the previous step rather represent costs for a company. However, all the components of a traceability system are of relevance for this end result as they directly influence the recorded attributes. In the following, attributes that would be relevant to record, analyze and share in relation to environmental impact of TRU’s within supply chains are outlined as sustainability metrics.

6.2. Sustainability metrics

Traceability attributes can be broadly classified as product-, process-, and quality-related (European Commission 2016). While these factors are generally widely integrated in apparel supply chains, the fourth type of information, concerning the social and environmental impact of a product throughout its transformation stages, which is the focus of this study, forms a separate category (Agrawal and Pal 2019). However, there are naturally links between the categories. At the moment, information about origin, composition and manufacturer of end-products are the only mandatory details that brands and retailers are forced to provide information about to including the end consumer. These aspects, however, give a limited insight into the -environmental- sustainability of a product. In order to grasp the real impact of a product and all processes behind, reliable, science-based sustainability metrics are the first requirement in order to identify possible pain points within the supply chain and react accordingly.

As an initial step towards the development of a traceability systems focused on supply chain sustainability, a number of key information sets have been identified in the literature.
Environmental metrics

- Relevant environmental certifications (e.g., EU Ecolabel, FSC certification, chemical certifications like OEKO-TEX, GOTS, Cradle to Cradle)
- Life Cycle Assessment impact data
- Higg MSI impact data
- Raw materials used
- Chemicals used
- Amount of water used
- GHG emissions
- Waste, byproducts, and coproducts produced
- Biodegradability, compostability
- Responsible disposal instruction
- Responsible care instructions

Figure 8: Relevant sustainability related traceability information sets (ASQ, 2018)

6.3. Examples of traceability systems

This section is divided in different approaches divided in three levels with increasing refinement and accuracy namely PLM software and databases, solutions centered around LCA and more refined systems based on RFID as more precise identifiers.

Traditional software solutions - example: PLM systems

Some of the common systems to organize and record product and process specific information in collection management are centered around Product Life Cycle Management tools which have quite a long history of use in the textile industry. These systems were first and foremost designed for quality assurance, risk management and efficiency purposes and freed the industry from using old-fashioned tools as excel sheets to gather collection data. In this way, PLM solutions have advancing the sector towards higher levels of digitization by using sensors, IoT and other measures for real-time data management, exchange and collaboration among supply chain actors and are nowadays also able to include sustainability related information. However, companies use different software solutions which makes it difficult to compare performance. Moreover, the content selection of metrics, verifiability as well as the nonexistence of a common, interoperative language and tool to share the information between different stakeholders remain an issue (Kumar et al. 2017). In this way, supply chain data is stored in silos in form of centralized databases and is therefore often limited to one brand, department,
supplier or manufacturer. Verifiability and accuracy of the collected and stored data are not fully provided. Examples of the most common currently used PLM software solutions are Lectra, PTC and Centric among others while all of these examples share the aforementioned deficits.

Mass Balance systems - Example: Better Cotton Tracer by ChainPoint

The Better Cotton Initiative's Better Cotton Tracer is a system developed with Chain Point and allows to follow cotton from farm to gin and trader level and has in this way a visibility into all tiers. It is recording volumes of Better Cotton and can be considered a system for managing Mass Balance. Data is verified, with some random, physical third-party checks and audits (European Comission 2016).

LCA-based systems – Example: Ecologtex by Hugo Boss

Based on the premise that science-based, reliable metrics should be the starting point for sustainability strategies, providing businesses with the needed data to make better informed decisions, Metrics-driven tools such as life cycle assessment (LCA), that tracks all of the flows of a production process are becoming more advanced and widespread. Credible data on environmental impact is, however, scarce and its collection signifies challenges and costs in globalized, complex supply chains such as apparel (Zeller et al. 2016)

Therefore, Hugo Boss, Quantis and other leading industry players such as SAC and Lenzing - founded the World Apparel and Footwear Lify Cycle Assessment Database (WALDB) which seeks to solve the data challenge and to deliver robust data for environmental impact assessment and footprinting (WALDB 2015). This database builds on EcoLogTex, a traceability tool developed by Hugo Boss and Quantis to collect supplier specific production data.

RFID-powered solutions - Example: Eon ID

EonID is considered one of the leading Digital Identity companies focussed on end-to-end connectivity across fashion, apparel and retail using the power of connectivity to unlock circular economy. By creating a unique Digital Identity for every product, being the first provider that integrates RFID in form of an actual thread, EonID enables brands and retailers to connect products to the Internet of Things and access end-to-end business intelligence with the benefit to connecting the entire value chain with data and knowledge. With embedded Digital Identity
(embedded & washable RFID, NFC, QR), brands can gain visibility and transparency across the value chain - including reuse, rental, resale and recycling. In addition, EON.ID plans to use its platform to introduce the first global tagging system for textile lifecycle management and recycling.

6.4. Challenges

Although PLM systems have helped to advance digitalization of the apparel sector and increased the measurement of product, quality and process related attributes as well as operational efficiency and collaboration, these software solutions are not going far enough in integrating sustainability metrics. Although there is a great variety of emerging and promising systems, software and tools that are more focused on sustainability integrating traceability schemes, the main challenge is the lack of a standardized system and the variety of different approaches which is leading to even greater complexities and lacking interoperability. Moreover, there seems to be no consensus on which metrics should be traced and which technology should be applied. Moreover, as many systems and standards are private and do not include sufficient third-party verification schemes, collected data must be considered a claim rather than a fact. Significant measures would have to be taken to verify data which poses administrative challenges and is connected to high investments of money and time. Another barrier for a fully functional system is the cost to implement and maintain more refined technologies such as RFID sensors in form of unique identifiers such as in fabric threads, which prevents the widespread adoption of these solutions. A key point of these technologies is the state of privacy, especially for the end consumer in case of integrated tags and sensors integrating the use and recycling of a product. It is also notable that many more advanced traceability initiatives and systems like the BetterCottonTracer are exclusively focused on cotton. Although it is one of the most used fibers and has a significant environmental impact, it does not fully cover the reach of a complete traceability systems as it is too limited considering the variety of materials used.

6.5. Conclusions

The main issue remains the lacking consensus of all stakeholders regarding the adoption of a single system or standards for the implementation of traceability systems. There are few existing standards covering the whole supply chain integrating a combination of environmental, social and economic areas, but they are neither interconnected nor widely used. There is the
possibility to combine systems and standards covering different areas of the supply chain but this could become complicated and expensive for users as well as for the interconnection of individual traceability systems and methods. Data collection itself is another time and resource consuming factor and even with automated collection with tags and sensors, verifiability and accuracy are a huge challenge. Therefore, data collected in common traceability systems must be considered a claim not a fact and there are no effective, widespread measures for validating the information. Wrong claims can occur easily due to fraud or errors (Borit and Olsen, 2012). To go beyond these isolated actions, laws backing a mandatory detailed list of metrics including chemical uses, water footprint, and CO2 emissions, verified by third parties such as certification bodies and independent initiatives while also considering the use and requirements of IoT applications would be indispensable to enable traceability and sustainable development in apparel supply chains (European Commission 2016).

7. Blockchain technology for traceable supply chains

This chapter will give an insight into the characteristics, potentials and challenges of blockchain as an emerging technology found in the literature and illustrates its application in case studies using the technology for supply chain traceability in apparel in order to conclude potentials and challenges for this purpose solving the aforementioned issues.

7.1 Origins and capabilities

Origins

In a White Paper called “Bitcoin: A Peer-to-Peer Electronic Cash System” published in 2008, a Japanese hacker or group using the pseudonym Satoshi Nakatomo first introduced the cryptocurrency BitCoin which is built on a technology that was later called the blockchain (Nakamoto 2008). The intention behind the technology was to provide an immutable, decentralised peer-to-peer-system making the need for a third-party verification of a transaction obsolete. Although the currency itself was first implemented to serve as a solution to the double-spending problem, the blockchain can be used separately from Bitcoin (Nakamoto 2008).

Capabilities

Generally, a blockchain, as a type of distributed ledger technology, is explained as a decentralized, public record keeping system maintained by a group of peers (Mougayar and Buterin 2016). On such ledgers, all transactions are secured and cannot be modified once they
have been stored on the chain. Further, a BC ledger database can be described as distributed and decentralized due to the multiple copies that are kept on different nodes of users. In contrast, a centralized system usually employs an intermediary or third party to verify transactions like it is the case in the financial industry for example. This step, however, is often time consuming and costly, especially when used for transnational transactions.

Another crucial aspect is trust. BCT gives parties with very low levels of trust towards each other a medium to interact and share transactions. Each user is assigned end-to-end visibility depending on the level of permission, which claims to make it a more transparent and secured network. Moreover, all information shared on the BC has to be verified by all users before being recorded with an exact timestamp and all records can be seen and audited by each member anytime and anywhere. For this procedure, three main cryptographic features are implemented on BC which are called hashes, keys and digital signatures. First, a hash is the result or output of the input for a transformation of original information entered on the blockchain. Whenever a transaction is registered, on each following block a hash is shared with the previous one which creates a chain. In the case of manipulation, each block and hash will be invalid and the complete chain is broken which ensures that data cannot be manipulated. Further, private and public keys give access to the network and digital signatures are mathematical computations that are used to prove the authenticity of any kind of data entered on the chain (Mougayar and Buterin 2016). Each transaction needs to be digitally signed to be valid.

**Smart contracts**

Another important aspect is the development of BC’s that could implement small computer programmes called *smart contracts*. Smart contracts have given blockchains the ability to implement a varied set of business functions involving the transfer of information and or value, while leaving transparent and reliably auditable information trails (CEFACT 2019). They are self-executing computer programs that encode business logic and automatically execute certain actions when pre-defined conditions are met which can be a certain period of time or another specific value. Therefore, their execution does not need to be initiated, or at least not directly, by human intervention which offers several benefits (Mougayar and Buterin 2016):

- Improved security and predictability as they eliminate the human element and potential contract breaches caused by human action or error;
- Transparency as the code of a smart contract can be public and visible, anyone can review it and predict how transactions under a given contract are;
- Simplified programming for systems that require the need to accept, match and then act upon data for certain procedures (CEFACT 2019).

Blockchain and Internet of Things integration

The Internet of Things (IoT) is using sensors, small computing devices or chips in physical objects that can communicate via the Internet to one another, computing systems and humans. IoT devices can collect a wide variety of data. Examples of information communicated by IoT devices include location and movements via GPS or for more valuable items such as pharmaceuticals or luxury goods, the tracking or identification of individual packages or products.

IoT devices can be a useful way to capture data that is analysed by other systems that then add these results to a BC. However, writing constant data readings to a BC can be expensive for networks where every time you write data you have to pay a small amount.

A good example of the use of IoT data with a BC is to assure that very temperature-sensitive goods like for example certain food where handled in the correct way during transport. An IoT device in transport containers can track the temperature which can be connected to a smart contract that automatically initiatives a payment request in case the temperature conditions are not met. This can significantly decrease the costs for all involved parties as the IoT data as a solid proof that does not require more investigations.

Private and public BC’s

Another important feature of the blockchain is its division into public and private depending on permission requirements and ownership. Private or permission-based blockchains are owned by organizations or companies while public ones are open for everyone. Further, there is the option to encrypt certain details to make sure that only permissioned parties can decrypt it which is then rather a BC consortium, a mix of a decentralized and centralized database.

In conclusion, BC’s capabilities can be summarized as follows:

- **Immutability**: The creation of data records that cannot be secretly changed;
- **Decentralization**: The access by all participants to all data on a blockchain;
- **Smart contracts**: The implementation of programmes automatically executing once a set of agreed conditions are met;
- **Real-time data with timestamps**: The ability to identify the time and origin of every entry in a blockchain.
- **IoT integration**

### 7.2. Case studies
Blockchain technology application can be divided into two areas: First, its implementation as an addition in a company and secondly its integration from the very beginning like it is the case with several start-ups that evolved during the last years. In the following, insights are given into approaches taken by some of these start-ups using BCT for supply chain traceability and sustainability in apparel in order to conclude challenges and potentials.

**Provenance**

*Provenance* is a London-based blockchain start-up founded in 2011 aiming to increase transparency and traceability in product supply chains using a blockchain application system and a software platform. Provenance found that although certifications aided consumers in evaluating general brand conduct, they are often not adding a lot of meaning for consumers due to the lack of insight into their actual implications and authenticity. Claiming that “the digital age can provide a system to revolutionize why and how we chose to trust one product and company above another.” (Provenance News, 2017), the company uses two different types of data systems to tackle this issue. The “transparency tools assemble image, identity and location to create profile, product and story pages. The traceability system confirms identities and product attributes in tracking items through supply chains.” (Provenance, 2017). The decentralized application (Dapp) also aims to connect data silo systems to prevent data from being falsified. This includes the advantage that products that are certified with a sustainability certificate cannot be sold twice and the authenticity of the certificate can be traced accurately through the chain (Provenance News, 2017). By using the application, businesses will be able to create “a secure link between physical products and their digital counterparts through serial numbers, bar codes, digital tags like RFID and NFC, genetic tags” (Provenance, 2015), enabling businesses to access real-time data telling a story around their product so that consumers can trace the journey of their product.

Key features: Decrease of data silos and falsification, backing certificates with verification

**Sourcemap - Collaboration with provenance**
Sourcemap was launched in 2008 as a supply chain management platform aiming to provide radical transparency. Since 2011 the New York City-based startup develops software and services enabling companies aiming for accountability of global supply chains. In 2017, Sourcemap partnered with the aforementioned blockchain-powered start-up Provenance, in order to link their digital platforms for supply chain transparency, enabling businesses in the food and fashion industries to map their supply chain, gather data and track verified claims with the movement of product. Sourcemap's supply chain social network connects all of the suppliers and sub-suppliers in a global network, ensuring that they are who they say they are while provenance blockchain-aided system tracks every transaction between the suppliers to verify that every product is sourced through the authorized chain of custody. Combining Sourcemap’s upstream mapping, macro risk analysis, and data capture with Provenance-verified business and product claims, as well as downstream batch-level tracking for automatic supply chain traceability, Provenance and Sourcemap did pilot their joint technology platform with major food businesses. The goal was to offer consumers in the future to scan a product on a store shelf and know exactly who made it, when and where but also to verify the quality, the social practices, the environmental footprint.

Key features: Data verification, supply chain connectivity and mapping

**Bext360 - Organic Cotton Traceability Pilot**

Bext360 is an agricultural blockchain startup providing traceability technology to liberate critical supply chains of commodities such as coffee, seafood, timber, minerals, cotton and palm oil from opacity and inefficiency by providing accountability and a traceable fingerprint from producer to consumer (Bext360, 2018). The start-up partnered with multiple tech companies, especially non-profits and fashion-based platforms. One of them, a partnership between the C&A Foundation, the Organic Cotton Accelerator and Fashion for Good supported by C&A, Zalando, PVH Corp and the Kering Group, is a pilot test to see if blockchain technology can find a use case in the sourcing of organic cotton on the supply chain. The pilot has three phases. In the first phase, the cotton is traced from the farm to the processing gin, during the second phase from gin to the consumer and the final stage will link organic farmers, textile producers, and fashion companies. Based on statistics from Textile Exchange, organic cotton currently accounts for under 1% of the total global production of cotton. However, that percentage still accounts for over a $15 billion market, since it costs so much to produce and purchase (Textile...
Exchange 2018). Between the demand from consumers and the high price premium, fake organic cotton is on the rise which incentivized the pilot project in the first place. Therefore, the cotton sources are “tagged” to ensure that the authenticity of the cotton is logged, giving it a “fingerprint” in the supply chain backed with the specific DNA of the cotton source. After recording this data, the blockchain software product from the platform creates a “token,” with which the cotton can be traced, ensuring that consumers can see every part of the path of the cotton. Next to the proof of authenticity, farmers can also benefit from the technology. Each individual cotton source is attached to the blockchain, enabling the identification of each farm and hereby the adequate payment for their work by a digitized payment. Furthermore, companies can identify the cotton traders that are supplying the level of quality that they claim.

Key feature: Cotton provenance backed with DNA samples and tokenization to incentivize farmers.

**TrusTrace**

Recognizing that current PLM systems are often deficient concerning the information sharing of product life-cycle data, Sweden-based startup TrusTrace aimed to deliver a tool using machine language and a blockchain-powered platform in order to fill the missing gaps in data in the fashion supply chain, increasing efficiency around information access and to tell the story of every garment from fiber to fabric. Hosted on a cloud platform, the startup creates visualizations of supply chain maps with verified supplier data. Those data dashboards help brands identify their weakest links, undertake risk analysis, improve sustainability efforts as well as communicate these to the end customer. The first step is data collection. TrusTrace is running pilots with several sustainability frontrunner brands including Filippa K and Houdini, with each setting up its own information requirements. Through the platform, the brands are sending customized questionnaires to tier-1 suppliers, who can further forward the online forms to the next tier like spinners or dyers, adding more people to the chain. The second aspect is data accuracy. The platform is using multiple methods to test that before putting it onto the blockchain to ensure that fake certifications can be avoided. Currently, this process is partly automated and still supported by human intervention. In this way, the platform’s algorithms are being trained with publicly available data like GOTS (Global Organic Textile Standard) and other relevant industry standards. As more brands and suppliers come onboard, the system’s logic will also further improve in the process. The validated claims and assessments will be placed on a blockchain platform, which is partly private and therefore
visible only to specific brands. In this way, brands can decide what information to exchange with each other. By being at the heart of knowledge sharing between brands and suppliers, TrusTrace wants to be the TripAdvisor of suppliers by rating them based on information shared, along with ethical and sustainability credentials (TrusTrace 2018).

Key features: supply chain mapping with verified data, support for data collection at all stages, proof for certifications

7.3. Challenges and opportunities of BC for apparel supply chain traceability

Corresponding to the previously detected challenges in traceability and system implementation, considering the approaches taken by the case studies as well as information found in the literature, the following opportunities and challenges have been detected.

Opportunities

Supply chain challenge: Fragmentation, complexity & information asymmetry

*BC solution: Decentralized data storing and sharing*

The first advantage is decentralized, secured and verified data storage. As outlined, supply chain actors usually store information in data silos in different formats which makes it difficult to share and compare relevant information. BC could act as a secure, decentralized data base for all supply chain stakeholders.

Supply chain challenge: Responding to stakeholder pressure - supporting sustainability claims with proof of provenance

*BC solution: Increase of Trustworthiness - Data validation*

BCT can provide data authentication methods with potentially higher levels of reliability (Mougayar and Buterin 2016). Related to proof of provenance, track and tracing of products and proofing sustainability claims, IoT, sensor and RFID integration offer the possibility to access supply chain data in real time and therefore increase speed and efficiencies as well as granularity of data. The question remains: what is the added value of BCT for these aspects?
As mentioned, a major issue in the track and trace of a product is the reliability of data mainly due to two aspects: first, ensuring a continuous end-to-end traceability chain with no missing events and secondly the quality of the data recording and processing. For both issues, blockchain technology could potentially offer a solution. Concerning the first point, in order to record each relevant event, a BC itself cannot enforce continuous tracking and tracing in a supply chain. However, using timestamps, it can verify when, where and the content of each event that is recorded, so when used at each node in the supply chain, the blockchain can verify the track and trace record of a product from the supplier to the last node where data was recorded (CEFACT 2019). For the second aspect, the quality of the recorded data and data processing, blockchain technology can provide a solution. In a standard track and trace system it is not necessary to provide business partners with the track and trace data for a product in real time or even near real time. This provides a window of opportunity for the hidden correction or manipulation of data. In other words, the administration of the track and trace system can be used to cover up fraud through the manipulation of recorded data on processes and products (CEFACT 2019). Having the data stored in a BC, these corrections would be transparent to all users who will see both the original data and the changes. However, Blockchain technology does not fully prevent poor data quality and fraud is not eliminated with blockchains, it will only be made more difficult – provided that all conditions are fulfilled, such as proper identification of the product, location and parties together with the right authorization of parties.

Moreover, the fact that all records can be seen and audited by each member anytime and anywhere has the potential in apparel to enable an authentic insight into the lifecycle of a product as several features such as certifications and other assessments can be added to the BC.

**Supply chain challenge: Reluctance to share data**

**BC solution: Incentives and permissioned BC’S**

Supply chain actors, especially in upstream positions are often reluctant to share information and have no incentive in doing so. With the help of smart contracts, this could be changed as the provision of data could be linked to renumerations automatically transferred by BC. Access to information can be controlled via user profiles that specify the access permissions for each participant in order to ensure that competitive information is not shared with the wrong stakeholders (CEFACT 2019).
Supply chain opportunity: Increased operational efficiencies

Many inefficiencies in supply chains are due to the time and effort required to gather accurate information on the location, condition and estimated-time-of-arrival of goods. Blockchains can enable real-time access to accurate information could then facilitate faster and potentially better decision-making by stakeholders all along the supply chain. The use of smart contracts can further decrease administrative challenges in transactions by making human intervention for certain business processes obsolete.

Supply chain opportunity: Risk management

Using the mentioned capabilities, a BC system could enable a better identification of raw materials sources as well as other information that may be helpful in pattern recognition and identification of causes for supply chain disruptions (CEFACT 2019). This information could also include the history and location of an item after it left the factory and could increase real-time monitoring of production processes.

Challenges

Immaturity and scalability of the technology

First of all, although its maturity stage was projected to take place within 2019-2020 (Havard Business Review 2017), the technology itself is still in its infancy and faces several constraints, making this projection seem rather unrealistic. Further, it can be argued that the manufacturing industry is not ready for blockchain technology (Harvard Business Review 2017). This is supported by the factors described in the following. One of the first challenges with regards to implementing blockchain as a new technology is its scalability. Blockchain as a technology is rather slow as it has to reach consensus before transaction is approved while centralized databases do not need this step and therefore tend to be faster. Therefore, it is important for companies to be sure that a decentralized ledger is adding a significant benefit in comparison to a usual database or cloud.

Costs, resources and capabilities – lack of integrative, standardized solutions
The implementation of BCT requires significant financial and organizational resources which most actors in apparel supply chains are unable to afford. It might be possible that this will change in the course of its development and scaling, but observing the current trends and developments, this is not likely to happen in the near future. Most of all small and medium-sized enterprises, and especially supply chain actors in developing countries, may be reluctant or unable to make the investments needed for participating in BC networks. While the cost of sensors and computing power is likely to decrease, the required hardware is unlikely to be a barrier to implementation. In some regions, however, a greater challenge is the provision of reliable, secure internet connections at all of the required points within supply chains. The provision of technological support to maintain a BC will also be difficult and costly and in some countries and areas. Moreover, installation and running costs of such solutions in remote areas may not be financially justifiable. Local, national, and even multi-national government agency support would be required in order to prevent suppliers from being forced out of markets due to their inability to contribute information to BC’s (CEFACT 2019). This is a scenario that seems very unrealistic.

**Data collection and reliability: “garbage-in” issues**

Data collection would need to be automated in order to maximize the efficiencies that can be achieved. Although the technology to achieve this already exists today (RFID, QR Codes, IoT sensors) when used at larger scale, implementation challenges have been observed in relation to incomplete readings. These issues will have to be addressed to ensure 100% accuracy at each stage to support the full reliance on the data that the BC collects. Discrepancies in data accuracy will widely decrease the usefulness of BC and its adoption. This aspect emphasizes the so-called garbage-in” risk which means that the information that is entered into a BC by, for example in case a sensor isn’t giving accurate data, and would lead to creating permanent faulty data on the ledger. In this sense, the most important feature of BC, immutability and irreversibility of transactions, can become an issue in itself. Further, the ability to recognize nodes with the authority to make correcting entries to original data will be critical to prevent hacking (CEFACT 2019).

**Computing power and energy use**

One of the major issues is the required computing power and resulting high energy use which leads to the question of its sourcing and remains a problem comparable to electric cars and the
source of energy that is used which can significantly diminish the environmental impact it seeks to improve. Especially in the context of this research, aiming to find solutions in traceability for improvements for the sectors negative environmental impact, this is a major constraint.

**Lack of standardization and increased complexity**

As illustrated in the case studies, BC has inspired many providers to offer potential solutions regarding diverse problems including traceability and sustainability. While all of these examples of pilots and proofs of concept (POCs) solutions for BC application offer interesting perspectives, the question remains how all of these solutions would work together in practice and how they will connect and compare to each other. Without clear standards, each BC solution might just work in isolation but further increase the interoperability issues that was already detected in existing traceability systems. Therefore, a broader BC ecosystem with clear standards would be needed for a successful implementation which is still not the close to being established.

**Regulation**

One feature of BC is the potential for anonymity. Although this is an aspect that could be engineered into or out of any BC, the potential for hiding or manipulating important information is a major concern to governments. Without tailored regulation, it would be possible for entire economies to operate in the dark while avoiding taxes, fees and financial laws such as those on money-laundering, especially with the use of crypto-currencies (UNECE and CEFAT 2019). Due to these concerns, governments are likely to inhibit BC implementation until clear and enforceable regulations are in place.

**Private blockchains**

Another concern is the rise of private blockchains, which are in fact working against the initial concept of decentralized information sharing. On public BC’s, every user can see all transactions unless they are encrypted, which is considered an issue for some parties not willing to share information for competitive reasons. Therefore, some solutions, such as some of the case studies, are now looking at alternative models of private, or “permissioned,” blockchains, which distribute a shared ledger according to authorization. While it can enable a more efficiently governed system, it reintroduces some of the risks associated with centralized data bases such as silo building and a lack of access to authentic information.
8. Interview results

In order to obtain secondary opinions and perspectives on the researched topic, industry professionals and experts within the field of sustainability, supply chain management and software development have been consulted leading to final conclusions on the role of BCT solving prevailing traceability issues in textile supply chains.

While all interviewees agreed that traceability can act as a key enabler for accountability and more sustainable practices in apparel, the opinions about the role of BCT where more divided.

Concerning the use of blockchain in apparel and on a wider scale, especially interviewee 5 expressed clear doubts of the technology. His main points where energy use which he considered as unproportionally high, especially when used in supply chain traceability in sustainable apparel stating that it would mitigate all the efforts that the increased traceability would accomplish. Another concern he mentioned was the rise of private BC’s. According to his sources that he did not further specify, IBM owns approximately 20% of private blockchains and the use of permissioned BC networks would come with all known risks to centralized databases and control.

Interviewee 1, Business development and Marketing Director at Sourcemap, clearly expressed that blockchain technology is not ready to be implemented on a large scale for mainly three reasons. On the one hand, the constraints of the technology itself as well as the lacking access besides all, mostly upstream, supply chain actors who often do not even possess any device to be able to collect data, as well as the economic cost that its implementation implies for businesses, which makes it an “elite” option for story-telling and marketing of bigger companies but leaves smaller players and suppliers who cannot afford it behind.

However, mentioning the current development lead by the OECD, UNECE and other influential stakeholders to establish guidelines and a policy-recommendations for blockchain implementation in the apparel and footwear sector, are interesting to observe for a possible future application.
9. Final conclusions

Recognizing the aforementioned research questions that have been formulated, the following conclusions can be deducted from the literature, case studies and interviews.

RQ 1.2.: What exactly does complete traceability entail, especially regarding sustainable development and accountability in apparel?

First, regarding traceability in apparel supply chains and its link to environmental sustainability it can be stated that traceability implementation can act as a prerequisite and basic condition to enable accountability and the verification of sustainability claims as well as the identification of key sustainability pain-points in supply chains that can in this way be addressed. The importance of traceability has been recognized by several highly respected actors such as the United Nations and the SDG’s and all interviewees as well as the literature found confirmed this statement.

On the other hand, although many advances in form of multi-stakeholder initiatives, standards and regulation have been made, these developments have increased complexities for all stakeholders leading to the conclusion that to enable accountability, data quality and reliability as well as a lack of hard laws backing end-to-end traceability are key challenges.

RQ 1.2: What are the most pressing issues in apparel supply chains regarding environmental impact, its traceability and related systems?

Secondly, the state traceability of the industry is still deficient which is exemplified by the fact that most apparel businesses do not track and trace their supply chains and mainly reach until tier 2, while much of the environmental impact takes place further down the chain. Key barriers for traceability that have been detected are the complexity and information asymmetry in global supply chains, involved costs, missing regulation as well as a lack of incentives while increased stakeholder pressure, proofing product provenance, increased operational efficiencies as well as better alignment of stakeholders are seen as key incentives.

Further, while the requirements of a functional traceability system are widely known, the most important challenges hereby remain a lack of consensus regarding a single system and the metrics to include, the lack of a interoperable technological language, increased costs and administrative burden related to the recording of data as well as data reliability concerns.
Finally, the lack of supporting regulatory frameworks for traceability in apparel are seen as a key deficit.

**RQ 1.3:** What are the challenges and opportunities of BCT applied in traceability systems to solve the detected prevailing challenges?

Thirdly, regarding the applicability of BCT for traceability systems in apparel to hold actors accountable for environmental breaches, it becomes clear that, although there are several significant features of the technology that have the potential to deliver on these points, it will not be affordable, scalable and applicable within the timeframe that would be necessary in order to meet environmental and climate change mitigation goals. While the features of BCT, namely decentralized data recording and sharing, increased trustworthiness of stored information due to immutability of data as well as increased efficiencies and stakeholder incentivization using smart contracts are valuable, the list of challenges, barriers and concerns about the wide-spread use of the technology greatly outweigh these benefits. Main challenges remain immaturity and scalability of the technology as well as costs and resources needed for implementation – which would leave the majority of industry players and especially supply chain actors in developing countries far behind. Further, the immense energy use of BCT is another issue to be tackled and works against the intention of aiming for less environmentally impacting practices. Other concerns range from data security, regulations to the questionable concept of private blockchains.

**RQ 1:** Can blockchain technology disrupt current traceability systems in order to hold supply chain actors accountable for negative externalities and in this way advance sustainable development?

Finally, answering this main research question and based on the findings of this report, it can be argued that, at this present moment in time, the significant challenges of BCT, especially when applied for supply chain traceability in apparel, still prevail over the detected opportunities which make the technology unapt to solve apparel’s current issues around traceability and sustainability on the scale that would be necessary.

However, it is important to follow the current developments for eventual future considerations to implement a more advanced and scaled version of the technology. For this purpose, industries such as food and pharmaceuticals, where the capabilities of BC might be more suitable and investments can be better justified due to the significant influence on consumer health, can be
an area to explore and observe the application of the technology. It is possible that these related issues of BC are going to be solved in this process but it is not projected that this will happen in the near future. However, especially regarding the environmental impact of apparel and the urgent need to improve it, the industry needs traceability solutions that are available and applicable today and should therefore focus on making the best use of present resources to achieve this goal.

**Recommendations for further research**

Regarding the area of BC, an exact comparison of cloud databases and distributed ledgers would be of use as well as a guidance for companies to assess how BC can benefit them in their individual cases. Regarding traceability systems, an analysis of best-practice examples could be an interesting approach.
10. Appendix

10.1. Traceability types: Mass balance, segregation and book and claim

![Supply Chain Traceability Types](image)

UNGC and BSR, 2014

10.2. Interview guides

I. Sustainable apparel experts

Opening segment:

- What are your responsibilities at (...) and in which area are you currently working?
- How long have you worked with that role/area? What is your background?
- What is your main area of interest within sustainable fashion? What role does traceability play in your working environment?

Sustainability in apparel supply chains

1. What are the biggest sustainability challenges, in particular regarding environmental impact, within apparel supply chains in your opinion?
2. Which possible solutions do you see to these issues facing the urgency of climate change?
3. Which main challenges do you see when businesses adopt sustainable practices in their supply chain? (for instance regarding scaling, feasibility etc.)
4. How do you evaluate the state of accountability for apparel’s environmental impact? What would need to change?

Traceability for sustainable supply chains

5. How do you gauge the link and relevance of traceability within sustainable supply chain management?
6. What are the most pressing issues and challenges regarding (the lack of) traceability in apparel?
7. Do you know of any traceability systems? If so, which ones do/did you work with?
8. Which are the flaws you detected?
9. What do you think are the greatest obstacles and challenges of traceability systems?
10. What would be the most important features of a complete traceability system?
11. What are the greatest challenges of the implementation of traceability systems?

Blockchain technology for traceable apparel supply chains

12. What is your degree of knowledge about the technology itself from a range of 1-10?
13. How do you gauge its application in apparel supply chains?
14. Which of the (mentioned) pressing issues in apparel could it possibly solve?
15. What are challenges and opportunities of BCT in apparel supply chains?
16. What are your opinions on scalability, feasibility and widespread implementation of BCT?
17. Do you think BCT could become the “single source of truth” regarding supply chain impact?

Future Perspectives

18. Looking into the future, which role do you see traceability playing when aiming for sustainable supply chains?
19. What do you think can motivate big fashion companies to work towards sustainable development in a more immediate and bold manner?
20. How do you envision the progress of sustainability in the fashion industry?

Concluding segment: Follow-up questions
Are there any topics you’d like to comment on that have been neglected or would you like to stress anything you mentioned earlier?

II. Supply chain experts

Opening segment:

• What are your responsibilities at (…) and in which area are you currently working?
• How long have you worked with that role/area? What is your background?
• What is your main area of interest within sustainable apparel/supply chains?
• What role does traceability play in your working environment?

Sustainability in (apparel) supply chains

1. What are the biggest sustainability challenges, in particular regarding environmental impact, within apparel supply chains in your opinion?
2. Which possible solutions do you see to these issues facing the urgency of climate change?
3. Which main challenges do you see when businesses adopt sustainable practices in their supply chain? (for instance regarding scaling, feasibility etc.)
4. How do you evaluate the state of accountability for apparel’s environmental impact? What would need to change?

Traceability for sustainable supply chains

5. How do you see traceability linked to sustainable practices in the supply chain?
6. Which benefits do you see in having more traceability in supply chains?
7. Which key barriers do you see for reaching more traceable supply chains?
8. What are the most interesting business case studies you have worked with at apparel companies regarding traceability and environmental impact?
9. What kind of traceability systems or tools did you work with in your current position and previous ones?
10. Which are the flaws you detected?
11. What do you think are the greatest obstacles and opportunities of traceability systems?
12. What would be the most important features of a complete traceability system?
13. What are the greatest challenges of the implementation of traceability systems?

Blockchain technology for traceable apparel supply chains

14. What is your degree of knowledge about the technology itself from a range of 1-10?
15. How do you gauge its application in apparel supply chains?
16. Which of the (mentioned) pressing issues in apparel could it possibly solve?
17. What are challenges and opportunities of BCT in apparel supply chains?
18. What are your opinions on scalability, feasibility and widespread implementation of BCT?
19. Do you think it could become the “single source of truth” regarding supply chain impact?

Future Perspectives

21. Looking into the future, which role do you see traceability playing when aiming for sustainable supply chains?
22. What do you think can motivate big fashion companies to work towards sustainable development in a more immediate and bold manner?
23. How do you envision the progress of sustainability in the fashion industry?

Concluding segment: Follow-up questions
Are there any topics you’d like to comment on that have been neglected or would you like to stress anything you mentioned earlier?

III. Blockchain and software experts

Opening segment:

- What are your responsibilities at (…) and in which area are you currently working?
- How long have you worked with that role/area? What is your background?
- What is your main area of interest within sustainable supply chains? What role does traceability play in your working environment?

Supply chain sustainability and traceability

1. How would you define traceability in supply chains?
2. Which benefits do you see in having more traceable supply chains?
3. Which key barriers do you see for reaching more traceable supply chains?
4. What role do you see traceability playing when aiming for more sustainability in supply chains?
5. Where do you see the biggest potential impact of BC in sustainable supply chain management?
6. Which actors in a supply chain do you see benefitting the most from BC and which ones do you see facing the biggest challenges?
7. Which benefits do you see for intermediaries (wholesalers, distributors etc.) in supply chains from implementing BC?
8. Which disadvantages do you see for intermediaries in supply chains from implementing BC?
9. (How) do you link BC to more accountable and responsible business practices?
10. How far would you say that traceability is a part of sustainability?
Technology

11. What are the most pressing flaws in BCT itself that need to be tackled? (e.g. energy consumption etc.)
12. (How) do you see availability of information affecting sustainable supply chain processes?
13. Do you see this availability of information as a tool that can be used to make supply chains more sustainable?
14. What do you think about permissioned BC’s?
15. What are organizational and economic costs of BCT?
16. Which features of the technology do you see as the most suitable for (apparel) supply chain traceability?

Future perspectives

17. What are the most interesting pioneering projects or pilots regarding supply chains and BCT?
18. Which future challenges do you see with BC for traceability and sustainability?
19. How would you evaluate the progress of BC becoming a tool or “the single source of truth” for supply chain traceability and/or sustainability?
20. Do you see any more viable and readily available alternatives to BCT in the described context?
21. The apparel industry is quite slow in implementing new technologies. What advice would you give to bridge this gap?

Concluding segment: Follow-up questions
Are there any topics you’d like to comment on that have been neglected or would you like to stress anything you mentioned earlier?

10.3. Interviewees

Interviewee 1: Head of Business development at Sourcemap
Interviewee 2: Acting Head, Sustainable Trade and Outreach Unit, UNECE
Interviewee 3: Innovation manager at Fashion for Good
Interviewee 4: Product Manager at Trustrace
Interviewee 5: Full stack software developer at Plug&Play Tech center

11. Bibliography


Francisconi, M. 2017. *An explorative study on blockchain technology in application to port logistics*. Delft University of Technology.


Centre for Trade Facilitation and Electronic Business, (2019). *Blockchain in Trade Facilitation: Sectoral challenges and examples*