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Designing circular supply chains with digital technologies for competitive sustainability: An operation management perspective

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Abstract

The objective of this research is to investigate how digital technologies, specifically blockchain, artificial intelligence (AI), and the Internet of Things (IoT), can be integrated into circular supply chains to enhance sustainability and preserve a competitive advantage. The goals of circular supply chains, which are founded on the ideas of the circular economy, are to reduce waste, promote resource regeneration, and lessen their negative effects on the environment. The study highlights the critical role that digital technologies play in guaranteeing transparency, promoting real-time monitoring, and optimizing resource distribution. Blockchain offers traceability and trust, IoT boosts visibility and operational efficiency within supply chains, and AI improves demand forecasting and resource efficiency.

Though the benefits are obvious, there are significant obstacles to overcome, including high implementation costs, complex technological issues, scalability issues, and regulatory barriers. The research demonstrates how these digital technologies can effectively promote sustainability while enhancing operational efficiency through case studies of well-known companies like HP, Walmart, and Philips. The report also highlights important future trends and makes suggestions for companies looking to develop their workforces, invest in digital technologies, and work together on circular economy platforms. In the end, digital tool adoption is essential for creating supply chains that are more sustainable and competitive in the modern global economy.

Keywords: Artificial intelligence (AI); Blockchain; Internet of Things (IoT); Circular supply chains; Circular economy; Digital technologies; Supply Chain 4.0; Sustainability

1. Introduction

Sustainable operations are not an option, but a requirement in the current business environment. Due to the negative environmental effects of the take-make-dispose linear supply chain model, businesses and policymakers are looking for sustainable alternatives (Korhonen et al. Rajput and Singh, 2019; 2018). The circular economy (CE) promotes reuse, recycling, and recovery in order to cut waste and extend the life of products (Mendoza et al. 2017,). The circular supply chain sometimes referred to as the "closed-loop supply chain," is based on the ideas of the circular economy and gives priority to material regeneration and restoration while taking environmental and economic sustainability into consideration (Min et al., 2021).

Recent advancements in digital technology, such as blockchain, artificial intelligence (AI), and the Internet of Things (IoT), have made circular supply chains feasible. Blockchain technology provides transparent material monitoring and ensures ethical sourcing, while artificial intelligence minimizes overproduction through inventory optimization and demand forecasting (Bressanelli et al., 2018). (Saberi et al. 2019). Supply chain resource allocation is improved by real-time asset tracking made feasible by IoT (Zhong et al. 2017).

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This paper examines how digital technologies and circular supply chain models interact, providing useful advice on how businesses may use AI, blockchain, and IoT to improve sustainability and preserve competitiveness. It seeks to add to the expanding body of knowledge on digitally enabled circular economy projects and offer tactical advice to companies making the shift to sustainable supply chains.

2. Literature Review

One of the most evident trends in operations management today is the evolution from traditional supply chains to circular supply chains as control on resources and environmental awareness has increased. Circular economy entails the minimization of waste and making the most of the materials in circulation which has been viewed by some scholars as a way of achieving more sustainable competitive advantage with less environmental pollution (Geissdoerfer et al. 2017). It is now possible to manage circular supply chains with the help of such advanced information technologies as AI, blockchain, IoT that support high resource use efficiency, tracing ability, and low-price competition in the environment.

2.1. Circular Economy

The traditional linear economic model, which is known to encourage resource depletion, environmental destruction, and waste production, has gradually seen the emergence of the concept of circular economy (CE) as a valid alternative (Lieder and Rashid, 2016; Korhonen et al. 2018). Pursuant to principles of circular economy, the linear 'take-make-dispose' approach is replaced with a closed-loop system where the use and waste of natural and/or man-made resources are kept at a minimum (Bocken et al. 2016). For any of the CE goals to be achieved, the process of design and choosing materials that would provide for the reduction, recycling and reuse of a product and its components throughout its whole life cycle enhancement are crucial (De Angelis, 2018).

In advancing any necessary shift in business approach and strategy, such innovations include the design of the products and their environmental consideration (Bocken et al. 2016,). Nonetheless, due to the fact that there is a need for new technologies, infrastructure, and business models, many organizations find it difficult to implement (De Angelis et al. 2018,). CE principles contribute to such goals as the environmental sustainability and long-term competitive advantage of these businesses (Korhonen et al. 2018,).

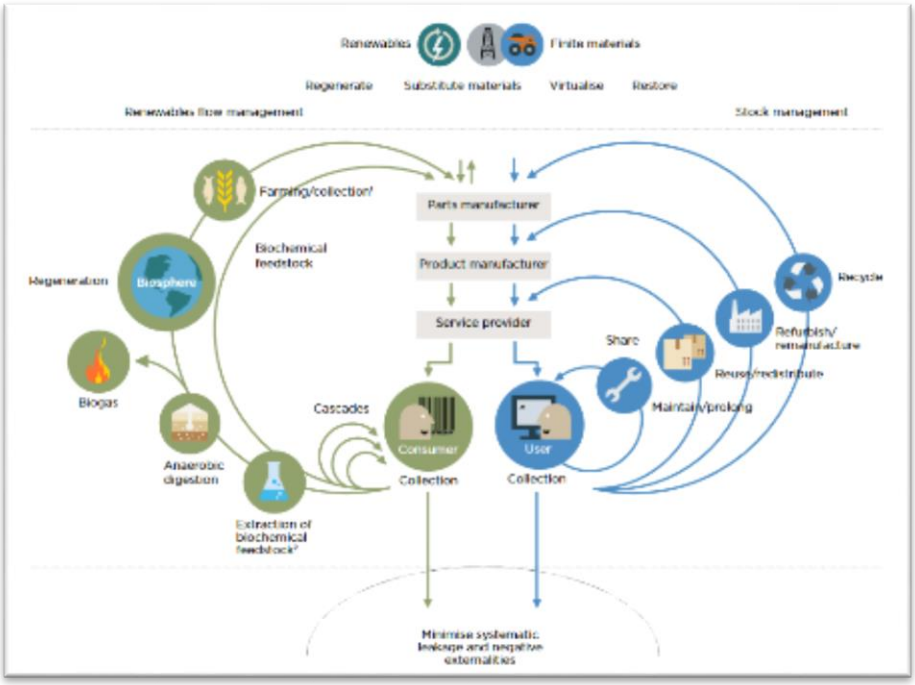

Figure 1 The circular economy system diagram (Source: [43])

In summary, the general concept of circular economy provides an innovative opportunity for companies to achieve sustainable development through reducing wastes, enhancing product lifespan and adoption of new business strategies. Thus, this process, however, requires clear changes in supply chain practices which focus on improved resource efficiency and better environmental practices.

2.2. Circular Supply Chains: A Paradigm Shift

The circular economy (CE) forms the basis, in turn, for circular supply chains (CSCs), focused on eco-design, reuse, refurbishing and recycling, with an aim to reduce waste, enhance resource consumption and create regenerative processes (Ellen Macarthur Foundation, 2020). One such aspect is closing the loop that maintains the CE by ensuring the materials go through both forward and reverse logistics as corporations are increasingly required to be sustainable (Korhonen et al. 2018.). For instance, in cases where it becomes imperative to avoid wastage of boxing procedures, CSCS create a loop by recycling and remanufacturing old products in their production process where such resources would otherwise end up in waste landfills (Genovese et al. 2017, as well as Nasir and colleagues. 2017; Mangla and associates. 2018,).

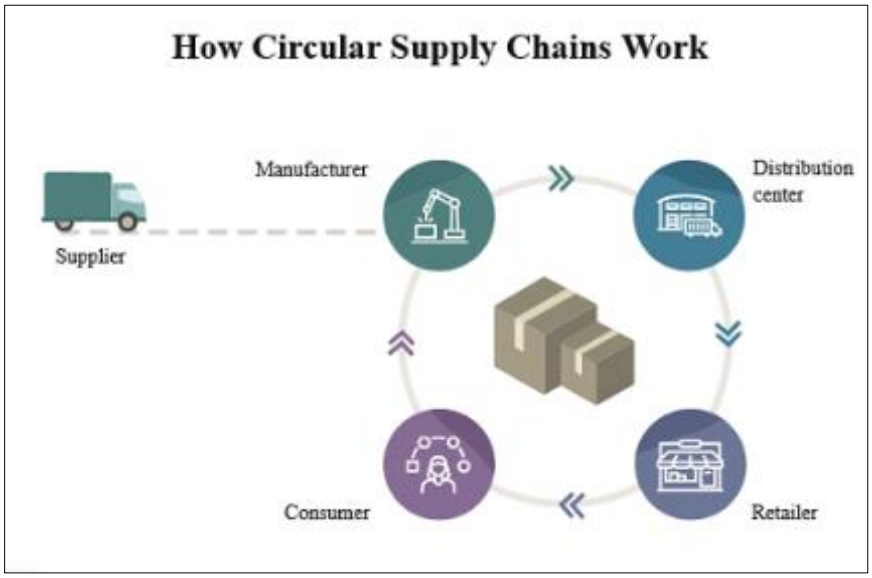

Figure 2 Supply Chain work flowchart, (Source: [44])

Due to the need to optimize the resource recovery and increase the cooperation for further using the depleted resources, the CSCs also consist of such stakeholders. These zero-waste campaigns are evidence in projects such as conversion of waste cooking oil to bio-diesel or grinding used vehicle tires and using them in roads construction (Farook et al. 2019; Genovese & associates. 2017). From an environmental standpoint, CSCs constrain the rate at which virgin materials are mined, increasing resource conservation, and minimizing emissions. In financial respect, they reduce material expenses and assist in balancing the supply chain (Geissdoerfer et al. Stahel (2016) and, 2017). In this regard, by providing sustainable development and reverse logistics with circularity, circular supply chain management (CSCM) helps living products longer and makes them more resource efficient and less wasteful (Tukker, 2015).

2.3. Industry 4.0 – technological revolution

Industry 4.0 (I4.0) seeks to streamline the synergy of various new technologies such as big data analysis, blockchain, cloud computing, and the Internet of Things (IoT) into industrial activities while enhancing the strategies because the processes must be more sustainable, efficient and adaptable (Romero et al.,2021). The integration of the two technologies reduces costs and improves inter-business coordination along the value chain as manufacturing activities are complemented by information and communication technologies (ICT) which facilitate tactical response in the production environment (de Sousa Jabbour et al. 2018). Because of these technologies, processes are rendered easy which in turn helps save costs as well as the environment (Dubey et al. 2017).

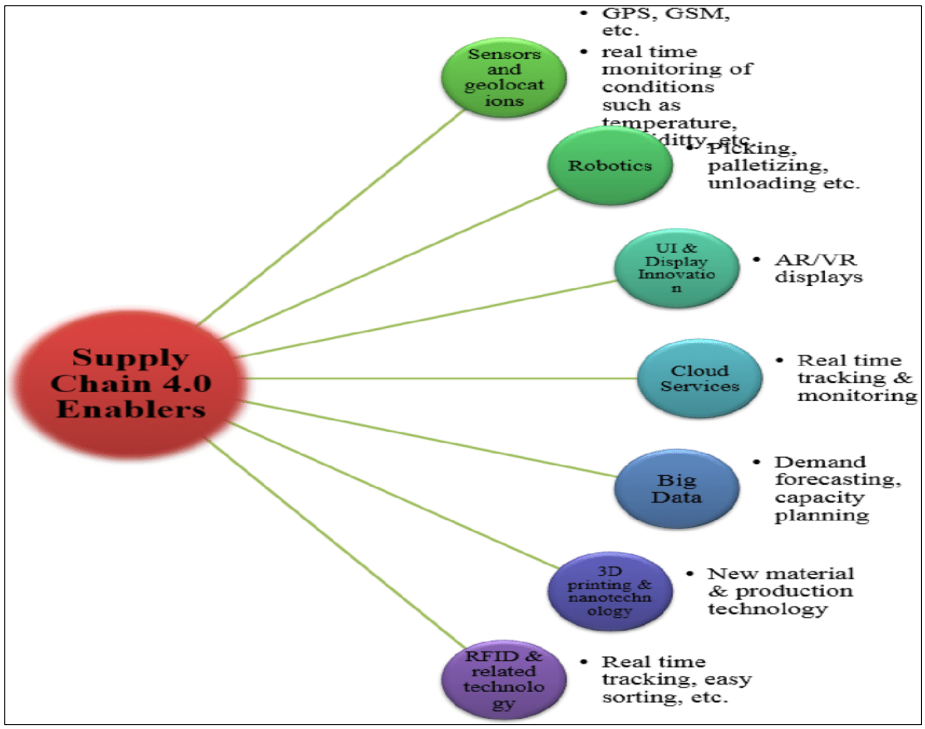

Figure 3 Enablers of Supply Chain 4.0, (Source: [45])

In addition to CS of business, I4.0 technologies offer cloud and additive manufacturing for increased logical abilities and customization options to support flexibility of business (Fettermann et al. 2018,). If academic literature can be trusted, this technique works in practice as well, stirring wealth creation as envisaged by Joseph Schumpeter. Big data and IoT properties are employed by Tata Power to enhance electricity usage while Voltas employs IoT to assist in the service of chillers (Kumar et al. (2021). One of the key features of I4.0, Supply Chain 4.0 leverages several emerging technologies such as IoT, AI, ML, and DL to trace and follow supplies and movements in real-time so as enhance the supply chain's production and organization efficiency (Unhelkar and Co. 2022).

2.4. Digital Technologies in Supply Chain Transformation

Digital innovations are keys to changing the conventional supply chain processes to digitalized ones that allows the adoption of circular economy (CE) principles. (Manavalan & Jayakrishna, 2019; Kouhizadeh & Sarkis, 2018). The Fourth Industrial Revolution combines IoT, blockchain, and AI as a solution to business performance, resource management, and waste reduction (Rajput & Singh, 2019; Zheng et al 2021).

- **Artificial Intelligence (AI) in Circular Supply Chains:** AI augments the circular supply chains by employing machine learning algorithms and other resources in resource optimization, forecasting needs, and waste minimalization. It also assists lifecycle management and reverse logistics, therefore advancing sustainable supply chain practices (Wang et al. 2020).
- **Blockchain Technology for Transparency and Traceability:** To enhance the traceability of materials flowing through a supply chain, blockchain technology helps to record the transfer of materials from production to the recycling stage by the help of supply chain management system. It shrinks the demand for raw materials and embraces the concepts of recycling and reuse (Demetis, 2018; Saberi et al., 2019).
- **Internet of Things (IoT) in Enhancing Resource Efficiency in Supply Chains:** The Internet of things is one of the technological advancements that has positively changed the way supply chains are managed since it offers real time update on the products and their movements which has increased resource efficiency within the circular supply chain management. The technology that is referred to as IoT also includes other features such as sensor and RFID tags that helps the organization to optimize the utilization of the resources, reduce their footprint and improve their reuse and recycling activities (Zhong et al., 2017; Turker & Altuntas, 2014).
- **Cyber-Physical System (CPS):** CPS is a convergence of the use of IT and the physical environment such as in the case of manufacturing. This each autonomous unit in an organization will possess its own rationale system to carry out its functions including automation, decision making and stakeholder management (Lee et al., 2015; Wang et al., 2018).

- **Cloud Manufacturing (CM):** CM is about interconnecting different geolocated production resources through the internet in order to achieve better flexibility and scalability of production processes (Xu & He, 2017; Zhong et al., 2017). As noted in Rajput and Singh (2019), the efficiency of product design, its manufacturing, and ultimate distributive can be improved by the flexibility and scalability of this system.
- **Big Data Analytics (BDA):** BDA can be defined as returning timely actionable insights from a multitude of stored data to refine the processes of production within an organization as well as the management of the organization itself (Wang et al. 2018; Lee et al 2015). Competent and skilled work force is a prerequisite to fully exploiting its strategic benefits (Dubey, 2016).

2.5. Sustainability and Competitiveness: The Balancing Act

To remain competitive, companies are integrating digital technologies into the supply chain management systems to enhance the sustainability of their operations. To gain the competitive advantage in the market, improvement in customer satisfaction, reduction of costs and improving efficiency are very important, and this is where say blockchain technology, AI, IoT come in (Kouhizadeh and Sarkis, 2018). However, for most businesses this is a challenge since the cost of implementation is higher and integration is more difficult (Zheng et al. 2021). In the process of achieving success, businesses must manage market demands against sustainability requirements, operational agility and cost efficiency (Stahel, 2016). Such balancing act is achieved with the help of digital technologies through real time information, resource use efficiency and increasing the level of visibility.

3. Methodology

3.1. Research Design

This study employs a multi-textual design integrating both qualitative and quantitative methodologies to investigate the incorporation of modern technologies such as AI, blockchain, and IoT into the circular economy supply chain aimed at enhancement of competitiveness and sustainability (Creswell, 2014). As for qualitative part, interviews and secondary analysis of industries such as electronics, retail, and manufacturing will be undertaken where best practices, challenges and success factors on the use of these technologies will be outlined.

The quantitative portion focuses on analyzing the industry's reports and secondary data with a specific focus on performance indicators like carbon emission reduction, resource recycling enhancement, and economical efficiency. Combining these approaches allows for studying the changes brought by digital technologies to the circular supply chains from a broader point of view.

3.2. Data Collection

There are two main stages of data collection of this study. The first stage of data collection will center on owing secondary data through the study of industry reports, journals, and sustainability bulletins of the World Economic Forum, publications of the Ellen Macarthur Foundation, among others. These will provide an understanding of how digital technologies can be used for sustainability and circular supply chain activities. Theoretical building will be supported by the scholarly literature, to frame the context and track the tendencies and emerging patterns of the diffusion of digital technology.

3.3. Data Analysis

For this research, both the thematic analysis and descriptive statistical analysis are to be employed. It is guided by qualitative case studies and thematic analysis Wang & Duh, 2009 helps in identifying critical aspects regarding the integration of digital technology, sustainability, and competitive advantage on circular supply chains. It will point out the use of AI, Blockchain, and IoTs application and address typical problems, success keys, and best practice frameworks. This method will seek to categorize performance statistics concerning greenhouse gas emissions, waste materials, and energy reduction using descriptive statistics. The study contrasts the two- one that uses digital utility and the other one traditional operation to show how business practitioners can gauge the extent to which business processes such as digital transformation can enhance environmental and financial performance (Patton, 2015).

3.4. Scope

This paper discusses the manufacturing, wholesale, electronic and clothing industries, where circular supply chains utilizing tools like AI, Blockchain and IoT are gaining headway mainly for their environmental advantages. For example, in manufacturing, industries such as electronics and automotive are implementing circular supply chains to support the

increase in the lifecycle of products and reduce material consumption with the help of advanced computer technologies which are designed to track product lifecycle and ensure adherence to sustainability standards (Bressanelli et al., 2018). As far as retailing is concerned, and particularly in the fashion sector, recycling using circular models is being adopted with IoT and Blockchain aiding in quantifying or measuring the waste (Kouhizadeh & Sarkis, 2018). In relation to electronics, there are designs within circular supply chains which enable the product design to include recyclability and AI as a reverse logistics system along with IoT (Bressanelli et al., 2018). These trends provide lessons for other businesses which are interested in at a time when it is possible to marry the principles of the digital economy with those of circular economy in a bid to improve performance and sustainability.

Limitations

Nonetheless, it is true that the contributions of this study are greatly hampered by some limitations, this study provides a comprehensive description of how new technologies are incorporated in circular supply chains. First, the use of case studies may be limited to one sector since it may not be possible to obtain all the best practices in all the sectors especially for smaller firms with limited capability. Others would argue that small businesses may have barriers that revolve around still within the scope of sustainability practitioners which does not capture entirely the target market. Second, appropriate methods of analyzing the data are limited because most of the data collected is secondary data, analysis of which does not involve direct field observation, interviews, or surveys. To address this limitation, attempts are made to combine the findings of case studies with quantitative indicators of performance.

4. Digital Technologies Driving Circular Supply Chains

To help ease the shifting of conventional supply chain frameworks into supply chain frameworks that address sustainability and competition needs, there is need to integrate advanced technology solutions. Key technologies such as, Artificial Intelligence and IoT as well as companies bring down waste, utilize resources better, enhance transparency and make decisions that are timely and knowledge which is crucial in achieving a circular economy. Making use of these technologies helps enterprises create useful and sustainable models of supply chain which give them the competitive edge in the global matrix. (Kumar et al., 2021).

4.1. Artificial Intelligence in Circular Supply Chains

In the context of circular supply chains, artificial intelligence (AI) is very important in resource allocation, demand prediction, and forecasting among others along the supply chain. Reduce over production in circular economy of the supply chains as well as improve reverse logistics by artificial intelligence which helps in demand forecasting and also recovery, reengineering and reuse of products (Bressanelli et al., 2018).

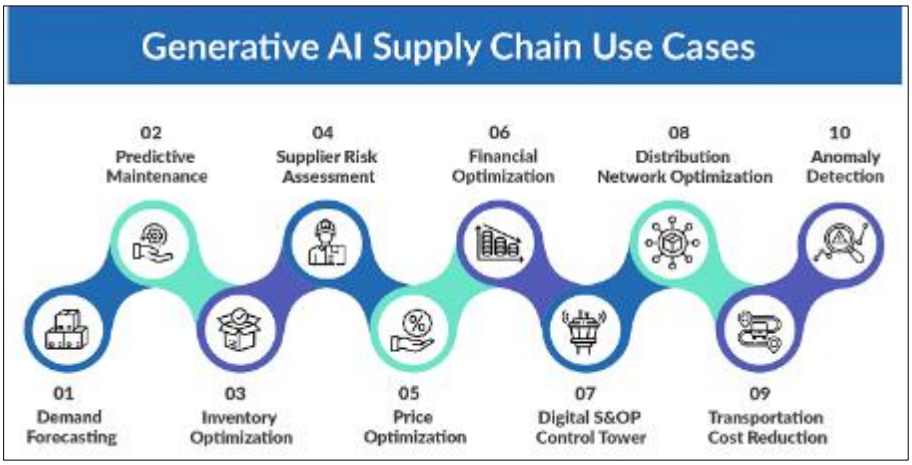

Figure 4 Generative AI in Supply Chain, (Source: [46])

Automation generally utilizes elements employed in developing or implementing new products' attributes through improvement as opposed to development of more resources. However predictive maintenance algorithms reduce maintenance efforts to a minimum level based on asset usage monitoring to prevent loses related to supplies for new resources (Gupta et al.2020). To support such goals, and stay competitive in the market, AI technology is used at Philips to enhance the return and recycling of products, thereby increasing resource turnover and reducing operational costs (Bressanelli et al. 2018).

4.2. Blockchain Technology for Transparency and Trust

The use of blockchain technology would bring huge enhancements in transparency, tracking and responsibility in a circular supply chain. Blockchain is simply an incorruptible and distributed asset registry which keeps track of assets and records transactions. This aspect helps stakeholders to validate efforts towards sustainability such as recycling and responsible sourcing (Demetis, 2018). Such a commitment without violating environmental regulations is assured, and consumers will be provided with accurate information on the green attributes of the product (Saberi et al., 2019).

Additionally, trust among the members of the supply chain is developed and fraud is reduced using blockchain, especially in industries where sustainability is of importance. For instance, Walmart has embraced blockchain technology to track food products through the supply chain to verify responsible sourcing (Kouhizadeh and Sarkis, 2018). In addition, the implementation of such systems makes it possible to conclude so-called smart contracts that automatically perform specified actions. This is beneficial to sustainability since it ensures that payment is only made for the delivery of recyclable or reusable materials (Saberi et al. 2019). We see how this kind of transparency builds trust and facilitates compliance with circular economy principles.

4.3. Internet of Things (IoT) in Enhancing Resource Efficiency

The Internet of Things (IoT) is one of the major digital transformation technologies that support the uptake of circular supply chains. It allows data to be gathered and analyzed at every step of the supply chain almost in real-time. This provides immediate access to information, for instance, based on electric sensors or RFID-bases, regarding what is on stock, if resources are being wasted and whether freight comes out in the correct amount and form. Such capabilities are critical for measuring the effectiveness and the possibilities of making further steps towards sustainability across different supply chain operations (Zhong et al. 2017). Since successful implementation of IoT features puts into account the actual number of materials that is used, there will always be support for the accelerated retrieval of goods and other parts in readiness for upcycling. When discussing reverse logistics, means by which products return through the supply chain for repair, rebuilding or recycling, it is useful to add that the movement and concept of these products and devices may be controlled via sensors and other connected machines. This use of IoT is very important when it comes to circular supply chains.

This capability helps companies to improve the logistics and scheduling of returns by supporting diversion and reclamation of valuable materials rather than disposal (Turker and Altuntas, 2014). In the example of the automotive industry, IoT sensors have been used to check how well a car part is functioning and determine when it is best to replace or refabricate it to achieve less wastage and enjoy a longer vehicle life (Bressanelli et al. 2018).

According to Kumar (et al.2021) all such systems that make use of IoT technology, monitor energy, waste, and resources, and provide a basis for businesses to understand where they are operating inefficiently and address these issues to minimize their negative effects on the environment. For instance, in the electronics industry, IOT sensors serve the purpose of keeping track of the quantity of energy used to carry out certain manufacturing processes. In this way, businesses can improve on the efficiency of output while minimizing energy requirements and carbon emission more so during production processes.

4.4. Supply Chain Sustainability

As business organizations are now faced with the demands of corporate citizen responsibility, scarcity of resources as well global environmental change, sustainability of the supply chain is increasingly becoming an important business strategy. The development and implementation of such strategies are intended not only to reduce but also to eliminate many adverse impacts, while seeking for options that promote benefits around the globe (Zhong et al. 2017). These include not only reducing and eliminating carbon emissions and increasing energy efficiency, but also reducing the use of those materials, which are not sustainable for labor which meets the test of Kumar et al., 2021. It will be evident that sustainability brings practical business advantages such as saving cost and reducing risk, strengthening corporate image while addressing avoidable business practices (HBR, 2021).

The primary drivers behind the promotion of sustainability appear to be the collaboration of industry stakeholders and the disclosure enhanced by digital technologies (Geissdoerfer et al.2017). Sustainably built supply chains also create a “triple benefit”, providing cost-savings while enhancing social and environmental benefits as well nurturing growth and innovation in frameworks that advance business sense (EY, 2021). In one of on-demand recently published reports by the EY consulting company 525 executives covered the subject of sustainable supply chain management. Besides, the following graph lists the main factors that influence the improvement of sustainability.

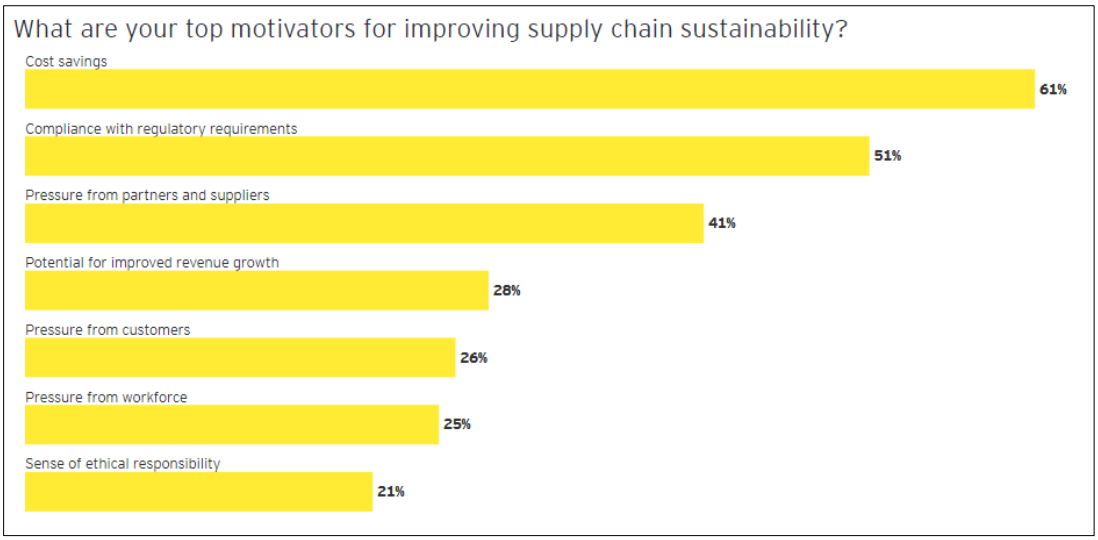

Figure 5 Top motivators for improving supply chain sustainability, (Source: [47])

4.4.1. Components of Sustainable Supply Chains

Sustainability in supply chains extends to the integration of ethical, ecological and circularity approaches which foster long term supply chain sustainability.

Figure 6 Elements of a sustainable supply chain, (Source: [48])

Green, transparent, and circular practices are particularly important. A green supply chain incorporates artificial intelligence (AI) and machine learning (ML) to minimize waste and in the process, enhance effectiveness at every phase of the product lifecycle. Transparent supply chains enabled with blockchain, and RFID are industries do not leave room for ambiguities in the origins of products, their manufacturing conditions and processes. Finally, circular supply chains focus on the retrieval of materials from already consumed products through disassembly of products or conversion of products to their original forms, in this case improvement of analytics and 3D printing technology and minimizing the amount of waste to be disposed.

4.5. Synergy of Digital Technologies for Competitive Sustainability

Circular supply chains that integrate AI, blockchain and IoT create a varied effect that enhances competitive advantage while ensuring that the environment is protected. Each of the individual technologies has certain benefits- for instance, the accountability of the blockchain system, the visibility of the IoT system and the optimization of AI in the usage of resources, but all these are combined to form a supply chain ecosystem that is more reliable, effective and is not prone to obfuscation. The great advantage of combining these technologies is the availability of such “intelligent” supply chains that have self-healing attributes to normal sees threats from even the quietest of markets and adapt to changes for optimal flows of the resources on hand.

This ability to change is important to companies who operate in volatile environments where being competitive cannot be combined with being sustainable. People can strike a balance between the different aspects of environmental protection and the commercial activities of businesses through the employment of these digital technologies which ensure that their supply chains are both sustainable and efficient (Wang et al. 2020).

5. Challenges in Implementing Digital Circular Supply Chains

Circular supply chains can benefit greatly from the integration of digital technologies like blockchain, artificial intelligence, and the Internet of things, but there are drawbacks. The regulatory obstacles, high implementation costs, technological complexity, and scalability are a few. Enterprises need to effectively tackle these challenges if they are to fully leverage the competitive benefits and sustainability of digital circular supply chains.

5.1. Technological Complexity

Many organizations are unable to implement the modern technologies comprising IoT, blockchain, and AI-backed systems due to the need for substantial infrastructure, and trained personnel to handle the systems, especially in SMEs (Turban et al., 2019). For example, due to performance uncertainty, when developing AI systems large volumes of training data are required, which includes ensuring that data is of high quality consistently over time. Problems with data quality can decrease the abilities of the AI to optimize the allocation of resources and help in waste reduction (Wang et al., 2020). However, blockchain as a technology brings with it security and transparency but it uses a lot of processing power and fitting this technology among the existing systems becomes difficult owing to the inflexibility of the systems (Kouhizadeh & Sarkis, 2018). The same case applies to IoT systems where volumes of real-time data are produced hence expensive cloud infrastructures and analytics are required posing other difficulties (Zhong et al., 2017).

5.2. High Implementation Costs

One of the major obstacles to the use of new technology in circular supply chains is the high up-front investment cost. Technologies such as artificial intelligence (AI), blockchain (comprising distributed ledger systems), and the internet of things (IoT) require large capital on development, commissioning, and maintenance in particular blockchain systems (Saberi et al. 2019). The costs associated with the adoption of IoT as well include large investments on the cloud platform, connectivity and sensors and many other overheads which can scare away organizations with small margins. In many cases, employees do not get training on these methods. Companies without enough internal skills must send their staff for external training, which can even be more demoralizing to smaller organizations (Dawson & Wilson, 2018).

5.3. Scalability Issues

There are considerable hurdles concerning the integration of digital technologies into sustainable supply chains. Often, the adoption is still at the pilot level due to the high costs of scaling up blockchain, AI and IoT (Turban et al., 2019). The human and financial resources required to scale AI for the purpose of distributing resources across the entire supply chain are immense (Bressanelli et al., 2018). Likewise, the blockchain faces some limitations regarding scalability with respect to speed and security (Zheng et al., 2021). Certain factors impede the scalability of IIoT including the coordination of processes, integration of data, and the processing of data in real time. The problems are made worse by the need to provide device interoperability and protect the data (Kumar et al., 2021). For these technologies to deliver value to circular supply chains effective scaling up s fundamental.

5.4. Regulatory and Compliance Barriers

Regulatory and compliance aspects are amongst the most challenging factors in the utilization of the digital circular supply chain. Contrasting laws, e.g. that of the GDPR in Europe, make it difficult to cross border use of data-intensive technologies (Zhong et al., 2017). It is not easy to standardize circular supply chain processes where there are varying levels of green compliance enforcement (Wang et al., 2020). Further, the use of blockchain technology in organizations is faced with other challenges since governments are still coming up with regulations on the use of this technology and also the fact that there are tendencies of criticizing its high consumption of energy which should bring about more regulatory constraints (Kouhizadeh & Sarkis, 2018; Saberi et al., 2019).

5.5. Data Privacy and Security Concerns

Implementation of digital technologies in circular supply chains creates high concerns for privacy and data security. IoT devices are known to be used in generating vast amounts of critical data, inviting in cyber-attacks, information leaks and insider threats, the activity that may cripple operations and banish confidence (Zhong et al.,2017). Despite the security that blockchain provides, threats such as malicious users or stolen keys exist (Demetis, 2018). Considering the specific legal requirements placed on each organization, for example GDPR, organizations need to put in place very sophisticated governance mechanisms which hamper legal AI decisions making by companies' lawyers (Daugherty & Wilson, 2018). These concerns are important in the realization of benefits from the adoption of digital circular supply chains.

6. Case Studies

Several of the leading global companies have shown that it is possible to incorporate digital technology into closed loop supply chains. These case studies showcase the use of AI, blockchain and IoT technologies for competitiveness, sustainable development and improving the efficiency of operations. This part analyzes the strategies and outcomes of these companies using digital technologies to promote circular supply chains with real life evidence.

6.1. Philips: Using IoT and A.I taxation for circularity in electric devices

Philips illustrates the best practice in terms of utilizing digital technologies into a circular model within the electronics industry particularly. The company's circular economy strategy emphasizes the prolongation of product life cycles through the application of artificial intelligence (AI) and the Internet of Things (IoT), facilitating the reuse, recycling, and repurposing of electronic items such as household appliances and medical devices (Bressanelli et al., 2018).

Essentially, it is the usage of predictive AI that forms part of Philips' current strategy to develop better reverse logistics and extend product lifespan. AI algorithms are used to determine when to collect used things and whether these should be recycled, refurbished, or upcycled in order to decrease waste (Kumar et al., 2021). For instance, product oriented IoT sensors help to understand the use of the products, their condition and maintenance requirements to help Philips to focus on improving the lifetime of its products and reducing its environmental footprint. Such a close system optimises the resource consumption rate also plants additional sore to the customers (Bressanelli et al., 2018). In 2022, 18% of total Philips revenues was represented by the product, service and solution sales contributing to circularity based on the methodology which our external auditors verified.

6.2. IBM and Walmart: Blockchain for Supply Chain Transparency in the Fashion Industry

Walmart and IBM have entered into collaboration with an objective to build a system for food supply chains which is based on blockchain technology. This gives Walmart the possibility to control food products through the entire chain of production and distribution all the way to the consumer to make sure there are no unethical issues (Kouhizadeh and Sarkis, 2018).

Since certain characteristics of blockchain such as rigidity of its ledger assure total legal compliance, Walmart is able to confirm the ethical sourcing of the food products as well as their compliance with the society's ecological standards. Saberi et al. 2019 refers to this as conformity. This enables gaining a greater accountability while, at the same time reducing the chances of food-borne disease and food product recall. Walmart shows how distribute ledger technologies support green economy in an exemplary case by increasing business productivity by reducing wastages and enhancing customer confidence toward the firm through rapid response to contamination sources (Kouhizadeh and Sarkis, 2018).

6.3. Patagonia: IoT and AI for Circularity in the Apparel Industry

Based on its core values of environmental protection, Patagonia, one of the first brands to take CSR seriously in the fashion industry, embeds IoT and AI technology into its circular economy supply chain. Patagonia utilizes certain aspects of circular economy by asking its customers to return the used products for recycling or repairing (Turker & Altuntas, 2014). To optimize return logistics, returned products are monitored with IoT sensors in order to inform the company whether a product should be repaired, reused, or recycled (Turban et al. 2019,). Also, AI based predictive analytics improves further keys operations for the Patagonia's business where the demand for recovered materials is predicted so that resources will be consumed efficiently, and excess production will be avoided. This strategy helps Patagonia to meet the objectives of sustainability while still being able to compete in the market (Turker & Altuntas, 2014).

6.4. Schneider Electric: AI and IoT for Resource Efficiency

Leading energy management company Schneider Electric uses AI and IoT into its circular supply chain to improve sustainability and resource efficiency. The application of these Internet of Things technologies makes it possible for the people to manage the energy and the environmental impact throughout the product's lifecycle hence identifying energy inefficiencies and minimizing carbon emissions (Bressanelli et al. 2018). Such systems of maintenance rely on the predictive capabilities of artificial intelligence systems which help determine when a system might fail and therefore prevent any such potential failures, hence improving the usable life of products lowering the demand for virgin products and reducing waste generation (Wang et al. 2020). In integrating these AI and IoT technologies, it not only enhances Schneider Electric's sustainability but also its overall market competitiveness by lowering the cost of operations and enhancing reliability of products. These digital technologies allow the company to create added value for stakeholders while being environmentally responsible (Kumar et al. 2021).

6.5. HP: 3D Printing and AI for Circularity in Manufacturing

HP Inc. is a pioneer in the application of 3D printing and AI to manufacturing to support circular supply chains. HP has fillable cartridges which are made to make sure that more of the printer is recycled and less waste. Besides creating an efficient item out of suboptimal materials, Artificial Intelligence based systems for product design and manufacturing optimization helps in minimizing the amount of raw materials used and ensures that manufactured items can be disassembled easily when the need for recycling arises (Gupta et al. 2020). Combing recycled materials with the 3D printing of HP, it also reduces than impact on the environment even more. It also helps the company in demand planning, as well as the real-time adjustment of production processes, all of which achieves optimal resource utilization and minimal waste. An example of digital economy principles in the business sustainability area is HP's circular supply chains, which demonstrates how 'HP's ideas' can build more competitive and sustainable ex-ante manufacturing technologies (Gupta et al. 2020).

7. Future Trends and Recommendations

It is anticipated that advancements in digital technologies will improve the efficiency, performance, and effectiveness of the circular supply chains, while sustainability is becoming vital for the company to be successful in the long run. In this competitive environment, companies are required to tap into future opportunities although some challenges still exist. This part describes some of the important trends that are emerging and how these trends can be utilized by companies that seek to use digital technologies to develop competitive as well as sustainable supply chains.

7.1. AI in Supply Chain 4.0: Improvement of Predictive Capabilities and Automation

Assuredly, AI will facilitate the automation and integration of circular supply chains, improve the efficient distribution of resources, offer alerts when there is a likelihood of disruption, and minimize damage to the environment. Performing such tasks as improving advanced manufacturing and efficient incineration of reverse logistics systems will be the responsibility of AI-enabled/supported automation, including robots and models, in which accurate predictive analytics will be utilized. Companies are obliged to undertake measures to improve AI-sustainability by integrating certain predictive and automation strategies.

7.2. Blockchain's Potential: Decentralized Supply Networks and Smart Contracts

Decentralized supply networks will also be improved using blockchain, while providing security trust and lower costs of transactions. Through Smart contracts, these processes will be simplified, and payments will be linked to the recycling processes and other sustainable activities. Adoption of Blockchain is expected to improve the competitive standing of businesses dealing with ethical sourcing and traceability among other sectors.

7.3. IoT and Smart Supply Chains: Enhanced Real-Time Monitoring and Resource Efficiency

The future supply chains will be supported by the IoT which will monitor the real-time tracking of products, resources and their environment. This will assist organizations in comprehending the existing system shortcomings and in advancing sustainability at all levels through the use of information. Also, IoT devices will help in designing systems for localized production and usage of infrastructure, upcycling products through preventive maintenance.

7.4. Advanced Data Analytics and Circular Economy Platforms

Advanced data analytics, such as machine learning, big data and other integrated platforms can assist organizations in streamlining the circular supply chain by predicting violations and cutting down resources. Circular economy platforms will give an organized support for interactions of several companies in the purpose of resource economies, waste reduction, byproduct resourcing.

7.5. Recommendations for Businesses

To incorporate digital technologies into the renewed resource supply chains, businesses need to look more into the future and address both present problems and future opportunities. Making the case of investing in AI applications for predictive analytics and automation aids will improve the efficiency of the supply chain, lower waste, and assist in resource optimization. Moreover, integrating the organizational structures with the help of blockchain will promote ethical practices thereby improving trust in the stakeholders on verifying sustainability. There is a need to exploit IOT for product, resource, and environmental monitoring effectiveness in real time to make decisions that will increase the likelihood of sustainability. Working together on each other's platform in circular economy practices will enable companies to utilize each other's resources and promote efficiency and sustainability. Last but not the least,

organizations will need to work out on skills development for the employees, that will focus on operating and utilizing AI, blockchain, IOT, and data analytics in complex and dynamic supply chains.

8. Conclusion

This study has brought out the opportunities that arise mainly from the use of modern digital technologies such as blockchain, artificial intelligence and the Internet of things that can transform circular supply chains. However, implementing these enables waste minimization and better business performance management as resources can be optimized, they can be tracked, and their flow can be monitored in real time. Blockchain ensures that there is traceability and trust of people involved in a transaction while IoT includes such data that can assist in search and energy efficiency during a product lifetime and AI improves forecast and distribution of products.

Nevertheless, other issues such as high costs of setting up businesses, time-consuming technologies, scalability concerns, and legal issues still constrain many users. This helps to illustrate how effective these technologies are in building sustainable supply chains through examples from companies such as HP, Walmart and Phillips.

Thus, employees of the middle level must purchase digital instruments, enhance collaboration, and increase qualification to make a profit from future value added by blockchain, artificial intelligence and the Internet of Things to global supply chains. Doing this will enhance the firms to design supply chains that are of great competitive edge and sustainability positioning them well in the global arena.

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