Discovering Blockchain for Sustainable Product-Service Systems to enhance the Circular Economy

Jannis Vogel[1], Simon Hagen[1] and Oliver Thomas[1]

[1] University of Osnabrueck, Chair of Information Management and Information Systems
Katharinenstr. 3, 49074 Osnabrueck, Germany
{jannis.vogel,simon.hagen,oliver.thomas}@uni-osnabrueck.de

Abstract. An increasing amount of use cases is discovered for blockchain technology, since it promises tamper-proof recording of product-related data. It has the potential to improve the reliability of information management for whole supply chains and thus enables new ecologically and economically service offerings. Integrating products and services into one marketable bundle is no new concept and is referred to as product-service systems (PSS). Therefore, the methodical integration of knowledge on sustainable businesses, PSS and blockchain is a promising approach to overcome current barriers to achieve an applicable circular economy. Our study contributes a structured literature review on ongoing research in the field of sustainability-focused blockchain applications. From this, we elaborate a holistic perspective by the integration of key concepts from two additional literature reviews for blockchain and PSS. As a result, we point out potential benefits and present the effect of blockchain on sustainable PSS with a product-life cycle model.

Keywords: Blockchain, Product-Service Systems, Circular Economy, Supply Chain

1 Introduction and Motivation

Circular Economy is a concept to increase the efficiency of resources and to implement sustainability in product-life cycles that will interrupt the phase of pure resource extraction, production, usage, and waste [1]. Barriers such as the customer's perception, information management, and missing performance indicators hinder a comprehensive application in businesses [2]. Hence new approaches are necessary to solve current problems in the domain of circular economy. One promising approach is the technology Blockchain. Blockchain has evolved as a capable technology to enhance information exchanges between individuals [3]. This contribution investigates how blockchain technology can improve sustainable business activities in particular regarding the circular economy.

However, in Gartner's Hype Cycle of uprising technologies, the blockchain is currently in the "trough of disillusion", expectations were thus not met [4]. From an environmental perspective, the blockchain is even more in a negative focus since it has a high demand for resources (e.g. for mining the cryptocurrency Bitcoin) [5]. The new

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technology raises many unanswered research questions, e.g. how blockchain systems have to be designed to be sustainable itself and follow concepts like Green by IT. In contrast, a disseminated research approach is the design of product-service systems (PSS) that have an evidenced impact on sustainability [6].

Hence, we propose the integration of blockchain as a technology, i.e. as enabler, and PSS as a business strategy to create ecologic and economic sustainable offerings. Blockchain allows the independent and tamper-proof record of product-related data and the traceable accountability regarding reuse or recycling [7]. Furthermore, the enhanced transparency of product components and materials they are made of contributes to a simplified recycling process and the estimation of resource values [8]. To obtain a holistic view on the concerned fields (blockchain, PSS and sustainability, i.e. circular economy) we conducted a literature review to identify current sustainable-, product- and service-related blockchain-based use cases. In a next step, we combined our research results with blockchain [3] and sustainable PSS characteristics [6] to determine which blockchain-based use cases subject to precise blockchain characteristics and how they influence existing sustainable PSS characteristics. By doing so, we answer the following research questions:

1.) *What are current blockchain-based use cases and how do they influence sustainable PSS characteristics?*
2.) *How do blockchain-based sustainable PSS influence the use of resources and enhance the circular economy?*

By the combination, we designed a blockchain-based product-life cycle model for PSS according to Blinn et al. [9]. Thereby the model demonstrates what kind of impact the application of blockchain in PSS has onto the product-life and resource efficiency. Overall the paper contributes first proposals how blockchain and PSS can be combined to achieve sustainable potentials in the circular economy. The blockchain-based product-life cycle model can be used to redesign PSS with the application of blockchain in a more sustainable manner and to overcome barriers in the circular economy. The remainder of this article is structured as follows: Section 2 explains the applied method to streamline this research. Followed by section 3 that describes the fundamentals regarding blockchain and product-service systems. Section 4 presents the findings based on the conducted literature research and the combination of blockchain and PSS characteristics. Section 5 presents based on the literature review the blockchain-based product-life cycle model. Finally, section 6 discusses limitations and further research needs.

2 Method

In order to clarify the research questions stated above, we conducted a literature review [10] to obtain an overview of current use cases regarding the application of blockchain technology in product, service and sustainability domains. The applied literature search process (cf. figure 1) is based on Dybå and Dingsøyr [11]. We queried the scientific databases *AISeL*, *Google Scholar*, *ScienceDirect*, *SpringerLink* and *Web of Science* with the term "Blockchain" AND ("Circular Economy" OR "Supply Chain" OR "Sustainability" OR "Environment" OR "Recycling" OR "Provenance" OR "WEEE" OR "Service") and their German translations. No limitations regarding the year of publication or any other attribute were made. Initially, this brought up 2393 sources in total, from which we removed articles by title and abstract. The process revealed 51 relevant articles that were then used for an in-depth analysis. In doing so, we focused on practical use cases of blockchain technology for sustainability with particular importance on saving data of a product during its complete lifecycle, cp. Blinn et al. [9]. The findings of the remaining 22 publications were then transferred into a concept matrix according to Webster and Watson [12] (cf. figure 3).

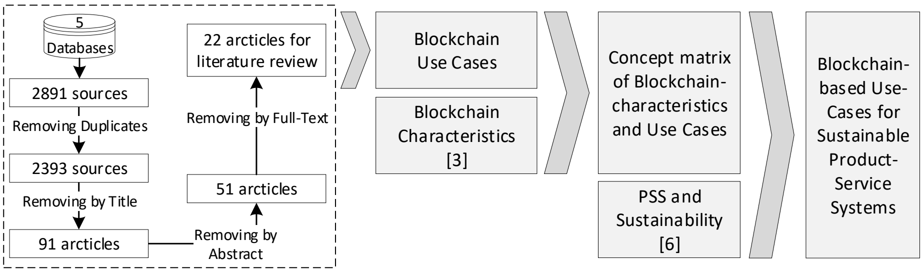

Figure 1. Literature Research Process and derived Research Outcome

The identified blockchain use cases were then combined with the blockchain characteristics examined in a literature review by Seebacher and Schüritz [3], in order to classify which blockchain-related characteristics realize the identified use cases. In a next step, the combined matrix is compared to factors of sustainability of PSS, which were analyzed by Hüer et al. [6], who also performed a literature review. The combination enables us to link all three literature reviews in an intertwined matrix (cf. figure 3) to answer what kind of blockchain-based use cases are realized by which blockchain characteristics and how they influence sustainable PSS characteristics. The related impacts on a circular economy are examined with a product-life cycle model for blockchain-based PSS (cf. figure 4) in accordance to Blinn et al. [9].

3 Fundamentals

3.1 Blockchain

We follow the Blockchain definition by Seebacher and Schürlitz for this paper [3]: "A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity." Thereby blockchain fundamentals are based on the whitepaper by Nakamoto [13] in 2008. In the last decade, different application areas evolved as postulated by Nofer et al. [14]. Li et al. [15] also investigate current blockchain applications within the business context with a literature review. They discovered that most blockchain-based articles focus on how the blockchain technology works and neglect to answer on what and why in terms of potential use cases and motivation factors that make blockchain favorable. Further related work that identified business application areas were contributed by Konstantinidis et al. [16] and by Witt and Richter [17] showing a high interest in practice and academic. Finally, Risius and Spohrer [18] developed a research framework for blockchain systems to guide researches and practitioners.

3.2 Product-Service Systems

PSS follow the idea of combining physical products and intangible services into one marketable bundle, which in combination serves the demand of the user [19, 20] and have a holistic view on the life-cycle of an offering, realized in an "extended value creation network" [21]. This is to be achieved by providing the right amount of product and service share (cf. figure 2) and therefore generating value for the customer, not by onetime selling a product or service solely. An example how this can be achieved is by providing the "solution" for a certain period, which leads to constant revenue for the offering company and calculable value and costs for the customer [22], e.g. by leasing a machine. Morelli [23] defines a PSS from three perspectives: First, from a traditional marketing point of view, where an entity can be reduced to its material components, to "an entity whose material component is inseparable from an immaterial one". Second, from a marketing service perspective, which shifts from "standardized services towards personalized ones". Lastly, from a product management perspective, the substitution of (physical) product shares by services and vice versa.

According to this, the "bundle" is not required to have a certain product or service share [24] and can be offered by a single company or a company-network [25]. The different shares of the components within a PSS are shown in figure 2. As one can see, the transition is fluent and Tukker [26] groups the different partitions into three core types, namely product, use, and result-oriented PSS.

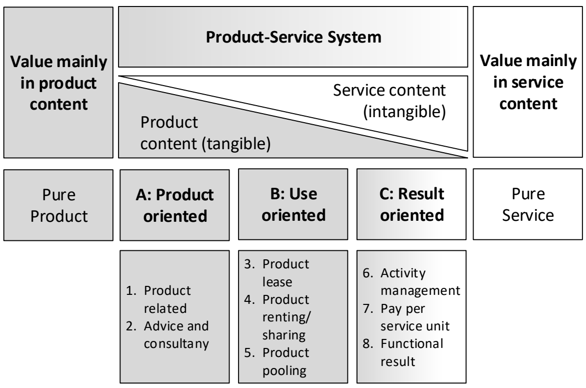

Figure 2. Product-Service System Classification according to Tukker [26]

Since PSS have a holistic view of the product itself and its life-cycle, many scientific publications examine the potentials of PSS regarding sustainability, e.g. by Tukker [26]. However, even though different PSS enabled business models, like renting or leasing, seem to have a positive influence on sustainability in the first instance, PSS are not a “sustainability panacea” [27]. Hüer et al. [6] performed a literature review on how PSS influence the sustainability and found six distinct characteristics: Substitution, Ownership, Product-Life, Cooperation, Sharing, Consumption. Though, the characteristics identified have both positive and negative influences on sustainability. Also, only a few practical methods on how to develop or use PSS in a sustainable way were proposed [6]. This circumstance is, amongst others, due to a perceived reduced user experience of PSS compared to “regular” products and the very different skills required to implement PSS. Thus, they have the potential to enable resource efficiency and ecologic sustainability, but key drivers, e.g. technologies or user experience, are missing for wide implementation.

4 Literature Review on Blockchain-based Use Cases

4.1 Classification of Blockchain-based Use Cases

We identified 22 relevant papers in our literature study, which revealed four closely related categories during their analysis. The first category contains literature that addresses the aforementioned research domain directly, referring to blockchain-based applications in the circular economy and sustainability domain. The second category consists of blockchain-based literature that focuses mainly on products while the third category relates to service and sharing economy aspects. The fourth category includes blockchain-based applications that support a tamper-proof track and traceability of supply chains to collect additional information that can lead to new services. An overview of the identified use cases, how they are realized and what kind of influence they have on PSS is shown in figure 3 and addresses the first research question.

In total 14 blockchain-based use cases are identified in the literature review which are explained in more detail in the following sections (4.2 – 4.5). Four blockchain characteristics mainly implement the identified use cases: Trust, shared and public, immutability, and decentralization. According to Seebacher and Schürlitz [3] trust is achieved amongst other blockchain characteristics principal through the tamper-proof data recording and the shared and public data transmission in a network. Decentralization is supported by the characteristics stated above and allow the creation of a network. Furthermore, decentralization enables trust with the consensus mechanism that removes the need for a trusted third-party [3].

The identified blockchain use cases have an impact on existing PSS characteristics. The concept of *substitution*, i.e. replacing products with customer-oriented services [6], is affected by new blockchain-based concepts for a sharing economy [28], [29] that allow a higher customer acceptance. Furthermore, blockchain influences the *ownership* concept. The PSS characteristic assumes that a product is designed more sustainable if the ownership belongs to the producers since they have direct incentives to create a robust product, perform maintenances and to design more recyclable products [6]. We expect a decreased influence of ownership in a sustainable PSS concept. This is justified with blockchain use cases such as product stewardship [7], [30], [31], [32], product history [30], [31], [33–36] and track and tracing systems [31], [34], [37–40] that allow a constant product traceability and a shared disclosure of product quality ensuring a permanent incentive to generate sustainable PSS without the importance of ownership. *Sharing* activities can enhance the utilization of products [6] due to simplified reselling [30], [32], [35], [41], [42] and sharing of goods [28], [29] with blockchain based on continuous tracking of the product's life and value that increases sharing activities. The *product life* is influenced by collaboration [6] and has a close relationship with the *ownership* concept. For instance, blockchain can influence collaboration with increased efficiency in the overhaul process of products with a more effortlessly access to maintenance-related data [31] or reduces adverse selection [42] and facilitate collaboration regarding the sales process. Moreover, blockchain has an impact on *consumption* by changing the customer's awareness for product quality and sustainability. Through a transparent supply chain e.g. corporate social responsibility activities can be tracked and communicated more reliably [33], [41]. Additionally, new services that are linked with the product using new information exchange and coordination mechanisms can be created [3], [43]. Overall the explicit information about the product's origin and quality lead to a higher willingness-to-pay for excellent quality products [36]. Blockchain-based supply chain management [7], [31], [40], [44–46] leads to a transparent tamper-proof product history. This can result in increased *cooperation* activities because of higher trust and shared information without the need of a third-party. In terms of PSS – cooperation has an overall positive effect on sustainability [6].

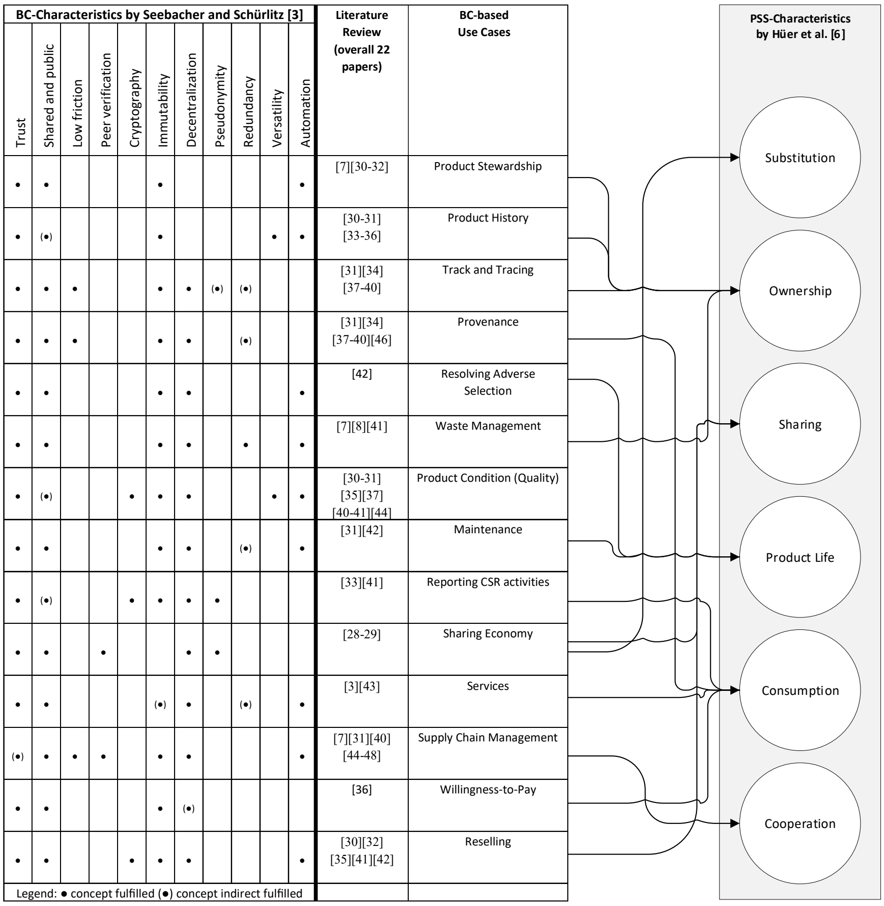

Figure 3. BC-based Use Cases realized by BC-Characteristics influencing PSS-Characteristics

4.2 Sustainability-related Blockchain-based Use Cases

Saberi et al. [7] propose a sustainable supply chain management concept that applies to electronic components which have to accomplish the Waste Electrical and Electronic Equipment Directive (WEEE Directive). They suggest blockchain as a feasible technology to effect higher product stewardship that positively affects the circular economy. In their point of view, the main benefits of blockchain are an easily accessible product history for every stakeholder in the supply chain, the tamper-proof storing of information and the resulting trust, smart contracts that enable to trace products and Internet of Things (IoT) devices that deliver reliable information gathered from the product or during processes. Ongena et al. [8] have a similar approach by working on waste management in general. They implemented a blockchain-based prototype and investigated if blockchain is a suitable technology to solve current issues in waste management. They discovered that a blockchain-based system for waste management addresses the deficits of information losses with the help of digitalization. However, they also found that blockchain-based systems solely cannot solve fraud and manipulations in waste management, due to the lack of control over the correctness of source data from other actors in the supply chain.

This shortcoming is tackled by Askoxylakis et al. [30] by using IoT devices to collect the "location, condition and availability" of assets to realize a blockchain-based system to exchange and collect the condition of assets. They propose to use these three properties to gather the value of specific assets. In addition, they suggest saving additional information that are relevant for customers into the blockchain, such as defects, maintenances or changes. In their opinion blockchain and IoT are the key drivers to enhance the circular economy with the gained data. Düring and Fishbeck [41] propose to use the blockchain and IoT components to create transparency in supply chains. Thereby, they especially mention the processes after a product is sold such as usage, reselling and recycling. Manufacturers could gain highly useful information to enhance their products with this kind of approach.

Due to e.g. the European Directive 2014/95/EU large enterprises are obligated to track their sustainability activities, also known as corporate social responsibilities (CSR), and publish an annual report [47]. Given that smaller companies are the contractor of obligated firms and perform services within the supply chain, they are indirectly concerned as well and have to provide information about their activities, too. Thereby, the challenge arises that firms often can only control and gain information from their direct corporate partners, which prevents a completely transparent supply chain. Schwarzkopf et al. [33] recommend using blockchain technology to comply with the legislative requirements to create a transparent supply chain that delivers extended information from all companies affected in the supply chain that exceed information from direct suppliers.

4.3 Product-related Blockchain-based Use Cases

One widespread proposed application area for blockchain-based systems is to track and trace food and deliver provenance data for customers such as in [34], [37–40]. For instance, in a study by IBM [34], two blockchain-based food traceability systems for pork and mangos were developed. Such systems should hinder food scandals and create trust in food products. Further, a retailer, in this case Walmart, can deliver additional services to their customers that create a competitive advantage.

Tian [37] conceptualizes a blockchain-based framework for an agri-food supply chain traceability system where Radio Frequency Identification (RFID) realizes the track and traceability system. This blockchain approach has several advantages compared to a centralized system combined with RFID. Firstly, due to the blockchain's decentralization every authorized actor in the supply chain can read and save data which creates higher flexibility to include new actors. Secondly, the decentralization of the blockchain leads technically to a non-existence of institutions, e.g. government departments or companies, and as a result no frauds or corruptions can happen. Thirdly, tracked and traced foods that have a unique ID in the RFID system can be used to protect against imitations. A similar approach like in [37] suggests Biswas et al. [39]

for a wine supply chain traceability system. Mentionable is that they identified mostly the same reasons for the implementation of a blockchain-based system to prevent imitations, food chemicals and in general bad handling of the products.

Besides food, the automotive industry is another suitable application area for blockchain-based systems. Notheisen et al. [42] developed a system to trade cars on the blockchain, more precisely they choose the domain of the Danish Motor Register. The solution tries to stop the adverse selection effect for used cars by recording the history of the vehicles. Moreover, it aims to replace today's institutional centralized registers with a decentralized autonomous system. A slightly different use case present Hua et al. [35], who implemented a blockchain-based system to track the status of batteries in electric vehicles to enable a battery swapping mode that allows a fast battery "refueling". In this concept trust regarding the battery's status and history is essential. According to Hua et al. [35] blockchain is appropriate to create the necessary trust between the electronic vehicle driver and the battery swapping provider. In addition, it allows correct billing due to the record of both batteries.

Another field of application, which has an interest in blockchain technology is the aviation industry. The supply chain in this industry is complex due to globally widespread assembly hubs. Further, systematic capturing of the condition and lifetime expectations from the observed parts is beneficial when scheduling airplane maintenance or overhaul. Besides a transparent supply chain, blockchain leads to a proper monitoring and prevents black market [31]. Also, Toyoda et al. [32] encountered imitations with their conceptualized and implemented "Product Ownership Management System (POMS)" that is based on blockchain and specially designed for processes after the first sale e.g. reselling. Marfia and Esposti [36] suggest using blockchain technology and sensors to elicit the quality of products for customers. The system should replace vulnerable certification systems and increase or stabilize the customer's willingness-to-pay. As a result, reshoring activities of businesses should grow because the customer can gain transparency and evidence regarding excellent quality.

4.4 Service and Sharing Economy-related Blockchain-based Use Cases

Although the aforementioned blockchain applications have a product-centric focus, they allow offering special services that are related to the product. Seebacher and Schürtz [3] carried out a systematic literature review to investigate the applicability of blockchain for service systems and found a high impact of blockchain to service systems. In their point of view, the blockchain characteristics such as trusted environment and decentralization are especially suitable to improve service systems. Hans et al. [43] focus in their study on insurances: One application area is to enhance the contract management for catastrophe swaps (CAT swaps) in the domain of natural catastrophe insurances. Smart contracts and the underlying blockchain technology can represent CAT swaps and trigger specific processes if the negotiated conditions are fulfilled. The second use case is within day-based insurances that can be requested for special circumstances e.g. time-based flight insurance against delayed or canceled flights. A sharing economy relies on information exchanges, Pazaitis et al. [28]

developed the framework named Backfeed that uses blockchain to realize decentralized cooperation. Thereby the framework addresses a more efficient approach for value exchanges in the sharing economy. Hawlitschek et al. [29] explore the effects of blockchain in the sharing economy, too. They discovered the challenges that arise with their implementation. Despite blockchain technology should deliver trust-free systems – the concept is not fully applicable within the sharing economy. A shift from trust in institutions into trust in algorithms was observed. Additionally, in their point of view trust build upon technology is not sufficient and therefore propose a supplementary feedback system.

4.5 Supply Chain-related Blockchain-based Use Cases

In a Delphi study, White [44] figured out that supply chain management systems and independent certification of product quality are possible blockchain-based applications in the future. Overall, the use case of supply chain management systems based on blockchain is evaluated with four of the most probable application scenarios with the highest impact in their Delphi study. Korpela et al. [45] investigate the application of blockchain into supply chains. In focus groups with business experts they elicit requirements and evaluate the applicability of blockchain within digital supply chains. They discovered that several of today's unsolved business requirements e.g. to accelerate digital supply chains could be met by blockchain technology. In a consortium research project, Sternberg and Baruffaldi [46] conceptualized and developed the ReLog concept that saves supply chain information into the Blockchain and thereby collects data along the value chain. Kim and Laskowski [38] try to enhance the specification of blockchain-based applications with ontologies. A formal ontology is used for the design of the blockchain and smart contracts. They developed a proof-of-concept in the domain of supply chains to realize traceability for products.

5 Blockchain-based Use Cases for Sustainable Product-Service Systems

We address the second research question with a product-life cycle model in accordance to Blinn et al. [9] to illustrate the impact of the blockchain technology. The presented blockchain-based product-life cycle model (cf. figure 4) is based on the identified blockchain-based use cases (cf. section 4) and explains the influence of blockchain on product consumption and recycling activities. Hence the model explains what kind of blockchain use cases cause sustainable effects on PSS. The product-life cycle is divided on the horizontal axis into RFID/IoT supply chain and post supply chain according to Toyoda et al. [32]. Thus the switch occurs when the product is first sold. On the vertical axis, the lower quadrants illustrate efforts to implement blockchain with track and tracing systems, e.g. RFID or IoT and to realize PSS. The upper quadrants constitute the perceived value of the entire solution, i.e. the blockchain system in combination with PSS. Due to the application of blockchain, inherent effects will be achieved that have an impact on PSS usage. In the process, the perceived PSS value will be stretched and increased by the application of blockchain, which results in an improved resource efficiency that supports the circular economy. The following concepts influence the graph of the perceived value:

A) *Provenance and Product History:* The perceived value of products and services will be increased because the customer's retrieve transparent information about the product assuming that the declared product quality will be reflected in the data. The provision of information reduces information asymmetry and returns trust in products that got lost in the past e.g. in the food industry [34], [39]. Furthermore, it prevents black market [31] and thereby reduces potential customer's distrust again. Overall to provide information about the origin of the product results in a higher willingness-to-pay for high-quality products [36].

B) *Life Time Expiration:* The lifetime of PSS will be stretched. Within reselling or sharing activities, we assume that no decrease of the perceived PSS value will take place. This can be explained by transparency and information exchange that reduces adverse selection [42] when products are resold or to track the estimated consumption when products are shared [35]. Further, the provision of information for maintenance [31] which is also imaginable for self-service and smart contracts that extends guarantees [43] can stretch the product lifetime.

C) *Waste Management:* The recycling phase occurred as a result of decreased perceived value during the lifetime due to consumption, aging or abrasion and the perceived PSS value is almost equal to the material value. Especially for complex PSS blockchain can support the waste management process [8] and ensure a higher probability to reuse product components [7]. Furthermore, product stewardship will increase because of information transparency, i.e. collecting historical data, that results in the design of more recyclable products.

D) *Track and Tracing Supply Chain:* The overall track and tracing of products in the supply chain will decrease frauds [31] and bad behavior [39] in PSS. In contrast, we expect a higher probability of good behavior and extra efforts to ensure high-quality outcomes.

E) *Data Analysis for Product Design:* The collected product-life cycle data can be used during the product design phase to receive new insights and to create more durable and sustainable PSS [31], [41].

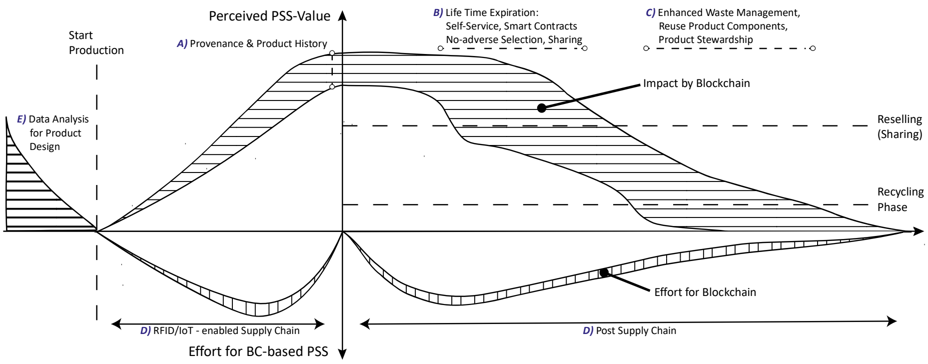

Figure 4. Blockchain-based Product-Life Cycle Model in consideration of Perceived Value

6 Limitations, Further Research, and Conclusion

6.1 Limitations and Further Research

We are aware of the limitations in our research. Therefore, we mention further research topics to overcome the existing limitations. The paper contributes an initial step and combines the three subjects blockchain, PSS and circular economy. Thereby, one limitation is that the findings are mainly based on academic contributions and theoretical assumptions. These expectations have to be validated with further research that is focusing on practical evidence and implementation. Further, the identified blockchain use cases resulting from different domains. Therefore, it is questionable if all use cases can affect each PSS in the same way, i.e. the limitation is an abstract perspective. Furthermore, the developed blockchain-based product-life cycle model is based on scientific literature but was conceptualized in a subjective view by the authors. However, the model serves to understand the different impacts of blockchain on the product-life cycle and how technology enhances resource utilization related to the circular economy. Future long-term studies (5 – 10 years) have to investigate each mentioned impact with practical blockchain implementations. During the studies, additional requirements from practitioners ought to be included and the existing list of blockchain-based use cases should be extended and prioritized. Additionally, investigations have to be made regarding the feasibility – not every product category is suitable to record the product-life cycle and estimated costs have to be relatively low. For instance, Toyoda et al. [32] assumes 1$ for six transfer actions with their blockchain solution and suggest to apply products above 100$. Finally, deeper research how blockchain, IoT, PSS, and circular economy relate together should be conducted.

6.2 Conclusion

The circular economy faces different implementation barriers [2]. We address these obstacles with the combination of blockchain and PSS. Thereby blockchain-based advances such as trust, information exchange, and immutability enable new potentials to solve current issues in the circular economy domain. PSS serves as the application area due to already proven positive effects on sustainability [6]. Based on a conducted literature review we identified 14 unique blockchain-based use cases that have a sustainable effect on PSS that are related to the circular economy. Hence, the paper presents for the first time to the best of our knowledge a holistic view on blockchain, PSS and circular economy.

The evolved blockchain-based product-life cycle model in consideration of perceived value illustrates the positive impact of blockchain on resource utilization. In addition, the model explains how a more effective information provision by blockchain cause a higher perceived value of products and services during the whole product life for society, which results in improved resource utilization and a realization of the circular economy. Thus, the paper contributes new insights how blockchain can be used to gain ecological and economic benefits through a new digital technology.

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