At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion

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Abstract: The circular economy (CE) is an emergent concept to rethink and redesign how our economy works. The concept recognizes effective and efficient economic functioning at multiple scales—governments and individuals, globally and locally; for businesses, large and small. CE represents a systemic shift that builds long-term resilience at multiple levels (macro, meso and micro); generating new business and economic opportunities while providing environmental and societal benefits. Blockchain, an emergent and critical technology, is introduced to the circular economy environment as a potential enabler for many circular economic principles. Blockchain technology supported information systems can improve circular economy performance at multiple levels. Product deletion, a neglected but critical effort in product management and product portfolio management, is utilized as an illustrative business scenario as to blockchain's application in a circular economy research context. Product deletion, unlike product proliferation, has received minimal attention from both academics and practitioners. Product deletion decisions need to be evaluated and analyzed in the circular economy context. CE helps address risk aversion issues in product deletions such as inventory, waste and information management. This paper is the first to conceptualize the relationships amongst blockchain technology, product deletion and the circular economy. Many nuances of relationships are introduced in this study. Future evaluation and critical reflections are also presented with a need for a rigorous and robust research agenda to evaluate the multiple and complex relationships and interplay amongst technology, policy, commerce and the natural environment.

Keywords: blockchain technology; circular economy; product deletion; sustainability; supply chain

1. Introduction

Imagine a world without waste [1]. That is the imagery presented by circular economy (CE) proponents. To make this vision a reality, social, technological, and commercial cooperation, at the very least, is needed. It is from this three-dimensional perspective, with support from other perspectives, that we introduce our thoughts and concerns.

The circular economy has taken on especial recent importance as a social innovation that helps to address economic, environmental and sometimes social concerns. The advent of new technologies and digitization has also taken on greater importance as a more interconnected world emerges. Blockchain is one such technological innovation. It has received increasing attention in both research and practice.

Blockchains are emerging in a traditional economic situation where marketing and consumption of products and services are still the engines of economies. We consider one aspect of products and commercial decisions as an illustrative business scenario—what happens when there is a decision to stop offering a given product by an organization; when a product is deleted?

This business problem of product deletion in an emergent technological environment has not been studied. The circular economy, where important but limited elements exist globally, causes an additional and important nuance. For the circular economy to function there is a dependence on product material from a product's end-of-life. There also needs to be a significant availability of these products for the economy of scale maturation.

Companies make decisions to stop manufacturing products for a variety of reasons. Whether they are automobiles such as the Chevy Volt, or a laundry detergent that has environmentally damaging chemicals in it. What happens to the potential circularity of these goods in a situation where the circular economy is gaining steam?

Can blockchain technology play a role in monitoring the circularity of potentially deleted products, supporting decisions on which products to delete, and managing the deletion and tracing of materials through the circular economy? These are some of the basic questions we seek to investigate and critique in this paper.

There will be practical and research issues related to evaluating the nexus of these three topics—product deletion, blockchains and the circular economy. Each of these concerns is necessary for advancement in multiple directions, but especially implicating the effectiveness and efficiency within a circular economic environment.

2. Background

Initially, we provide an overview of each topic separately. Some of the latest literature and thought in each of these subjects is presented to set the foundation of discussing and critiquing their nexus. Various use cases and analyses at various levels provide insights and exemplars into the relationships in later sections. Study directions, practical and theoretical, are also integral to their advancement.

2.1. The Circular Economy

The circular economy has a variety of characterizations and definitions [2]. It begins with the idea of materials cycles including recycling, remanufacturing, refurbishment, reuse, and reclamation. The circular economy also includes management practices that help to close-the-loop such as reverse logistics and supply chain activities. Industrial waste minimization also occurs with former wastes transformed into useful, revenue generating, byproducts. The sale of byproducts to other organizations for use in production has also been termed industrial symbiosis [3].

Another important aspect of the circular economy, at a minimum, is the involvement of consumers in a sharing or servicizing economy [4]. For example, in a service economy, products are not bought, but are leased as services; such as the leasing of document copiers instead of purchasing them outright. Where, after a time period, these leased products are brought back for refurbishing or recycling. A consumer, in this situation, is buying the service of making copies. The sharing portion comes in with a product that is only leased for a short time and it is shared with other consumers. The product used in the service at the end-of-life will have its materials reused, reclaimed, refurbished, or one of the other "Re's". This idea can be extended to almost any product that is currently purchased, where the leasing model has a retailer or manufacturer as the product steward.

Circular economy practices can reduce costs and create new revenue sources for companies by reusing materials and minimizing wastes. However, in most cases, the technology that is needed for a circular economy is costly and lack of financial resources impede the successful implementation of CE [5,6]. The challenges facing the circular economy are manifold. A few of these, which are core concerns in this paper, have been delineated in the literature; relating to governance, economic, and organizational theory [7,8].

The circular economy involves some form of transaction and exchange. For an effective circular economy, data and knowledge of sources and markets are needed. Many times, the suppliers and users of various products that flow within circular economy supply chains may originate from very different industries and regions.

In some of the more popular industrial symbiosis relationships, companies from very different industries would work together [9]. An example is a gel manufacturer that uses styrene to clean out its equipment. The manufacturer could use the styrene waste from this cleaning process for energy; or sell the waste on a materials exchange market [10]. However, information exchange across industries—such as with blockchain technology—especially with respect to wastes and byproducts can be difficult. Companies will typically focus on traditional customers and their own industries. Additionally, if a company stops making a product due to some sustainability or environmental concern—a product deletion decision—having this information becomes critical for a circular economy and byproduct management planning. The information symmetry and information search may be significant and expensive to address.

Other major concerns are uncertainties and lack of scale [11]. The scale for waste may be large overall, but the dispersion of waste streams can make it difficult to locate and acquire circular economy materials. Small, distributed and informal waste and material flows are difficult and expensive to manage [12]. Achieving sufficient economies of scale for circular economy materials will require systems to capture materials into useful quantities. Knowing the flows—through blockchain technology—and making sure that streams exist and remain—product deletion decisions—are concerns related to supply uncertainties and risks.

A circular economy requires broader and more inclusive supply chains, not only amongst industry, but communities, and individuals and their households. This dispersion and variety of actors cause difficulties in identifying, developing, and maintaining reliable circular economy sourcing. Various stakeholders such as industrial partners can provide material and component information, and thus communities and municipalities can organize regional circular economy efforts and eco-industrial parks [13]; and non-governmental organizations (NGOs) can offer expertise and information and lead consortia such as Nextwave for ocean plastics and upcycling (https://www.nextwaveplastics.org/).

Overall, as we have seen, CE practices, principles, and characterizations appear at multiple levels of analysis. There are macro, meso, and micro levels of analysis [14]. Although there are some disagreements and concerns on the definitions of these levels, we essentially present them as relative concerns from the broadest to more specific focused areas. We now provide some examples, some of which will guide our framework for the evaluation of blockchain, circular economy, and product deletion relationships.

Macro levels of analysis will include institutional issues that are typically global or broadly geographic and multi-governmental regions. It may include broader concepts such as full economies and principles. We will also be considering looking at major resources and markets, such as energy, that focus as very broad concerns and issues.

At the meso level, we essentially identify an environment that considers multiple organizations and their networks. These can include supply chains and their flows or elements of the closed-loop supply chain—such as supply chain monitoring or reverse logistics operations. Industrial symbiosis and eco-industrial parks are additional examples of this level of analysis.

At the micro level, we will be focusing primarily on issues facing specific organizational, intra-organizational, and individual consumer level issues. That is what type of value, knowledge and behavior, can be managed at these levels. There are many other ways to consider these issues, and the examples we provide is an initial categorization that fits well with relationships and influences of blockchain and product deletion.

2.2. Blockchain Technology

A potential breakthrough for future supply chains can be adopting technological disruptive innovations such as blockchain technology. Information sharing is an urgent requirement in supply chains; especially with greater interest of digitization and Industry 4.0 developments [15,16]. Information can connect dispersed entities, facilitate better relationships in supply chains, prevent fraud and falsification, and reduce risks. However, tracing information through a complex supply

chain network is a challenge. Blockchains can support information sharing in supply chains, link stand-alone systems, and provide real-time data to all stakeholders.

Blockchain technology records information through decentralized ledgers [17,18]. Ledgers are visible to all actors involved in transactions including supply chain partners [19]. Ledger transactions have cryptographic time stamping that elevates the security of information [20]. In this way, the blockchain allows customers to inspect the uninterrupted chain of custody and transactions from the raw materials to the end sale. This information is recorded in ledgers as transactions occur on these multiple blockchain information dimensions; with verifiable updates. For example, end customers can rely on the authenticity of valuable goods by tracing them to their origin [21].

Blockchain technology can benefit supply chain provenance and sustainability. A blockchain application that is connected with radio frequency identification (RFID) [22], Internet of Things (IoT) [23,24], and global position sensors (GPS) [25] can collect accurate data and address traceability issues in supply chains. High levels of transparency, verifiability, immutability, and reliability of data provided by blockchain can facilitate information flow among complex supply chain networks and stakeholders [26]. The immutability feature arises from the append-only concept of blockchain ledgers where a recorded transaction cannot be changed or altered without blockchain network consensus. This characteristic strengthens the reliability of blockchain information. Decentralized ledgers reduce the need for trust based on third-party transaction verification; shedding intermediaries from transactions [27].

Blockchain technology effectively supports updated tracking in the supply chain. Information related to the sources of materials, product supply chain journey, and participating actors in purchasing, producing and distributing products can each be presented on a blockchain platform; while maintaining visibility to supply chain network participants. Supply chain members may verify transactions and vote to maintain some trustworthiness in records.

A key element of blockchain technology is a smart contract, sometimes reflecting real-world contracts in a digital way. Smart contracts contain codes of agreements between parties, monitor conditions, and execute the embedded functions [28]. Smart contracts shift the need for traditional legal third parties to network consensus. Automatic execution of trigger points and digital records of regulations and business logic can increase efficiency and reduce transaction costs [29]. Smart contracts can also be utilized for supply chain process management and even process reengineering.

Permissionless (public) and permissioned (private) are two types of blockchain that deal with the openness of the platform. A permissionless blockchain allows anonymous users to interact with the system. Bitcoin and cryptocurrencies are examples of permissionless blockchains. Alternatively, permissioned blockchains limit information access to recognized users [30]. For example, IBM and Maersk have developed a permissioned blockchain that included a defined group of participants to trace information in the supply chain. Although the permissioned blockchain allows companies to control who can access critical information, the appropriate level of openness and information sharing is still debatable. For example, tracing individual items in a CE setting may mean the invasion of private information, raising ethical concerns.

A combination of permissionless and permissioned blockchain can enable supply chains to achieve a variety of purposes. For example, authentication certificates can be linked to a public blockchain for marketing purposes to assure customers about the provenance of products [31]. This addresses the other dimension of trust of source, which in itself addresses some ethical concerns on the veracity of statements made about products.

There are some concerns in the field related to whether permissioned blockchains are truly blockchains. It is an example of an essentially contested characteristic for blockchains [32]. We will not enter this debate in this article; we bring it to the general attention of the readership and it requires significant critical reflection for both researchers and practitioners.

Information technology has been linked to CE given the critical nature of data and information for its broad management (e.g., [33]). Blockchain technology can benefit circular economy activities

through information management. Accurate information related to recycling programs, reusability of materials, green packaging, energy consumption, and carbon emissions can be made available on a blockchain [34]. Companies can use this information to evaluate the circularity performance of their supply chain versus their competitors, recognize their strengths and weaknesses, and use benchmarking data to improve their circular economy practices.

Although significant possibilities exist, blockchain implementation may face challenges and require preparation. Scalability is a critical barrier that stems from the immaturity of blockchain technology [35]. Another challenge is that blockchain-enabled software requires novel and specialized software development tools and techniques, many of which still require development [36]. In addition, there is significant confusion concerning blockchain applications and adaptability in the supply chain context.

2.3. Product Deletion

Companies invest vast monetary and time resources launching new products, leveraging product portfolios, and acquiring rivals all seeking a competitive advantage. Managers are engrossed with product line extensions and proliferation, channel extensions, and supplier development while seeking to cater to their customer segments [37].

Complex and broad product portfolio strategies attract customers but do not necessarily sustain profitability [38]. Surprisingly, rarely do companies examine their product portfolio and doubt if they might be housing too many products. Product deletion, or killing, is perceived as a less appealing management activity when it comes to product portfolio management [39].

The inescapable fact is, for most companies, some products are not making a profit and drain valuable resources [40]. Managing them is sometimes more challenging than developing them; and keeping them requires more effort than killing them [41]. However, discontinuing or withdrawing these lagging products from the product portfolio is not necessarily a trivial decision. For example, deleting a specific product may negatively influence the market for the associated maintenance services that may have created financial value for the company. The product deletion decision can affect strategic and operational concerns including customer satisfaction, profit margin, market building, and supply chain relationships management [41,42].

Material, information and capital involved in products are important flows within supply chains [43]. Companies are interlocked in these chains to serve a market; these chains involve suppliers, channel partners, the government, employees and consumers. Products, components, and materials with their associated transactions flow through raw material sourcing, internal manufacturing, storage, transportation delivery, and end-user consumption in the forward chain. There also may be reverse logistics activities such as reusing, recycling, reclaiming and remanufacturing [42]. Close-looped product activities are necessary for a circular economy.

Product deletion can be defined as discontinuing a product from a product portfolio; deletion can occur at the product level (complete deletion) or product variate level (partial deletion) [41]. In this paper, product deletion mainly focuses on complete deletion—kill a product and most of its key components. This paper is one of the few papers that relates product deletion to supply chains in a CE environment, taking the perspective of original equipment manufacturers (OEM). Given this supply chain environment, product deletions have implications on circular economy operations; in turn, circular economy activities and actions can influence product deletion decisions.

The traditional linear economy presents a "make and dispose" model of product production. Within this model, when a product is deleted, its inventory will immediately become obsolete and transform into waste. It may be disposed, sometimes to third parties for resale purposes; or disposed of in a traditional fashion into landfills.

In a circular economic system, deleted product inventory and their finished components may be reclaimed as input in resource, energy and material loops through remanufacturing, refurbishing, reusing and recycling [44]. Product deletion may become, in the short-term, profitable not only from

more rationalized product portfolio management, but also from the utilization of freed up resources and materials as closed-loop inputs [45].

The circular economy's focuses on design thinking, systems thinking, and product life extension influence the product deletion decision. Product deletion occurs for many reasons, including customer complaints on performance issues, product defects and quality concerns. Long-lasting designs help to decrease the likelihood of occurrence of such issues, hence, also decreasing the likelihood of product deletion [41,46].

Another major trigger for product deletion lies in resource concerns including capacity and efficiency aspects; especially those that closely relate to operational performance [41].

Circular economy practices help to minimize resource inputs into and the waste and emission leakage out the supply chain and production system. Resources in a CE environment may arise from recycling approaches, efficiency improvements, and product use extensions.

Product deletion decisions can be affected by CE practices. Product life extension in a CE alters the product deletion decision. Traditional product deletion typically occurs in the decline stage of a product lifecycle. The phases of product lifecycles are likely to be extended in a circular economy context, potentially delaying many such decisions. A product's decline in a CE environment may result in a decision other than deletion. Specifically, the organizational focus will be on rebooting a new life cycle for products rather than closing the current life cycle through deletion.

Having credible, transparent, traceable, and secure information and exchange systems can greatly benefit the CE and product deletion management situation. Blockchain technology can enable some of these capabilities at multiple CE levels. As an initial caveat, similar to CE, blockchain is still an 'essentially contested concept' [2].

3. Framework and Propositions

The product deletion, circular economy and blockchain technology nexus conceptualization is presented in Figure 1. We offer two general propositions from the previous background discussion in Section 2. Additionally, they set the stage for more a detailed analysis and evaluation in Section 4. These propositions are generic and serve the secondary function as research questions.
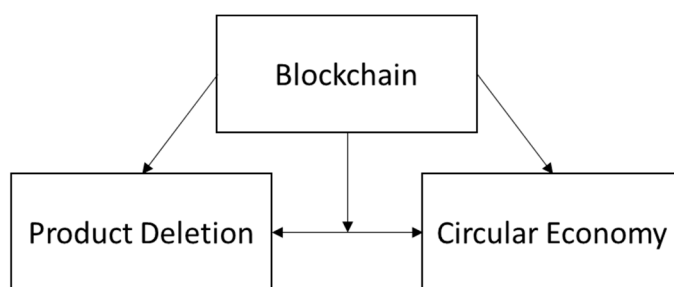

Figure 1. A Conceptual Framework of Product deletion, Circular Economy and Blockchain Relationships.

Figure 1 shows the interrelationships between blockchain as both a direct and indirect influencer with both product deletion and the circular economy. We have shown and made this argument in a number of examples. The primary arguments made thus far have shown a number of dyadic relationships between the three subjects. The complexities involve multiple relationships, including two-way interactions and moderating relationships. Thus, we initially posit three general propositions.

Proposition 1. *Product deletion is interrelated with circular economy practices. Product deletion impacts circular economy practices and circular economy practices support product deletion management concerns; the relationships aid improved product deletion decision making processes and reduces product deletion risks.*

Proposition 2. *Blockchain technology is an enabler that can moderate the interrelationships between product deletion and circular economy. Blockchain technology activates and upgrades the inter- and intra-organizational*

information management systems that facilitate product deletion decision making and advances circular economy development and operations.

Proposition 3. *Although not explicitly shown in Figure 1, we posit that these relationships can occur at multiple circular economy levels. Micro, Meso, and Macro level influences and relationships exist amongst the three subject areas.*

Some of the practical and theoretical foundations of this framework and discussions are further elicited in Section 4.

4. Blockchain Enabled Product Deletion Decision Making in a Circular Economy

This section introduces how blockchain-based information management enables and facilitates the product deletion relationships within a circular economy (Table 1). The analyses are conducted at three levels, the macro (institutional) level, the meso (networks and supply chains) level and the micro (organizational and consumer) level. At each level, the discussions are organized by circular economy initiatives, followed by a short discussion on how blockchain technology can contribute to the circular economy initiative and additional short discussion concerning blockchain, product deletion and circular economy synergies.

Table 1. At the nexus of blockchain technology, the circular economy, and product deletion.

Circular Economy	Product Deletion Analysis, Evaluation and Decision Making
Macro (Institutional)	
Sharing or servicizing economy	○ Products designed for CE ○ Increase the scale of product portfolio for CE purpose ○ Focus on Product durability—delete short-term components ○ Complete deletion on unendurable products; ○ Partial delete products with less sharing value
Energy	○ Delete the utilization of non-green energy ○ Focus on energy usage/consumption level ○ Focus on energy usage/consumption efficiency ○ Delete products with poor energy consumption efficiency ○ Utilize the free-up energy from deleted products to reverse energy cycles ○ Accurate energy consumption data ○ Energy trading ○ Energy decentralization
Market for secondary materials	○ Utilize secondary materials to new product development ○ Replace material sourcing from the primary market to the secondary market with quality and performance assurance ○ Focus on material innovations—reduce material waste ○ Create a material cycle on supply chain incorporating secondary material market and product deletion waste and inventory ○ Extend product candidates' lifecycle by reducing material cost and increasing material efficiency and durability

Table 1. *Cont.*

Circular Economy	Product Deletion Analysis, Evaluation and Decision Making
Meso (Networks and Supply Chains)	
Reverse logistics	○ Implement reverse infrastructures in product development ○ Information on quality of returned products
Industrial Symbiosis and Eco-Industrial Parks	○ Intra-organizational involvement ○ Benefits to stakeholders ○ Waste exchange and byproduct information managed and verified by block chains can influence product deletion decisions.
Supply chain monitoring	○ Increase product information and waste exchange between supply chain actors ○ Increase the involvement of supply chain actors into product deletion decision making ○ Invest in technological platforms for product development and lifecycle management monitoring
Micro (Organizational/Consumer)	
Organizational Value and Knowledge	○ Firm strategy ○ Value and culture: i.e., sustainability/CSR; openness to change; product attachment ○ Byproducts ○ Product design and differentiation ○ Operational capacity ○ Replace product components with higher end-of-life value
Consumer Knowledge and Behavior	○ Customer demand ○ Customer loyalty ○ Consumer involvement in product deletion ○ Consumer post-purchase behaviors

4.1. Macro: Circular Economy at the Institutional Level

Our categorization of circular economy initiatives at the macro level includes (1) sharing or servicizing economy; (2) general energy management and (3) secondary market management.

4.1.1. Sharing or Servicizing Economy

In CE a sharing or servicizing economy enables exchanging or leasing products and services. However, lack of information products throughout their lifecycle is a barrier of successful implementation of these and other circular economy principles [47,48]. Accurate and real-time data sharing is an urgent need for shared economy activities. Blockchain technology can provide a platform for such activities. Blockchain can support transparency to supply chain networks to trace closing-the-loop activities. Network participants can track updated transactions, understand the product status, and exchange data efficiently. Blockchain technology can facilitate sharing economy activities by reducing the need for third parties in transactions [49]. Users can exchange their services and products through a blockchain platform directly, without intermediaries, and thus save money and time. This can further leverage sharing activities.

Blockchain can contribute to product deletion management by providing accurate and reliable information related to shared products and services [50]. The ability to collect accurate updated data related to products can include the quality and circular possibility of products, their locations, and their current stage in the product life cycle. This gives companies the opportunity to trace and analyze reusability, performance, and durability of products and identify the points of failure. Those products

with poor sharing value and with durability issues, e.g., contains short-term components and circularity concerns, can be candidates for removing them from the product portfolio. Companies can further build up their circularity capacity by designing products with maximum sharing values and circularity, expanding the scale of the product portfolio for the CE purpose, and introducing new CE technology or components to products.

Records of leased products can be captured, no matter the location of these products, with performance information to determine if expectations of usage were met. Given that products in this environment are shared or leased, their attachment and care by consumers may not be as high. Thus, durability is an important performance measure for their circularity capabilities. If durability or maintenance requirements are too large, then the information may support produce deletion. Blockchains without intermediaries can also bring down sharing fees greatly, allowing some shared products and materials to be resourced for maintenance and delaying product obsolescence and deletion.

4.1.2. Energy

Energy is a key source of supply chain activities. CE proposes that the circularity of energy and materials improves sustainability values [51]. To specify, minimizing energy consumption, environmental pollution, and the usage of green energies can support circular economy purposes and sustain the environment. Converting wastes to biomass energy can further leverage the circularity of energy [15]. However, waste-to-energy is generally not considered a preferred option in the waste hierarchy model, which ranks different waste management techniques [52]. Alternatives such as recycling and remanufacturing are preferred, with reduction typically the most preferred option.

Blockchain technology can facilitate energy exchange and trading by offering new developments for decentralized energy markets. Agents and network participants can share their energy usage and surplus and trade their carbon credits through a blockchain platform. This may provide information for governments, policymakers, and communities in the broad design of these systems. Cryptocurrencies and the reliability of information supported by blockchain can further boost energy markets performance [53]. Governmental regulators and stakeholders can observe and evaluate energy markets information and monitor their compliance with environmental goals.

Accurate information that is presented on blockchain ledgers can enhance real-time monitoring and assessing the energy consumption level of materials and products. Numerous materials are extracted from rare and non-renewable resources or use non-green energy resources in their processes. Those materials and energy are not only consumed but may create wastes and damage the environment.

Product manufacturing and usage information that is continuously and accurately monitored can provide energy performance. Blockchain helps identification of energy problems by providing the traceability of materials and products back to their origin and metrics to evaluate their energy usage to ensure sound and effective product deletion decisions. Products with a high level of energy usage and poor energy efficiency can be candidates for deletion that, in turn, can enhance the circular economy. Policymakers can also tax products with poor energy performance more accurately, internalizing external energy and related emission costs.

The freed energy from deleted products can be used to source circular economy activities and reverse energy cycles. Although circular economy activities, such as refurbishing, remanufacturing, and recycling, require intensive resources and energy, the environmental damage is typically less than primary production processes. Using a blockchain-enabled system helps companies determine the materials and products that use non-renewable resources and remove them or invest in alternative green resources to benefit the circularity of energy.

However, while blockchains are maturing, vast amounts of power and energy are needed for data validation. This process is through so-called mining in cryptocurrencies and thus can have negative impacts on the environment. Growing interest in blockchain technology motivated technological advancements that shift blockchain toward green and renewable energies [54].

4.1.3. Secondary Materials Markets

Substituting primary components with materials that are acquired from secondary markets can effectively support circular economy principles. Blockchain technology can provide a distributed platform for trading secondhand materials and products. Improving information transparency and verifiability allow network participants to sell and buy their wastes and used materials and products in secondary markets. Amazon and eBay are examples of current secondary markets. The presence of real-time information regarding the veracity and status of the used materials and products can further boost circular economy efforts.

This information can also denote the feasibility of replacing materials from a primary market to a secondary market. Reducing material costs can provide financial resources for extending the product life cycle and increasing material efficiency and durability. Quality and performance of the secondary materials are traceable on a blockchain. This information can further address the potential and opportunities for developing new products that incorporate secondary materials, meet the green initiatives, and maximize circularity. Knowing this information can help delete products that do not meet the necessary circularity criteria.

Disintermediation is another advantage provided by blockchain that can cultivate secondary market activities by connecting buyers and sellers without any intermediaries and reduce the costs of transactions. Those materials or products that cannot be managed with fewer intermediaries may result in more costly and complex systems, causing the deletion of these products from further consideration.

Accurate and updated information about the secondary materials and markets can ameliorate product deletion analysis and decision making. Blockchain-based information can provide more accurate reusability and recyclability of materials and products information. Transparent market pricing and costing information on secondary materials may also provide information to determine which products are more feasible or should remain in a portfolio. Products that demonstrate poor performance in the secondary market or incorporate materials that are not replaceable by used items might be candidates for deletion. Agents and business entities can make their deletion efforts more profitable and leverage the circular economy by selling their wastes and marketing the inventory of deleted products on a blockchain platform.

4.2. Meso: Circular Economy at Networks and Supply Chain Level

Circular economy initiatives at the meso level may include systems and multi-organizational and regional practices such as (1) reverse logistics; (2) industrial symbiosis and eco-industrial parks and (3) supply chain monitoring.

4.2.1. Reverse Logistics

Environmental concerns motivate supply chain networks to incorporate reverse logistics activities and networks into their classical supply chain processes and close their supply chain loops. Reverse logistics refers to collecting and transferring products from the point of consumption (end consumers) to the origination of supply chains in order to recover value [55]. Reverse logistics may contain various "Re's" activities such as recycling, recovering, remanufacturing, and refurbishing. Products in each stage of their life cycle might be subject to return and reverse logistics. Accurate information regarding the condition of products, their location, their quality, and the undertaken processes is the core of efficient reverse logistics operations. This information is difficult to acquire through complex and multi-tier supply chain networks and after use by consumers. Blockchain can address this issue by presenting reliable information on the history of the materials and products. Every classical and reverse supply chain transaction can create a record on blockchain ledgers that are immutable and traceable. This historical information that is visible to supply chain networks can be used to help them make a sound decision about the proper reverse logistics activity that best matches the condition of products.

Blockchains can further leverage reverse logistics using smart contracts. Smart contracts can facilitate returning, reusing, and recycling activities between supply chain parties when product deletion occurs. A smart contract may reflect the agreement about the condition and quality of a product or material. When a returned product or material is identified, the smart contract can automatically generate the payment based on the defined product conditions [34]. The product condition may be evaluated and certified in the system. It can also determine the eventual plight of a product or material, e.g., reuse, recycle, or remanufacturing the product or material. For example, some companies have a take-back system that allows their customers to return products at the end of their lifecycle back to the stores and receive a discount for future purchases [52]. Using smart contracts, those customers who returned products with high recyclability potentials which can create more revenue for the company can receive more discounts and credits. This approach can further incentivize customers to return products and close the supply chain loop.

Payment can be done in terms of cryptocurrencies and thus save time, especially in international transactions. The processes would be easier for customers and thus motivate customers to return the problematic products. Customers can track return products back to the supply chains. Furthermore, traceable information regarding the reverse logistics of products can be used to evaluate the reusability of the deleted products and their associated materials. Products with minimum value creation over their entire life cycle can be deleted or replaced with products that create more value to the reverse logistics activities.

When products are deleted, the reverse logistics cycles will likely start to lose material from that product, or temporarily have additional obsolete non-saleable material. In each case, knowing the length of time a product or material is in a CE is important to be able to plan for reverse logistics returned resources. Information, long and short-term information, can provide this forecast and returned products and materials inventory. Thus, if a system is dependent on a particular material or returned product, then there might be possibilities to keep producing a product or material due to value for material supply for a reverse logistics network. For example, for remanufacturing, knowing the location and condition of a 'core' for a product is necessary and the technology to trace this material is necessary [56]. If a product is deleted, the need to capture and return cores is no longer a necessity and there might be a shift in the reverse logistics from remanufacturing to recycling.

4.2.2. Industrial Symbiosis and Eco-Industrial Parks

An eco-industrial park contains several companies that cooperate to share their resources and manage their wastes in an environmentally sound way. Waste management is an important part of a circular economy. Although based on the sustainability principles, the primary focus is on a no-waste strategy, in most cases, complete waste elimination is not possible, and thus produced wastes need to be managed effectively. Waste exchange programs are important aspects of industrial symbiosis and require collaboration among companies to address environmental issues and support the circularity of resources.

Blockchain technology can provide a platform to connect companies to exchange and trade their wastes and recreate value. Companies can interact directly to exchange their wastes without any middle-men and improve profit margins. Smart contracts can further facilitate waste exchanges by automatic execution of waste exchanges based on factors such as the condition of wastes, their volume and quality. In addition, electronic sensors and tracking devices can capture the location and value of wastes and make data available on blockchain ledgers. Traceability of wastes is critical, especially for hazardous wastes [34]. Stakeholders can use blockchain information to evaluate the efficiency of waste exchange programs.

Information regarding the waste exchange can be recorded on blockchain ledgers. Blockchain can present information about the number of waste exchanges in a network and the value and quality of exchanges. This accurate information can be used for product deletion management. Those products that generate wastes with a low likelihood of waste exchanges can be candidates for removal from

supply chains. The waste exchange information may also help supply chain participants assess how well products and materials are selling at their final stages and thus make sounder product deletion decisions. Byproduct synergies are another aspect of product management decisions. For example, if an important byproduct that is profitable is made with waste from a product targeted for deletion, the decision may be impacted the value of the by-product. Information on this by-product and other potential verified byproducts can be managed in the blockchain.

4.2.3. Supply Chain Monitoring

A circular economy contains operations that recollect the value of materials and products. Recapturing circular economy values require tracing materials and product flow in supply chains with sometimes complex and multifaceted networks of participants. Information discrepancy and asymmetry among supply chain participants can impede the identification of opportunities and potentials for enhancing sustainability efforts and a circular economy [57]. Blockchain technology provides supply chain transparency and traceability. Supply chain members from upstream to downstream can obtain accurate and updated information about the products and inventory levels.

Supply chain transactions related to the materials and product flows can be recorded on blockchain ledgers. Some transactions may be generated automatically by smart contracts or collected by automatic electronic sensors, such as RFID or Internet of Things-enabled devices [58]. Supply chain members can monitor and audit information using blockchain ledgers and adjust their inventory, optimize resource usage, and modify their processes to generate minimum wastes. Effective information sharing can proliferate collaboration among supply chain members and build strategic and operationally beneficial relationships [59]. Supply chain members can address sustainability issues by integrating the information, evaluating the efficiency of their supply chain processes, and positing solutions to optimize circularity of materials and products such as replacing some materials or investing on green technological advancements.

From a CE perspective, waste exchanges within supply chains and amongst partners may exist. Blockchains can be used to find additional supply chains from existing waste streams. If a product or material has profitable byproducts that can form new supply chains, blockchain can help identify these alternative mechanisms. Blockchain information of product history can identify past materials uses and byproducts that may be used to identify future supply chains. This type of additional and easily accessible information may delay deletion decisions. Alternatively, byproduct and waste exchange information that was found not to be valid and performing well, maybe cause to delete a material or supply chain branch.

As blockchain technology presents a platform for data sharing in supply chains, product information exchanges among supply chain actors can be captured on blockchain ledgers. Supply chain networks can monitor the lifecycle of products and evaluate the green performance of supply chain activities and products flowing through them [60]. Those materials and products that degrade the environment from their sourcing and undertaken operations and processes and create more wastes are candidates for deletion or altering by environmental-friendly products. A blockchain-enabled supply chain requires a high level of coordination among supply chain members [16]. This can increase the involvement of supply chain actors into product deletion decision making. Supply chain members can make joint decisions about removing products with poor circularity from the supply chains. The joint decisions may decrease conflicts and challenges of product deletion implementation, as supply chain members already agreed on the product deletion decision.

4.3. Micro: Circular Economy at the Organizational and Consumer Level

We have defined CE initiatives at the micro level to include (1) organizational value and knowledge, and (2) consumer knowledge and behavior. In this situation, we consider issues at the organizational and lower levels, such as households and even individuals. We try to keep the evaluation not on

specific activities or functions, although they are included somewhat, but at general characteristics such as value, knowledge, and behavior.

4.3.1. Organizational Value and Knowledge

Companies can build competitive advantages through developing their organizational resources and following a path of capabilities development [61]. Firms can improve their market power by sustaining the environment by reusing materials, minimizing environmental pollutions and wastes, reducing environmental costs of products, and implementing sustainable development [62,63]. Building organizational knowledge is a central factor in a circular economy.

Companies can build capabilities, e.g., better image and reputation, by investing in circular economy initiatives, green projects and implementing green values in their manufacturing operations and processes [64]. Blockchain technology supports knowledge sharing and development. Companies can monitor real information about the life cycle of materials and products and determine initiatives to extend their life cycle. Environmental knowledge and skills development are key capabilities that can be developed through sustainability efforts, such as green circular economy supplier development programs [65]. Knowing organizational capabilities and monitoring organizational improvements, can be managed through the blockchain, especially for products flowing in distant locations and information.

Shared knowledge, part of capabilities and value gaining, on a blockchain platform can help firms advance their strategies, values, and cultures to integrate circular economy initiatives. Companies can use the built knowledge and values to identify which products contain components that share less value for circular economic purposes. They can delete those products or replace product components with higher end-of-life value materials and further design materials and technologies that improve the operational capacity and durability of products. Companies can further gather accurate information from blockchain ledgers to improve their ability to repair and upgrade products and learn how to design byproducts from their wastes. Those products with higher resource usages and lower circularity potentials can be considered for removal from a product portfolio. In addition, deleted products and the remaining inventory can be by-products or side-products to the circular economy manufacturing processes to utilize operational capacity and maximize supply chain value.

4.3.2. Consumer Knowledge and Behavior

A large fraction of consumers expects companies to be sustainable [66]. Autonomous motivations, which are ideally embedded into humans' sense of self, contain intrinsic and extrinsic motivations that provide energy to individuals to actively pursue the goal of environmental protection or other goals of sustainability [67]. Intrinsic motivators may refer to inherent enjoyment that may drive consumers to purchase green products or adopt environmental-friendly behaviors such as returning products, repairing materials, reducing wastes, and recycling efforts. Reducing costs and meeting environmental regulations can be extrinsic factors that direct consumers to adopt circular economy and sustainability initiatives [68,69]. Similar to what we discussed in organizational value and knowledge, blockchains can play an important role in building environmental knowledge that fuels the intrinsic and extrinsic motivations in consumers.

Consumers can track product life cycle information, form knowledge, and adjust their behavior based on the available real-time information. Companies can also address proper reverse logistics strategies by using blockchain information regarding consumer demands, actions, loyalty, and post-purchase behavior. Being aware and confident of certain green product characteristics can help motivate purchase behavior for sustainable products. The transparency and traceability of blockchain technology can greatly improve this confidence; circular economy characteristics such as recycled materials can increase the confidence of an environmentally sustainable product.

Blockchain can be used to incentivize products returns to the supply chain. For instance, those consumers who return products at the end of the life cycle can be rewarded by cryptocurrency tokens. This can stimulate the circularity of products and provide integrated information about the

performance of the returning programs and funding management for these programs. The incentive systems also help identify those products with low returning rates which can be candidates for deletion, because they do not provide value for circular economy purposes. Traceability of information allows companies to identify products and materials that are collected by poor people and informal markets for recycling purposes and secondary markets. Deleting those products may conflict with moral values that should be considered in product deletion decision making.

In each case, we provided some examples of how the nexus can work together at multiple levels of CE. These activities and characteristics are exemplary. Many additional and emergent issues, as well as broader categories, also exist.

5. Implications and Future Research

In this section, we briefly discuss theoretical and practical implications which can both lead to future research.

5.1. Research and Theoretical Implications

The research and theoretical implications are quite varied. Given the multiple levels of analysis, the theory involved in the design, planning, adopting, general management of this blockchain, CE and product deletion nexus can become quite complex. A theory based issue at each of the three levels is introduced. Many theories exist for multiple levels of analysis and include economic, organizational, and even individual behavioral theories [70].

At the broadest levels, there are issues related to economic and policy theory. For example, ecological modernization theory [71] has been utilized to explain how various technologies are applicable to CE and sustainability issues. Given that blockchain technology can help with efficiencies and building efficiencies, through product deletion in this case; the theory can help in explaining how economic growth can be decoupled from environmental degradation. Whether this situation holds a broad country or even supply chain levels can be investigated.

Managing a circular economy is a 'wicked problem' [71,72]. It has been found that a single theoretic perspective cannot truly address wicked problems [73]. Finding appropriate theories to help study and describe phenomena are necessary. At the supply chain and information technology level, resource dependence, relational and organizational information processing theories have been used to evaluate complex relationships with big data (e.g., [74,75]). Whether these theories can help explain when and how to eliminate products in a CE and sustainability context needs investigation.

Finally, an example of a theoretical implication at the micro level is how individual consumerism and motivation relates to CE and information on product deletion. Numerous consumer theories exist [76], and motivation theory is a core aspect of these systems. Reward systems to motivate individuals to be involved in CE practices, e.g., recycling, is a big concern. We need to sure people are fairly rewarded and incentive mechanisms in this context need study. Would theories like self-determination theory [77] be able to help model situations where consumers can use the information for CE practices, even when demotivational pressures such as product deletion occur?

Given the relative novelty and the essential conceptual characteristics of each of the three topics within this nexus, there is ample room for further theoretical and conceptual development. What theories are most applicable is a research concern.

5.2. Managerial and Practical Implications

The managerial and practical implications of various examples of the interactions presented occur across multiple levels, governments, communities, supply chains, organizations and individuals. Much of what we presented is primarily through a product perspective, although supporting processes and information were also incorporated. The implications provided here, again, only represent examples of the many potential interactions and relationships. Our goal is to help show some of the complexities

that exist at the nexus. As mentioned earlier, these topics are all essentially contested concepts amongst academics, and it also occurs amongst practitioners.

Implicitly in all these practical issues and concerns, the need to draw an appropriate boundary may be critical. In fact, this is what we have done when looking at various levels of implementation and analysis. It is also a concern for those who are seeking to actually link all three areas or even any two of them. We provide a limited number, exemplary, practical implications at the nexus for each level.

From a policy perspective, managing the information across the blockchain can prove valuable for developing the necessary CE infrastructure. In some cases where products are deleted, policymakers need to determine not only the CE implications of this deletion, but broader environmental issues. The aggregation of information may be more easily developed in this case. The issue will arise from being able to monitor over a given planning horizon what inventory of materials exist for appropriate development material flows and natural resources policies. Knowing which products exist and which products may be deleted can help make sure that materials for specific industries are available.

For example, if plastic products are being phased out, then plastics recycling and availability may decrease. This may require additional petroleum investments that may not be environmentally good choices. Investing in biodegradables or other aspects may be a long term policy issue for communities and governments.

The determination and interaction of public or private blockchains are also concerns. Waste exchange information may be public, but private decisions related to product deletion may not be as easily available due to their proprietary nature. In this situation, some form of development along the lines of allowing some third-party management or smart contract situation that may anonymize the relationships may be required.

Example supply chain and network issues can also relate to transparency and security issues. Once again the sensitivity of information is critical to whether it should be shared. Eco-industrial park and industrial symbiosis systems can be set up to help identify virtual inter-organizational relationships, instead of physical close geographic proximity eco-industrial parks. The virtual nature, although allowing for transparency, will require constant monitoring. Whether this monitoring is automated through artificial intelligence, or by actual personnel needs to be determined.

Relatedly, the implementation of these systems is not in a vacuum. When there are novel systems and activities to be introduced, existing operations and systems require careful consideration of the legacy systems. The existing systems that supply chains use to communicate and make decisions with, whether formal or informal, are still in existence. Some can be easily replaceable if they are less costly or very difficult to use. Some may not be and may need integration with a new system. For example, Internet-based waste exchange programs are cheap and relatively quick to use; would blockchain add value? In this situation, blockchain may not add immediate direct waste exchange value due to its technological limitations. However, if product deletion decisions are something that companies value and can use strategically, then blockchain may provide a more proactive and transparent inter-organizational system.

Individual enhancements and consumer behavior incentive systems to complete transactions in recycling and other aspects can prove complex as well. The reward system may need to be reevaluated after the product deletion of modular systems that had been sold which can be returned for upgrading. How to incentivize people to make these returns would require their understanding and knowledge of blockchain incentive and cryptocurrency. These are not simple activities to complete and can provide substantial behavioral barriers.

5.3. Future Research

Blockchain as an enabler for facilitating business activities has received significant attention. Blockchain has some unique features that elevate this technology beyond the traditional supply chain integration information systems, e.g., Enterprise Resource Planning (ERP) systems. Traditional

information systems mostly use centralized databases that are vulnerable to being manipulated or crashing. Decentralized structures provided by blockchain technology removes central authorities from systems and minimizes the likelihood of system failure. In addition, blockchain uses a cryptographic signing structure that increases the reliability and security of records. Disintermediation, the immutability of information, trustless environment, and smart contracts are other specific technologies underpinning blockchain. However, blockchain is an emergent technology that requires greater clarity. What is and what is not blockchain and what characteristics exist is part of the essentially contested concept of blockchain. Additionally, there is confusion about the real-world and large-scale business applications and interoperability of blockchain, especially the scalability issue. More research is needed to address the real-world application of blockchain technology to clearly define this technology in different business contexts and elaborate on the governance and business models and structures for using blockchain.

As implied by many of the theoretical and practical implications, significant future research can be targeted for the study of the discussed joint topics: blockchain, CE, and product deletion. The studies can be at the dyadic level—such as blockchain and CE only—or at all three topics simultaneously. We posit further future research directions.

The first step may be to identify some real-world studies, especially case studies that attempt to consider all three actions. Data acquisition and empirical data are needed to further advance the application of blockchain technology in product deletion decisions in the circular economy context. Hypothesis development and testing may be possible with additional data acquisition for additional relationship identification and evaluation. Simulations can be completed to address various business scenarios including the industry type, product portfolio size, life cycle maturity and product characteristics to test the likelihood of deletion for circular economy reasons; as well as whether adopting and utilizing blockchain technology in those business scenarios is appropriate and feasible.

Sensitivity analysis and robustness can help validate and evaluate blockchain technology applications in product deletion decision making processes. Given the relative novelty of all three areas, simulation analysis may be the most appropriate approach for further investigation. In this situation, tools such as system dynamics can be developed and applied to determine what occurs in different scenarios. The complexity of relationships would need to be explicitly modeled and then executed to determine long-run implications at the various levels of analysis.

Stakeholders might have diverse opinions and concerns on blockchain technology application in strategic organizational decisions. Future research could develop certain tools or models to quantify their beliefs and concerns into the revitalization and evaluation processes for more rational and appealing product deletion decisions.

These future research directions are mostly considering the use of various tools and techniques. The many questions identified earlier in the discussion are also open research questions. We do not repeat them here given that this paper provides a conceptual series of issues that need to be studied. For example, each of the relationships identified in Table 1 can and should be investigated.

6. Conclusions

In this paper, we introduced a concern of current and emergent importance to nations, organizations, and consumers—CE, blockchain technology, and product deletion. The nuances and interactions amongst these three areas were presented. Much of the presentation was at a relatively conceptual and strategic level, although some operational concerns were also addressed.

The purpose of this work and its contribution was to identify various ways that these three areas interact and the research and managerial implications of each. By using a three-level analysis and sub-analysis of the macro, meso and micro concerns, a series of issues were identified. Clearly, there are some issues that are probably more prevalent and realistic, while others are still relatively conceptual. Making sense of these interrelationships can advance CE as a development—for communities and governments—and competitive weapon for supply chains.

Given that the ultimate goal is to improve the economy and the environment, we provide a number of additional theoretical and managerial concerns. Any one of these topics alone is a fertile area of research and practical development; together, the ground is very fertile for significant investigation. This investigation should not only be about how the three ideas can be integrated, but also the need to overcome some of the limitations of definition, capabilities, and feasibility of the linkages. There are many remaining concerns related to technological, organizational, cultural, and economic feasibility issues. Each concern needs attention by researchers and practitioners before the interactions and synergies can become reality. These caveats are self-evident; although, we wished to make them explicit as well, recognizing that the three—the circular economy, blockchain technology, and product deletion—are not panaceas for organizations, the society, and the future; but require critical reflection.

We hope that this paper has set the foundation to build a further and much-needed investigation.

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