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**“The Ascendency of AI-Driven Technologies on Sustainable Supply Chain Performance in Beverages Industries of Pakistan”**



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## **Abstract**

The study examines how digital technologies such as Digital Technologies Block Chain (BC), Internet of Things (IoT), Artificial Intelligence (AI) influences Sustainable Supply Chain Performance (SSCP) mediated by Big Data Analytics (BDA). The study aims to investigate how digital transformation leads to sustainability outcomes in the beverages industry of Pakistan, a developing economy context. Using a quantitative and cross-sectional research design, data was collected from a sample of 217 supply chain professionals working in beverage manufacturing and distribution firms across Pakistan during the year 2024-2025. Data will be analyzed via Partial Least Squares Structural Equation Modelling (PLS-SEM) to test the proposed direct and indirect relationships. The findings suggest that technological inputs enhance adoption of big data analytics, in particular we find that blockchain, IoT and Artificial Intelligence have positive effects on BDA. Also, Sustainable Supply Chain Performance is significantly enhanced by Big Data Analytics with regards to environmental, social, and economic performance objectives. The mediation analysis results show that Big Data Analytics partially mediates the relationship between digital technologies and SSCP; in other words, sustainability benefits arise mainly through the analytics-driven decision-making process. Integrating digital technologies with strong analytics capabilities can help improve supply chain sustainability, suggest the findings. Policy maker should promote digital infrastructure and skill in analytics to promote sustainable supply chain practices in developing economies.

**Keywords:** Beverages Industry, PLS-SEM, AI, Sustainable Supply Chain Performance

## Contents

<b>“The Ascendency of AI-Driven Technologies on Sustainable Supply Chain Performance in Beverages Industries of Pakistan”</b> .....	<b>1</b>
<b>Chapter 1</b> .....	<b>7</b>
<b>Introduction</b> .....	<b>7</b>
<b>1.1 Background of the Study</b> .....	<b>7</b>
<b>1.2 Problem Statement</b> .....	<b>11</b>
<b>1.3 Research Objectives</b> .....	<b>12</b>
<b>1.4 Research Questions</b> .....	<b>13</b>
<b>1.5 Significance of the Study</b> .....	<b>13</b>
<b>1.6 Scope of the Study</b> .....	<b>13</b>
<b>1.7 Structure of the Thesis</b> .....	<b>14</b>
<b>Chapter 2:</b> .....	<b>15</b>
<b>LITERATURE REVIEW</b> .....	<b>15</b>
<b>2.1 Theoretical Review</b> .....	<b>15</b>
<b>2.1.1 Block Chain</b> .....	<b>18</b>
<b>2.1.2 Internet of Things</b> .....	<b>22</b>
<b>2.1.3 Artificial Intelligence</b> .....	<b>26</b>
<b>2.1.4 Big Data Analytics</b> .....	<b>28</b>
<b>2.2 Research Gap</b> .....	<b>32</b>
<b>2.3 Theoretical Framework</b> .....	<b>33</b>
<b>Chapter 3</b> .....	<b>34</b>
<b>METHODOLGY</b> .....	<b>34</b>
<b>3.1 Research Design</b> .....	<b>34</b>
<b>3.3 Data Analysis Technique</b> .....	<b>35</b>
<b>3.4 Questionnaire Measurement Instruments</b> .....	<b>36</b>
<b>3.4.1 Measurement Items</b> .....	<b>36</b>
<b>Chapter 4</b> .....	<b>38</b>
<b>RESULT ANALYSIS</b> .....	<b>38</b>
<b>4.1 Pilot Study</b> .....	<b>38</b>
<b>4.2 Descriptive Statistics</b> .....	<b>39</b>
<b>4.3 Frequency and Percentage Distribution of the Items</b> .....	<b>39</b>
<b>4.3.1 Blockchain (BC)</b> .....	<b>39</b>
<b>4.3.2 Internet of Things (IoT)</b> .....	<b>40</b>
<b>4.3.3 Artificial Intelligence (AI)</b> .....	<b>40</b>

<b>4.3.4 Big Data Analysis (BDA)</b> .....	<b>40</b>
<b>4.3.5 Sustainable Supply Chain Performance (SSCP)</b> .....	<b>41</b>
<b>4.4 Measurement Model</b> .....	<b>41</b>
<b>4.4.1 Indicator Loadings and Indicator Reliability</b> .....	<b>42</b>
<b>4.4.2 Internal Consistency Reliability.</b> .....	<b>43</b>
<b>4.4.3 Convergent Validity (AVE)</b> .....	<b>44</b>
<b>4.4.4 Discriminant Validity (HTMT)</b> .....	<b>45</b>
<b>4.5 Structural Model</b> .....	<b>46</b>
<b>4.5.1 Direct Effect and Path Coefficient</b> .....	<b>46</b>
<b>4.5.2 Model Explanatory Power</b> .....	<b>47</b>
<b>4.5.3 Indirect Effect</b> .....	<b>48</b>
<b>4.5.4 Predictive Relevance (Q<sup>2</sup>)</b> .....	<b>49</b>
<b>Chapter 5</b> .....	<b>50</b>
<b>DISCUSSION &amp; THEORATICAL IMPLICATIONS</b> .....	<b>50</b>
<b>5.1 Discussion</b> .....	<b>50</b>
<b>5.2 Theoretical Implications</b> .....	<b>52</b>
<b>5.3 Limitations of The Study</b> .....	<b>53</b>
<b>5.3 Future Research Recommendations</b> .....	<b>53</b>
<b>5.4 Conclusion</b> .....	<b>54</b>

# Chapter 1

## Introduction

### 1.1 Background of the Study

Nowadays supply chains will become complex global web systems which face numerous challenges brought about by the fluctuations of the business world, environmental issues, technological revolution, and inconsistent compliance requirements. With businesses being taken global, there has been increased decentralization of operations to different regions in order to source materials, manufacture products and distribute them. Although this international growth comes with the advantage that the company will be able to optimize cost, access markets, and gain competitive advantage, it will at the same time increase the susceptibility of its supply-chain to a wide range of risks such as politically generated disturbances, weather disruptions, epidemic outbreaks, market volatility, and overdependence on specific suppliers. As a result, modern supply chains are evaluated not just in terms of efficiency and speed of delivery but also in the ability to maintain resilience, take responsibility and long-term sustainability (Alquraish et al., 2025).

Business organizations of all industries are challenged with increasing demands of maximizing the efficiency of their operations, flexibility and openness of their supply chains in responding to key environmentally responsible requirements related to sustainability of the environment, community, and economy. The main stakeholders- regulatory bodies, consumers, investors, and other interest groups- mount intense pressure on the organizations to embrace responsible behaviors that reduce the negative effects on the environment, embrace a fair labor market, and be economically feasible. In this regard, the concept of sustainable supply-chain performance (SSCP) has been one of the key strategic priorities of organizations struggling to keep up with the competitive, reputational, and stakeholder trust in a constantly changing market (Li et al., 2025).

The concept of sustainable supply-chain performance is multidimensional (that is, it has several dimensions that go beyond traditional operational indices). Environmentally, companies should focus on reducing carbon footprints, establishment of effective waste handling, resource conservancy and reduction of ecological impact. Social responsibilities include maintaining ethical labor practices, protecting the welfare of employees, and developing the community. At the

economic level, the firms should be able to fulfil the sustainability goals and maintain operational efficiency, financial performance and growth opportunities. Such divergent needs are very challenging to handle, especially in industries that have great demands in terms of resource and in industrial operations that are complex (okay et al., 2024)

In order to overcome these complex issues, the concept of implementing digital technologies into the supply-chain processes has emerged as a significant impetus to attaining sustainability goals. The digital transformation has transformed supply-chain management by making data-centric decisions, real-time coordination, and increasing visibility. New technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT) and Blockchain are becoming more actively used to facilitate the operations, increase product traceability, and strengthen collaboration across supply and chain networks (Samuels et al., 2025)

Artificial Intelligence can be singled out because it is one of the most radical digital technologies redefining the supply chain of work today. Through machine-learning algorithms and artificial neural networks AI enables advanced predictive analytics, intelligent forecasting, approval of demand sensing and systems of autonomous decision-making. The AI systems are successful in working with large amounts of structured and unstructured data to identify patterns, identify abnormalities, and come up with actionable insights that can be used to plan proactively and address risk in the supply-chain. As an example, AI can forecast fluctuations in demand accurately, optimize inventory management and suggest efficient production times, thus minimizing waste and maximizing the exploitation of resources. In terms of sustainability, AI-driven optimization can directly produce sustainable supply-chain performance by reducing the amount of energy and emissions, as well as wasting materials (Zaid et al., 2025)

In the same manner, Internet of Things (IoT) is a technology used as the backdoors in augmenting supply-chain visibility and real-time operational monitoring. IoT or Internet of Things Infrastructure consists of a network of sensors, devices and systems that monitor and constantly gain and send information regarding tangible assets, inventory position, the state of transport and the environment of production. This is a real-time information stream that helps organizations track the activities within the supply chain with the best precision and prompt response. The improved visibility can help the firms to minimize spoilage, prevent losses, maintain quality

standards and optimize the logistic processes as well. Following the sustainability perspective, IoT enables the steward control over resources, little fuel use, improved route planning, and other enhancements to environmental monitoring, which contribute to environment-friendly supply-chain activities (Zhang et al., 2024)

One of the fundamental problems that blockchain technology can help with in the supply-chain management is the establishment of trust and transparency among various stakeholders. The bespoke supply chains are often in a difficult position of dealing with the information asymmetry, manipulation of data, and limited traceability, which are obstacles to sustainability practices. Blockchain is an immutable, decentralized registry ensuring transactions and the movement of products across the supply chain are registered in a safe way. This technology enhances transparency, hence enabling the stakeholders to monitor the products origin to consumption, ethical sourcing methods, compliant to environmental regulations, and authenticity of the products. Blockchain can foster accountability, reduce fraud, and create trust between partners in sustainable supply-chain, which is a crucial aspect of the long-term partnership and the development of sustainability objectives (Samuels et al., 2025)

Although there is a transformative potential inherent in artificial intelligence, the Internet of Things, and blockchain technology, it is not always the case that the implementation of the digital technologies results in the improvement of the supply-chain performance or sustainability outcomes. These technologies depend highly on the ability of an organization to manage, process and analyze the huge amounts of data produced by the digital systems. Big Data Analytics (BDA) has therefore in this context become an essential organizational competency needed by firms in order to transform raw data into important insights and strategic value (Zaid et al., 2025)

BDA is a complex set of analytical process, computer devices and data-management procedures that are meant to process massive datasets, complicated and heterogeneous data sets. These datasets are usually obtained through many sources such as sensors, transaction systems, social media systems, enterprise resource planning systems, and external data repositories. Using descriptive, predictive, and prescriptive analytics, companies will be able to gain a deeper understanding of the supply-chain activities, identify the areas of inefficiencies, predict potential trends in the future, and determine sustainability performance. BDA helps in making fact-based

decisions, reducing the role of intuition in making decisions and aiding in making decisions that are constantly improved over the supply-chain processes (Zaid et al., 2025)

It is important to note that BDA acts as a mechanism that connects the digital technology adoption process with the sustainable supply-chain performance. Although artificial intelligence, Internet of things, and blockchain technologies are generating immense amounts of data, BDA helps organizations extract significant value playing out of this data. Without the effective analytics systems, the prospects offered by digital technologies are not used to their fullest extent. In a sustainable supply-chain setting, BDA enables optimum allocation of resources, minimization of environmental footprint, improved evaluation of suppliers, and improved tracking of sustainability metrics. This means that the organizations that invest in digital technologies as well as in analytics ability are at an advantageous position to deliver high-level sustainable outcomes in the field of supply chains (Zaid et al., 2025)

In less developed economies like Pakistan, the incorporation of digital technologies and analytics capabilities into the supply-chain management is at its inception. Although more people nowadays are appreciating the significance of digital transformation, several challenges are hindering its adoption on large scale. They are such limitations as limited technological infrastructure, lack of skilled staff, high levels of implementation and organizational opposition, and incomplete supply-chain networks. Additionally, the body of empirical research on the potential of digital technologies to improve sustainability results with regard to the context of developing countries is scant (Soomoro et al., 2024)

These are some of the implementation challenges, especially in the beverage sector that harbors complex supply chains that are resource-demanding. This industry involves a number of operations all the way to raw material sources- procurement, processing, packaging, distribution and retailing which pose various sustainability challenges. The changing demand dynamics, high quality standards, regulations on safety and heavy utilization of water, energy and packaging materials make sustainability a very significant issue in the industry. Moreover, supply chains of beverages have significant environmental effects due to waste, production of carbon emissions, movements,

and at the same time, an increasing pressure is placed on the supply chains to change their practices towards sustainability (Sanchez & Rubio 2021).

In the context in Pakistan the beverages industry plays a significant role in the economic growth by facilitating the growth of industries, creating employment and satisfying consumers. Nonetheless, the industry is faced with issues of increasing sustainability requirements associated with water, increased energy prices, waste-management needs, and environmental compliance. That being the case, the beverages sector offers a valid environment to explore the relevance of digital technologies and BDA to promote sustainable supply-chain operation. The knowledge of such relations is critical in developing strategies that can promote sustainability goals without compromising the efficiency of operations and competitiveness in the market (Ikram and Ismail 2025)

By conducting an empirical study of artificial intelligence, the Internet of Things, blockchain and BDA in a beverage business in Pakistan, the study aims at contributing to the literature on digital transformation and sustainable supply-chain management. This study seeks to give a theoretical insight on how digital technologies and analytics capabilities have synergistic impact on sustainability outcomes, as well as, offer practical advice on how the same can be applied by managers to conduct technology-driven sustainability efforts in developing economies.

## **1.2 Problem Statement**

Although the current research of digital transformation and sustainable supply chain management has made a substantial progress, a number of gaps remain in the existing literature. To begin with, the available literature of digital technologies and supply chain sustainability is more focused on developed economies with little empirical studies in other developing countries like Pakistan. The institutional environment, technological environment and visions of operations in the developing economies vary significantly in comparison to the developed world, which limits the generalizability of the existing studies (Flores et al., 2020)

Second, the current body of literature is more inclined to study digital technologies separately, the research that is often conducted in the field is usually conducted by refined technologies like AI,

IoT, or Blockchain, instead of examining their joint effect on supply chain sustainability. In practice, several digital technologies are often used simultaneously and in organizations, their interaction may have synergistic effects on a number of performance indicators (Wu et al., 2025)

Thirdly, though Big Data Analytics has been acknowledged as a key enabling tool to prone the digital transformation, the medium surrounding its functions in linking digital technologies to sustainable supply chain performance has not been examined adequately. The need to develop a holistic concept on how BDA transforms the use of digital technology to actualized sustainability outcomes is pivotal in the conceptualization and implementation of both the theorization and practice of the concept (Shatta 2024)

Finally, the lack of empirical studies that focus in particular on the Pakistani beverages industry is quite significant. Given the large economic role of the sector and the urgent sustainability issues, there is an acute necessity of the context-specific research with the practical implications to the industry leaders and policy makers. Considering such research gaps, this paper discusses the interlinkages between Artificial Intelligence, Internet of Things, Blockchain, Big Data analytics, and Sustainable Supply Chain Performance in the beverage industry in Pakistan in an empirical way (Mir & Zafar 2025)

### **1.3 Research Objectives**

The main aim of the current research is to determine the level to which the digital technologies can facilitate improvement of sustainable performance in the supply chain with the help of Big Data Analytics in the case of the beverages industry in Pakistan. The specific objectives are:

1. To examine the impact of the Blockchain-based technology on the Big Data Analytics.
2. To explore the role of the Internet of Things in the Big Data Analytics of the beverages supply chain.
3. To investigate how Artificial Intelligence impacts the Working of Big Data Analytics in the supply chain activities.
4. To evaluate the role of Big Data Analytics when it comes to sustainable supply chain performance.

## **1.4 Research Questions**

The study addresses the following research questions:

1. How does Artificial Intelligence Influence Big Data Analytics in the beverages supply chain?
2. What is the impact of the Internet of Things on Big Data Analytics capabilities?
3. How does Blockchain technology contribute to Big Data Analytics in supply chain management?
4. To what extent does Big Data Analytics enhance Sustainable Supply Chain Performance in the beverages industry of Pakistan?
5. How empirically authenticate a technology-driven context for sustainable supply chain performance in a developing-country environment?

## **1.5 Significance of the Study**

The present research contributes a lot both to theory and practice. Theoretically, the study contributes to the Resource-Based View (RBV) paradigm by placing digital technologies at the center of the strategic resources and by considering Big Data Analytics as a capability that enables the successful exploitation of the available resources. The research is also a contribution to the already growing literature in the area of the digital transformation and sustainable supply-chain management by providing empirical evidence based on the context of developing country.

Practically speaking, the results provide fundamental insights to managers in the beverage industry who would strive to improve on sustainability by using digital programmers. The research paper emphasizes the need to invest in both digital technologies and analytical capabilities so as to be able to make decisions using data. Also, the evidence of these findings can be utilized by policymakers to gain a better understanding of the role that digital infrastructure and analytics capabilities have in sustainable industrial development.

## **1.6 Scope of the Study**

The study is very specific to the drink industry in Pakistan, which includes supply-chain practitioners, taking part in procurement, production, logistics, and distribution business processes.

It takes the quantitative form of research and uses cross-sectional survey sampling method where data will be collected using structured questionnaires. This will be analyzed with respect to a Partial least squares Structural Equation Modelling (PLS-SEM), which is especially appropriate to examine issues of a complex relationship amongst the different constructs and amidst the effects.

## **1.7 Structure of the Thesis**

We offer a thesis of five chapters. Chapter 1 provides the introduction to the study, background, problem statement, objectives and significance. The second chapter due to the account of the thorough literature review, establishes the conceptual framework and constructs the hypotheses. Chapter 3 defines the research methodology. Chapter 4 is the analysis and empirical findings. The last Chapter is the discussion of implications, which analyzes the findings, limitations, and how further research can be conducted in the future.

## Chapter 2

### LITERATURE REVIEW

#### 2.1 Theoretical Review

One of the most powerful and comprehensive models of analyzing the process of organizations adopting and implementing emerging technologies is the Technology-Organization-Environment (TOE) framework (Tornatzky & Fleischer 1990). It assumes that the three dimensions are interrelated and three dimensions of technological adoption include organizational readiness, environmental conditions and technological capabilities. The technological aspect would include the availability of, the level of development, and the expected benefits of emerging technologies including blockchain, artificial intelligence (AI), and the Internet of Things (IoT). The organizational aspect deals with internal influences that determine the successful implementation of technology into business operations that can be introduced as organizational scale, top management support, workforce strengths, and financial readiness. The environmental dimension entails external factors that affect choices of an organization on technology adoption, including competition in the market, regulatory demands, and industry forces as well as industry-specific standards. Thus, the TOE framework has turned out to be a central theoretical basis of supply-chain management (SCM), as it presents the systematic understanding of how organizations uphold digital transformation efforts. It clarifies the complexity of internal and external factors influencing the automation, higher analytics and connectivity solution implementation, especially in the environment of more and more interconnected and data-rich supply chains.

The last several years have also seen the increased application of the TOE framework in the studies, carried out by researchers specializing in the intersection of digitalization and sustainability-related supply-chain initiatives. Evaluating the acceptability of organizational technology is a progression that has seen the adoption of environmental considerations in the digital transformation. Companies are currently using digital technologies not only to achieve efficiency but also to reach the sustainability goal, meet the environmental requirements, and improve the transparency. The use of IoT, blockchain, and big data analytics (BDA) has increased due to environmental pressures, such as the preferences of consumers embracing sustainable products and environmental regulations that are increasingly stricter, as well as global climate

accords. Empirical research indicates that internal technological capabilities and organizational preparedness are two characteristics that enable digital transformation. As an illustration, Duan et al. (2022) found that both organizational and technological competencies contribute greatly to digital technology use by small medium-sized enterprises (SMEs) resulting in better supply-chain financing and operational performance. Their results confirm the idea that the internal preparedness is decisive regardless of the externality or market forces. Rehman Khan et al. (2022) also gained that the introduction of sustainability factors into the TOE model contributes to the better understanding of the drive of organizations towards using advanced technologies. They report that organizational resources and environmental laws have a significant effect on the adoption of digital innovations to enhance the economic and environmental performance, which proves the effectiveness of the TOE framework as a theoretical framework to study the effect of digital technologies on the big data analytics capabilities (BDAC) and, therefore, sustainable supply-chain performance.

TOE framework has been well known in the analysis of large-scale digital changes in modern networks of supply chains as well as its applicability in the sustainability context in studies. TOE model, Triandini et al. (2023) opine that the model provides a systematic approach when it comes to evaluating how organizations are endowed with the requirements of internal operations, application of digital innovation spirits and converting technology to strategic fulfilment of the organization. The findings of their study highlight the concept that external environmental factors such as the changing consumer preferences, the increased competition of the global market, and the necessities of the environmental compliance influence the technology-adoption choices to a great extent. The results show that organizations seldom apply the digital technologies of blockchain, internet of things, or AI singly, but are undertaking comprehensive assessment of the technological possibilities, organizational needs, and environmental demands. Such a wider usage of the TOE framework explains its relevance in examining different avenues of the adoption of multi-technology and consequently developing a sound theoretical context with which the phenomenon of transforming digitally-enabling supply chains can be studied particularly in a setting where the outcomes of sustainability and performance are prioritized.

To supplement the Theory of Organizational Effectiveness, the Resource-Based View (RBV) is another imperative theoretical perspective of thinking digital transformation within the context of

the supply-chain. In formulation by Barney (1991), RBV assumes that organizations are able to attain sustainable competitive advantages through enhancing resources and capabilities that are valuable, rare, inimitable and non-substitutable (VRIN). In digitally-enabled supply chains, IoT, blockchain, and AI technologies, along with the power of big data analytics capabilities (BDAC), act as strategic assets that would enhance the sustainability, performance, coordination, and transparency. According to the RBV framework, competitive advantage comes as a result of development of organizational capabilities, which enable the effective use of advanced technologies and not as a result of being in possession of technology. In this context, BDAC becomes a central mediating capability which can help organizations to achieve better operational and environmental results, enhance predictive decision-making and convert raw data into valuable information.

The last empirical studies also support applicability of the Resource-Based View to the digital supply chain and sustainability research. Al-Khatib and Ramayah (2023) found that better efficiency of supply-chain in terms of fostered innovation, stronger resilience and more accurate decision-making is one of the superior outcomes of BDAC. Their research gives empirical evidence to categorizing BDAC as a VRIN resource that has a direct effect on organizational performance and competitive advantage. In the same manner, Bahrami et al. (2022) depicted that BDAC enables creativity and resilience in supply chains, and the researchers found these two features to be dynamic competencies that allow to deal with uncertainty effectively and attain operational and environmental sustainability. They find that BDAC is essential to the modern organizational competitiveness since it allows companies to build processes, reorganize resources successfully and respond to disruptions. Such findings support the focus of the RBV on internal capabilities as the central processes according to which digital technologies have an impact on the performance of supply chains (SP).

Since the Resource-Based View (RBV) has reached maturity, researchers have started to understand digital capabilities as key strategic capital that have been central in determining modern competition in the supply-chain context. In the current age of digitized and global supply chains, the advancement and reinforcement of non-tools digital capabilities through the application of more sophisticated tools has become a necessity to ensure continued competitive success. Bahrami and Shokouhyar (2022) underline the fact that advanced digital assets have particular benefits,

such as agility, faster innovation cycle, and better sustainability results. This sophistication has been in the form of the developed systems integration, overall analytical skills, and the establishment of data-based organizational cultures. These digital capabilities help organizations to process raw data into actionable strategic information, optimize the use of their resources, reduce waste during their operations and create value to their stakeholders and end-users. RBV: In perspective, the pioneering technologies, such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and Big Data Analytics and Cloud (BDAC), act as sets of strategic resources that supplement organizational competitive strength and propel high and sustainable supply-chain operations.

Both the Technology- Organization- Environment (TOE) and the RBV models form strong theoretical principles on how to comprehend the relations in the research model. Although the TOE concept demystifies the contextual factors behind the adoption of the digital technology, RBV depicts how the digital technologies coupled with organizational capabilities like the BDAC would create enduring competitive and sustainable benefits. In its turn, the production of these frameworks can be offered as an exhaustive prism through which the influence of digital technologies on sustainable supply-chain deliverables within the existing business setting can be explored.

### **2.1.1 Block Chain**

The technology, organization, and environment (TOE) model are used to analyze by Chittipaka et al. (2022) the factors that determine the adoption of blockchain technology in the supply chain operational context. The analysis assesses eleven key variables along organizational, technological and environmental dimension namely; relative advantage, trust, compatibility, security, technological readiness, top management support, firm size, financial resources, competitive pressure, partner pressure, and regulatory support using structural equation modeling (SEM). The information based on 287 supply chain professionals in India indicates that each of the components of TOE framework has statistically significant positive influence on the blockchain implementation decisions. Specifically, the results provide a strong emphasis on the significance of organizational size, competitive market pressures and support of the executive leadership as key factors in the success of technology adoption initiatives. The authors also show that the

implementation of blockchains can strengthen various operations, such as security and control measures when handling data, performance of processes, visibility systems in supply chain, and traceability systems of products, among others, to perform better in terms of organizational performance. However, the study also recognizes several weaknesses such as the restriction of the geographic scope, use of cross-sectional data collection, and the possibility of industry-specific differences that could influence the applicability of findings.

Wang et al. (2023) discuss the role of the blockchain technologies as sustainability during the supply chain in terms of enhanced visibility, traceability, and efficiency of operations in the supply network. The study examines the key attributes of blockchain, such as decentralized ledger and incessant monitor as well as tamper resistant data storage and secure information dissemination to evaluate how these specific characteristics contribute to the goal of environmental, societal, and economic sustainability. The study illustrates that the application of blockchain leads to a high level of performance in the form of reducing operational costs, efficiency and speed in the transmission of data, minimizing the threat of counterfeit products, as well as automated execution of smart-contracts. It is mentioned that the airport industry is one of the most exaggerated examples, where blockchain technology promotes stakeholder teamwork, integrated planning and streamlining of work processes. However, the research also states some obstacles to implementation such as technical system failure, insufficient empirical validation, and deficient implementation frameworks. Future research areas that the authors suggest should include empirical studies on diversified industries and geographical areas, analysis of cultural influences on the use of blockchain, as well as the creation of enduring implementation models to enhance the understanding of the long-lasting effect of blockchain to sustainable outcomes of supply-chain.

Kim and Shin (2019) examine the impact of the three attributes of blockchain such as information transparency, immutability, and smart contract on the supply-chain partnership and the overall performance. Based on resource-based and relationship-view theories, their structural model links blockchain attributes to the expansion and effectiveness of partnership, which in turn, influence the results of operational and financial performance. The study confirms that the permanence of information is the primary factor of long-term partnership development, not short-term performance improvement, whereas blockchain transparency, coupled with smart-contract implementation, is the key to partnership efficacy and growth, which is confirmed by voluminous

survey data by professionals in the supply chain industry. The results indicate that overweight on the efficiency may have a negative effect on performance by reducing its capability to be flexible and prompt in decision-making, but the growth of partnership has a positive effect on financial and operational outcome. These observations indicate that the quality of blockchain is not limited to the lower cost to build and develop relationship, gain trust, and improve collaboration among supply-chain participants. The authors also note that they have limitations in terms of cross-sectional information and focus on a specific context and suggest future research opportunities such as cross-industrial and country-specific blockchain adoption studies, analysis of longitudinal impact of blockchain on partnership development, and involvement of sustainability and resilience analyses to comprehend further the strategic relevance of blockchain in supply-chain management.

Jum'a (2022) examines the interplay between BTA and supply chain performance (SCP) in the Jordan manufacturing industry and the Arabian context and uses supply chain innovation capabilities (SCIC) and competitive performance (CP) as mediators. The paper is based on the dynamic capabilities theory and derives a structural model that is based on the relationship between BTA and SCIC, CP, and SCP. Review of 284 survey findings based on PLS-SEM shows that blockchain deployment in place of SCP has a great impact on reducing costs, improving operations as well as customer satisfaction. The partial mediation of SCIC and CP is validated and indicates that the organizations meet the benefit of blockchain by enhancing innovative practices and competitive advantages. Although the study contributes to the body of literature as it presents considerable empirical evidence, there are also limitations, including the use of non-probability sampling methods and the focus on a single country, which further studies are recommended to address this issue by using larger random samples, cross-nezne, and understanding of more mediating and moderating factors that can enlarge the knowledge base on blockchain effects on supply chains.

By incorporating operational outcomes with the organizational and relational factors, Kim et al. (2024) focus on the relationship between digital transformation of supply-chain partners and business performance. The study will seek to elaborate on the effects of digital transformation on performance and even investigate the mechanisms and time-based aspects of how this force is affected. The conceptual model is that inter-organizational exchange of information is an important mediating variable between the digital transformation efforts and the time-related

performance results. As the antecedents to the success of digital transformation, the study lists developmental corporate culture and B2B trust. The results of the analysis of 222 manufacturing organizations show that data sharing is a partial mediator of the positive impact of digital transformation on performance both with direct and indirect directions. One important observation is that digital transformation enhances the level of information exchange in even low-trust situations significantly, which allows assuming its ability to substitute the conventional relational governance systems. Although it includes valuable insights, the authors provide a number of directions that a future research should take, including the consideration of environmental and social sustainability metrics, running of longitudinal research to identify dynamic influences and testing their findings in other national backgrounds, to gain better insights on the strategic role of digital transformation in the construction of resilient and sustainable supply chains.

The Wanger et al. (2023) paper creates a holistic framework that can foster the holistic sustainability management of supply-chain operations. Their SSCM -IRIS model combines the sustainability balanced scorecard and Big Data analytics to assess current and future sustainability implications. The framework consists of six interrelated dimensions including methodology, organization, stakeholders, maturity model, human resources and technology and integrates qualitative and quantitative methods of evaluation to allow managers to align sustainability goals to operational strategies and improvement programs. The framework can be empirically validated through the evaluation of experts and the analysis of a specific case study with the aim of confirming that the new framework can increase levels of transparency, ease predictive decision-making and provide quantifiable improvements in the environmental, economic, and social performance indicators. Results indicate that incorporation of analytics of Big Data into a systematic sustainability model facilitates proactive sustainability governance to supersede the conventional reactive assessment. When the limitations of data availability and contextual applicability are taken into consideration, the study suggests that the implementation of the framework should be tested in different industries and geographical locations, involves more sophisticated AI techniques, and performs longitudinal studies that address the development of sustainability performance.

Eckstein et al. (2014) analyze the conditional influences of an item complexity whilst empirically differentiating the performance implications of supply-network agility and supply-chain

adaptability. Based on the dynamic capabilities view and contingency theory, the presented conceptual framework is connected to agility and adaptability in relation to cost and operational performance indicators and provides product complexity as a moderating factor and positioning supply-chain agility as an intermediary. Hierarchical regression analysis of the survey study involving 143 manufacturing and logistics organization in Germany states that supply-chain agility and flexibility have a positive impact on the cost and operational performance measures. The paper also confirms that supply-chain agility plays an intermediate role in the connection between performance and adaptability, implying that agile operation responses are the most promising agent that transforms adaptive structural changes into overall better performance results. Empirical measurements indicate too that, although agility is good across all levels of complexity, there is evidence that as the complexity of the product increases, the implication of supply-chain adaptability on performance also increases proportionally. Limitations like regional focus and cross-sectional study, the authors admit that further studies are necessary to advance the concept of capacity-performance relations, to apply the model in different industrial domains and different geographic restrictions, to introduce longitudinal study to track the capability formation, and to investigate other contextual influences including supply-chain alignment and environmental uncertainty.

**H 1:** Blockchain (BC) positively impacts and significantly influences the Big Data Analytics (BDA).

### **2.1.2 Internet of Things**

Shatta (2024) explores how the emerging digital technologies can transform to promote sustainable supply-chain performance (SSCP) in governmental procurement organizations with particular reference to IoT, blockchain technology, and the big data analysis (BDA). The theoretical framework in the research is constructed through the synthesis of the theoretical approaches of Innovation Theory by Schumpeter, the RBV, and the TOE approaches and regulatory structures are considered moderating variables that affect the effectiveness of technology, with BDA as a key mediating ability. Relying on the empirical study, the proposals by using PLS-SEM, the findings indicate that the implementations of IoT, blockchain, and BDA have a strong impact on strengthening SSCP, BDA is the strongest of mediating factors in the transformation of

technological capabilities into tangible sustainable performance. Moreover, regulatory models have positive moderating influence, which means that the effective regulatory frameworks promote the ability of digital innovations to promote transparency, efficiency, and sustainability in the supply networks of the public sector. The study admits the limitations, especially the fact that it focuses on one country and a limited set of technological applications, which makes it necessary to recommend a research variant in the future to include a greater number of technological applications, such as artificial intelligence, robotics, and predictive analytics, and use a variety of research methods in various industries and under various geographical conditions to enhance the reliability of generalization of results.

Tum et al. (2021) examine the transformational changes in the supply chain management and the logistics performance of the LEED-certified ready-made garment (RMG) sector in Bangladesh. Dwelling upon the inventory management, production planning, and transportation management, the study recognizes the technological integration as a necessity to operational excellence. A conceptual framework between the use of technology and sustainability, supply-chain operation and efficiency and practices that are ethical is placed across the operations of the supply-chain and qualitative data on thematic assessment of semi-structured interviews with senior RMG supply-chain managers is used with the qualitative method. The discussion shows that modern technologies RFID systems, automated solutions, IoT-capable devices, AI elements, GPS tracking, and blockchain applications can have a tremendous positive impact on real-time visibility, lead times, resource allocation, and coordination. Further, ethical sourcing and sustainability are facilitated through technology adoption through providing data-driven decision making, creating transparent information flow, creating extensive material traceability, and promoting environmentally friendly practices. The paper highlights the fact that to maximise the latter, strategic alignment, strong infrastructure, and human skills are necessary, and provides important information on how the transformations occurring in the manufacturing environment in developing economies caused by technological progress can contribute to making it more sustainable and productive.

Chowdhury and Quaddus (2020) build an extensive sustainability model of supply-chain, and empirically test its performance impact by dynamic capabilities perspective. Their conceptual model views supply-chain sustainability as a more advanced construct that incorporates a social,

environmental, and dual-economic aspect, and the sustainability risk is a mediator, and sustainability governance is a regulatory tool. Using data in the garment sector, in one of the developing countries, to run partial least squares structural equation modeling, they establish that sustainability-oriented policies have significant positive impacts on the market performance through both a direct and an indirect mechanism by eliminating a risk associated with sustainability. Noteworthy, well-developed sustainability governance mechanisms enhance the indirect impact of sustainability practices on performance, which highlights the critical role of governance in creating measurable results out of initiatives. The research proposes cross-industry validation, longitudinal investigation to monitor the development of dynamic capabilities, and the use of more extensive environmental and social measures as additional future research directions.

By incorporating operational outcomes with the organizational and relational factors, Kim et al. (2024) focus on the relationship between digital transformation of supply-chain partners and business performance. The study will seek to elaborate on the effects of digital transformation on performance and even investigate the mechanisms and time-based aspects of how this force is affected. The conceptual model is that inter-organizational exchange of information is an important mediating variable between the digital transformation efforts and the time-related performance results. As the antecedents to the success of digital transformation, the study lists developmental corporate culture and B2B trust. The results of the analysis of 222 manufacturing organizations show that data sharing is a partial mediator of the positive impact of digital transformation on performance both with direct and indirect directions. One important observation is that digital transformation enhances the level of information exchange in even low-trust situations significantly, which allows assuming its ability to substitute the conventional relational governance systems. Although it includes valuable insights, the authors provide a number of directions that a future research should take, including the consideration of environmental and social sustainability metrics, running of longitudinal research to identify dynamic influences and testing their findings in other national backgrounds, to gain better insights on the strategic role of digital transformation in the construction of resilient and sustainable supply chains.

Chalmeta and Munoz (2021) present a comprehensive framework that includes the organizational, environmental and technological perspective to help fill the knowledge gap on how digital supply chains can stimulate transitions to the circular economy. Their model also conceptualizes the

implementation of digital supply-chain as a system with the boundary problems as related to lack of digital competency, huge requirement of investments, lack of adequate regulatory frameworks, and lack of strategic planning. The framework highlights the solution to these implementation impediments as the use of circular economy-oriented strategies. The paper uses a mixed methodology where modified total interpretative structural modelling is used to work out hierarchical relationships of mitigation strategies, and fuzzy best- worst method is used to rank the barriers to adoption. Digital skills and resource scarcity are the main challenge of the problem, which is identified with the help of the empirical analysis, and the second issue is information security concerns and strategic misalignment. The study provides evidence that in the context of a circular economy, infrastructure creation, regulatory assistance, and governmental financing are considered to be the core enablers of a successful digitalization of the supply-chain. Strategies of a higher order, such as resource circularity, engagement with stakeholders, and collaboration across functional sectors, can, however, be successful only when the low-level planning has been completed. The paper pinpoints the following areas where future research can be performed, which are; longitudinal analysis of the sustainability effects of digital supply-chain adoption, incorporating quantitative measures of performance, and empirical qualification across, multiple industries and geographical settings.

Varriale (2021) discusses the joint application of blockchain, IoT, and RFID technologies to promote the sustainability of the supply chain and its order management efficiency. This study analyses the three main participants in the supply-chain; the producers, the carriers, and its retailers by simulating the three to highlight the difference between the traditional as-is conditions against digitally transformed to-be conditions in optimal and disrupted order management. The findings reveal a high level of improvement in the scenario with technology enhancement, saving about 72 minutes/order and disruption response rates increased about 3.2 percent. The analysis further indicates a significant cut in the order-processing time, improved real-time tracking of orders, and better management disruption of orders. By encouraging transparency and automating smart-contracts, these digital technologies are also applicable to the sustainability of operations, environment, and social responsibility. Nevertheless, limitations of the research include the lack of cost-benefit analysis, single focus on supply-chain, and limited simulation distances. The future research proposed by the authors includes the cost of implementation measurement, the analysis

of multiple stakeholders and international contexts, the optimization strategy building, and the impact on the environment measurement, especially the carbon-emission tracking.

**H2:** Internet of Things (IoT) has positive and significant impact on the Big Data Analytics, (BDA).

### **2.1.3 Artificial Intelligence**

Belhadi et. al (2021) performed quantitative studies to study the direct and indirect impacts of AI on the supply-chain performance based on their theoretical framework that is the Organizational Information Processing Theory (OIPT). OIPT considers artificial intelligence as a mechanism of information processing that can help firms to process complex data and adapt to environmental changes. The research is based on the structural equation modelling (SEM) and the survey data of 279 organizations that examines interactions between AI capabilities, adaptive capabilities (AC), supply-chain collaboration (SCC), supply-chain resilience (SCR), and supply-chain performance (SCP) through the lenses of the moderator of supply-chain dynamism (SCD). The findings indicate that AI has a major impact on SCP directly and indirectly because it has a robust positive effect on AC and SCC, which, in turn, boost SCR; and SCP increases the effects of AI in decision-making, which implies that dynamic environments can intensify the advantages of decisions supported by AI. The present research finds that AI technologies should be planned to create resilience and lasting performance, and in the further studies, longitudinal methods should be used, interactions in the service industry should be investigated, and the effect of AI-sustained innovation on the established supply-chain practice should be examined.

Danach et al. (2024) suggest that it will be possible to use AI-oriented framework as a universal model to deal with the modern-day supply-chain pain points, including demand prediction, inventory management, logistic optimization, and quality control measures. Their model incorporates the key AI elements such as enhanced analytics, predictive modelling, and automated process management showing how these technological solutions streamline processes and operational decision-making throughout supply chains. There is empirical validation of machine learning implementations, mostly of types used in Gradient Boosting, demonstrating very high improvement in inspection procedures, reduction of product defects, and improvement of supply-chain through systematic analysis of key parameters, including, but not limited to: production prices, manufacturing volumes, and delivery schedules. The study highlights the paradigm shift

brought about by AI in terms of better operational excellence, more resilient supply chains, and sustainable operations as well as outlines the potential future research areas aimed at improving AI capacity with managing global supply complexities, creating more unified solutions that will integrate AI with blockchain and IoT systems, and moving towards the autonomous, sustainable supply networks that are capable of meeting updated market demands.

Rashid (2023) developed insights into how integrated big data analytics and artificial intelligence (BDA-AI) affect sustainable performance (SP) based on the green supply-chain collaboration (GSCC), sustainable manufacturing (SM) and environmental process integration (EPI). The adoption of the Dynamic Capability Theory and Organizational Information Processing Theory, the study elaborates a structural model that is confirmed through the use of PLSSEM analysis of 249 respondents. Findings have shown that even though BDA-AI is positively affecting GSCC, SM, and EPI, only GSCC has been found to have significant positive impacts on SP and is the prime mediator between BDA-AI and SP. This is to imply that even with the latest technological development in the areas of integration, the main source of sustainable results is green-collaborative practices. The paper identifies weaknesses when it comes to the scope of the industry and the distinction between BDA-AI, proposing future studies to broaden the sampling framework, assess more variables, and consider the views of the circular economy and resilience.

The Wanger et al. (2023) paper creates a holistic framework that can foster the holistic sustainability management of supply-chain operations. Their SSCM -IRIS model combines the sustainability balanced scorecard and Big Data analytics to assess current and future sustainability implications. The framework consists of six interrelated dimensions including methodology, organization, stakeholders, maturity model, human resources and technology and integrates qualitative and quantitative methods of evaluation to allow managers to align sustainability goals to operational strategies and improvement programs. The framework can be empirically validated through the evaluation of experts and the analysis of a specific case study with the aim of confirming that the new framework can increase levels of transparency, ease predictive decision-making and provide quantifiable improvements in the environmental, economic, and social performance indicators. Results indicate that incorporation of analytics of Big Data into a systematic sustainability model facilitates proactive sustainability governance to supersede the conventional reactive assessment. When the limitations of data availability and contextual

applicability are taken into consideration, the study suggests that the implementation of the framework should be tested in different industries and geographical locations, involves more sophisticated AI techniques, and performs longitudinal studies that address the development of sustainability performance.

**H3:** Artificial Intelligence (AI) produces the positive and significant effect on the Big Data Analytics (BDA).

### **2.1.4 Big Data Analytics**

Al -Khatib (2022) explains the connection between data analytics capabilities (DAC) and environmental supply chain outcomes (ESCO), discussing how these capabilities can support environmentally aware decision making and operational optimization. The research uses a moderated-mediation model in which the environmental innovation is used as the mediating variable and technology adoption levels are viewed as the moderating one. As it was reported in the current literature, DAC helps organizations to detect the environmental risk, minimize waste, improve ecological responsiveness, and promote the knowledge-based environmental innovation activities. The positive impact of DAC is proved by the findings of their research, with environmental innovation provided by it having a direct impact on the better results in the ESCO. In addition, the rates of technological use reinforce these associations meaning that organizations that have superior technology infrastructure attain high environmental performance. The results of this study are consistent with the Natural Resource-Based View (NRBV) theory, which focuses on the competitive advantages based on environmental competencies. The future research areas would be to apply time-series or hybrid techniques, study of different industries and areas and study of other variables like environmental corporate culture, risk measurement and transfer of sustainability knowledge to gain more insights into eco-friendly supply-chain management.

The article by Gallo et al. (2023) considers the effect of Big Data Analytics -Artificial Intelligence (BDA-AI) on the environmental performance of the manufacturing industry both directly and indirectly. They base their proposal on the Organizational Information Processing Theory, that top-management commitment serves as a moderator, and green supply-chain collaboration is a mediator. They reveal that BDA-AI has the substantial contribution to improving environmental performance and green supply-chain collaboration, in accordance with survey information

gathered on 402 manufacturing enterprises in Turkey, which have provided answers with SPSS and the PROCESS macro. Additionally, the connection between BDA -AI and environmental performance is mainly moderated by green supply -chain collaboration, which means that inter -organizational collaboration is the main source of the relationship between digital analytical capabilities and sustainability achievements. The research also shows decreasing impacts of managerial commitment as down the ranks in which higher levels of managerial commitment enhances the positive impact of BDA-AI to collaboration and performance. The authors recognize the cross-sectional study design and the single country as shortcomings and suggest longitudinal studies in the future, model testing within various industrial and national settings, and the use of other contextual moderators including stakeholder pressure and regulatory intensity.

Acciarini et al. (2023) examine the constraints of fragmented sustainability systems and introduce an integrative approach that introduces a systematic way of integrating the functions of Big Data into supply-chain sustainability management. Their model of framework, SSCM-IRIS, takes the holistic approach consisting of six interconnected elements, which include methodology, organization, stakeholders, maturity model, human resources and technology, thus it is intended to be used in guiding sustainability initiatives across the supply-chain lifecycle. The methodology incorporates both qualitative and quantitative methods of evaluation, such as sustainability balanced scorecards and Big Data analytics to analyze the present performance metrics and the impact of the project on the sustainability in the future. The validity of the framework, which is achieved with the help of expert assessment and a case study carried out in real life, proves that the framework is able to improve decision-making, increase the levels of transparency and achieve the measurable results in terms of environmental, economic, and social performance indicators. The authors conclude that supply chains may become not reactive but dynamic and proactive in terms of their management and optimize the use of Big Data to stabilize not only its effectiveness but also the range of outcomes achieved in different supply-chain environments; however, they point out that further research, such as longitudinal performance research, cross-sector validation, and in-depth integration of advanced AI techniques are all avenues;

Qadir (2021) discusses the Big Data Predictive Analytics (BDPA) as a vital enabler of improved supply-chain and organizational performance especially in the emerging Asian economies. Extrapolating on the Resource-Based View, the past studies also theorize the concept of BDPA

not as an element of technology per se but a strategic resource that enhances the information processing capability, strategizing, and responsiveness of organizations. The proposed models can investigate whether BDPA adoption has an impact on the Supplies-Chain Performance (SCP) and Organizational Performance (OP) besides examining the mediating effect of SCP. With these notions, studies show that post adoption assimilation and capability building are the least considered ideas resulting in the unrestrained use of BDPA in most of the developing economies. The authors suggest that the future research should put more emphasis on the longitudinal analysis of BDPA integration, research on situational factors such as organizational readiness and leadership commitment, and application of frameworks in other businesses and in different countries to improve theoretical and practical content.

Bahrami (2021) investigates the connection between supply-chain performance (SCP) and big data analytics (BDA) capabilities, with mediating effects of supply-chain resilience (SCR) and supply-chain innovation (SCI) offered. The study constructs an elaborate structural model by the framework of Dynamic Capability View (DCV) and refers to PLSSEM to analyses survey data including 187 Iranian companies to explore their direct and mediation correlations. The results show that BDA abilities considerably improve SCR and SCI that in turn contribute to significant changes in SCP. The research however indicates that BDA capabilities do not have a direct effect on SCP, thus, acting solely via the resilience and innovation channels. Fine mediation corroborates that SCR wholly mediates and SCI partly mediates the correlation between BDA capabilities and performance and thus organizations need to adjust to disruption and institute new process to achieve the benefit of their BDA investments. In the quest to enhance generalizability, the authors note that one possible way forward is to consider the longitudinal research design, multi-respondent method in organizations, investigation on other moderating variables and cultural consideration and validation of the model across different geographic and industrial settings. The paper recognizes the shortcomings including the use of cross-sectional data, biases related to individual respondents, and situational factors in a specific country.

By incorporating operational outcomes with the organizational and relational factors, Kim et al. (2024) focus on the relationship between digital transformation of supply-chain partners and business performance. The study will seek to elaborate on the effects of digital transformation on performance and even investigate the mechanisms and time-based aspects of how this force is

affected. The conceptual model is that inter-organizational exchange of information is an important mediating variable between the digital transformation efforts and the time-related performance results. As the antecedents to the success of digital transformation, the study lists developmental corporate culture and B2B trust. The results of the analysis of 222 manufacturing organizations show that data sharing is a partial mediator of the positive impact of digital transformation on performance both with direct and indirect directions. One important observation is that digital transformation enhances the level of information exchange in even low-trust situations significantly, which allows assuming its ability to substitute the conventional relational governance systems. Although it includes valuable insights, the authors provide a number of directions that a future research should take, including the consideration of environmental and social sustainability metrics, running of longitudinal research to identify dynamic influences and testing their findings in other national backgrounds, to gain better insights on the strategic role of digital transformation in the construction of resilient and sustainable supply chains.

Investigating the impact of the BDA-AI capabilities on the environment, Mustaffa et al. (2023) consider the power of green supply-chain partnerships and focus on the top-management commitment as the key factor. Their study suggests a moderated mediation model, guided by organizational information processing theory, with BDAMin AI being the core information processing capacity leading to environmental performance in both direct and indirect way conferred by green supply chain alliance. The conceptual assumption of the study is that top-management commitment is a moderating factor according to which these relationships occur, and collaborative supply-chain practices is the mediating-variable. A survey analysis of 402 industrial organizations operating in Turkey, run on SPSS and using the PROCESS macro, indicates that BDA-AI enhances significantly the environment performance and collaboration in the supply chain. Results indicate the importance of inter-organizational alliances in transforming digital capabilities into long-term outputs, which proves the moderating role of green supply-chain alliance between BDA-AI application and environmental performance. Moreover, the study also shows that the moderating effect of BDA-AI on collaboration and environmental performance is stronger in the presence of top-management commitment with stronger effects being experienced at high levels of commitment. Although the authors acknowledge that the study is cross-sectional and only covers one country, they suggest that further research to improve the generalizability of

the study should be conducted longitudinally, address more moderators (including influence of stakeholders), and stress the relevance of the model in various industrial and national settings.

**H4:** Big Data analytics (BDA) positively and significantly impacts Sustainable Supply chain Performance (SSCP).

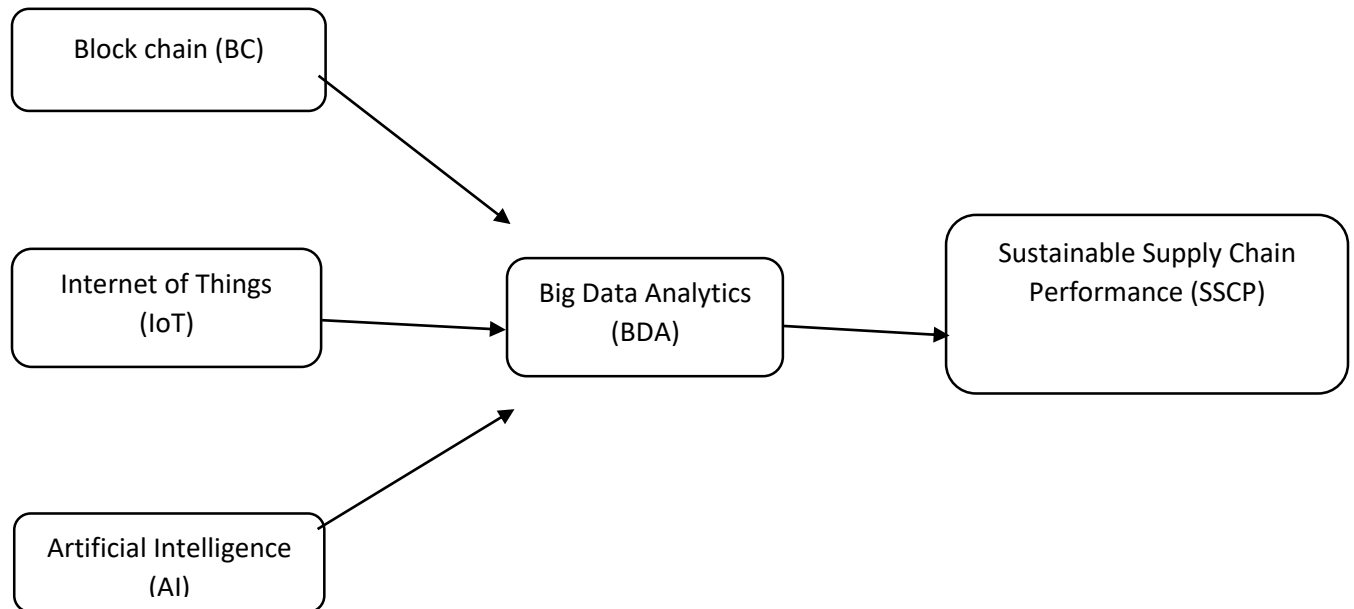
## 2.2 Research Gap

The current amount of the literature on digital technologies and sustainable supply chain management is still growing; however, there is still a vast amount of research gaps in the literature, especially the ones related to developing countries. The current literature is relatively vast and focuses on individual digital technologies, e.g., Artificial Intelligence, Blockchain, or the Internet of Things, and does not consider the synergistic impact of these changes on sustainable supply chain results. Such a limited scope prevents in-depth understanding of the mechanisms by which various digital technologies together demonstrating the improvement of sustainability performance. Besides, the mechanisms that connect digital technologies to sustainability enhancements are not well-defined despite the fact that the literature recognizes the importance of data-informed decision-making. The mediatory role of the Big Data Analytics, in its turn, does not possess a strong empirical support, at least, in the framework of the supply chain operations. Much empirical research often takes that there are a direct causal association between the adoption of technology and performance outcomes thus impeding the diffusion of the role played by analytical capabilities in transforming raw information into actionable lessons which support the process of environmental, societal, and economic development.

Moreover, most of the empirical studies have focused on developed economies with developed digital infrastructure and technological support. Therefore, there is a significant body of research gap when it comes to the emerging markets like Pakistan in which supply chains are faced with unique operational pressures, limited resources, and varying institutional systems. In this respect, the beverages industry is one sector that has been least studied considering its sophisticated, high data, and widely critical supply chain operations. The current study aims to fill in these gaps by studying how Blockchain, IoT, and Artificial Intelligence can produce a collective effect on the sustainable supply chain performance, with a particular emphasis on the role of Big Data Analytics as one of the bridge mechanisms, in the beverage industry of Pakistan. In this manner, the research

would add region-specific information and develop an improved theoretical swift of how digital transformation can contribute to developing economies towards achieving sustainability.

### 2.3 Theoretical Framework



**Figure 1: Theoretical Model**

## Chapter 3

### METHODOLOGY

The main aim of the study is to test the hypothesis of how emergent digital technologies, the Internet of Things (IoT) and blockchain and their impact on Sustainable Supply Chain Performance with the help of big data analytics (BDA) acting as the intervening variables in the beverage industry of Pakistan. The current research will be a quantitative research design that is explanatory and uses an approach where surveys are conducted across a defined period. The choice of this methodology has helped generate actionable information by the respective supply-chain managers and therefore add value to the body of literature. The information that will be used to carry out the study is received under the qualitative procedures which entail supply-chain professionals and departmental staffs in the beverage industry of Pakistan. This chapter is divided into six major sections namely: 3.1 Conceptual Framework; 3.2 Research Design; 3.3 Research Hypothesis Development; 3.4 Data Collection and Sampling Techniques; 3.5 Data Analysis Techniques; and 3.6 Measurement Instruments.

#### **3.1 Research Design**

The general aim of the research is to examine the effect of the digital technologies on the Sustainable Supply Chain Performance (SSCP), in the case of the beverage industry in Pakistan, in relation to the mediating variable of the Big Data Analytics (BDA). The research design used in the study is the explanatory research design that uses a qualitative approach, which is well-suited in testing the hypothesized relationships between the variables using statistical analysis.

The study employs the cross-sectional survey design to gather first-hand information using the survey of professionals in the beverage industry supply chain. The qualitative approach allows objective quantification of relations and helps to test the hypothesis through Partial Least Squares Structural Equation Modelling (PLS-SEM).

#### **3.2 Data Gathering and Sample Method.**

The sampling procedure is suitable to the diverse phases and strategic sampling techniques of the beverage industry sector of Pakistan. The research primarily used online surveys as a method of

data collection, where Google Forms was used as the main platform of data-collection as a way of increasing efficiency and accessibility. The target audience included supply-chain players and employees working in the beverage companies supply-chain departments in the country. Radiofrequency distribution was done in several online platforms, such as e-mail, WhatsApp, LinkedIn, and Facebook.

Based on the sample-size determination procedures by Krejcie and Morgan (1970), 217 respondents were chosen out of the approximated of 500 people, and the 95 per cent of certainty with a 5 per cent of error. The data collected were subjected to a tight scrutiny in order to detect possible errors and also to establish whether temporal segmentation was justified according to the periods of the collection.

The sample size of 217 respondents agrees with the suggestion proposed by Hair et al. (2020), which confirms the sufficiency of the sample to use in the structural equation modelling. The structural equation modelling (SEM) was used by the partial least square's method. The main intent of PLS-SEM as evident by Vinzi et al. (2010) is to assess interrelations among research constructs; the second-generation multivariate analysis methodology allows managing the relationship between the constructs without any distributional assumption.

### **3.3 Data Analysis Technique**

In its current form, the current study used Partial Least Squares Structural Equation Modeling (PLS-SEM) as the method of data analysis, which is broadly accepted as a method of data analysis in the field of supply-chain and information-systems studies. PLS-SEM was chosen due to its high ability to fulfill the predictive research goals, complex theoretical constructs, and data sets that might fail to follow the luster multivariate normality requirements. Furthermore, PLS-SEM has been especially beneficial in terms of replication of the researches with small sample sizes, which offer credible and strong estimations when traditional covariance-based SEM models fail. PLS-SEM is suitable when the researcher wants to develop a theory and make predictions but not confirm the theory, and this recommendation by Hair et al. (2020) fits well within the objectives of the research.

The method of analysis followed a two-step procedure as it is presented in the PLS-SEM literature. The first phase was a strict evaluation of the measurement model to check the construct reliability and validity. This analysis included the evaluation of indicator reliability using outer loadings, internal consistency reliability using Cronbachs alpha, composite reliability, alphas of the rho A and convergent validity using the Average Variance Extracted (AVE) and the discriminant one using the Heterotrait Mono Trait (HTMT) ratio.

The second stage involved analysis of the structural model testing the construct hypothesized relationship. This test involved correlation of path coefficients, determination coefficient (R<sup>2</sup>) to determine the explanatory power, effect size (f<sup>2</sup>), to determine the impact of exogenous constructs, and predictive relevance (Q<sup>2</sup>). Furthermore, **bootstrapping**, a non-parametric resampling technique, was utilized to test both direct and indirect effects, including mediation analysis. This method enhances hypothesis testing robustness by generating confidence intervals without depending on distributional assumptions.

### 3.4 Questionnaire Measurement Instruments

The questionnaire instrument measured the respondent views regarding the research constructs. The indicators measure using 5-point Likert scale (1= strongly disagree, 2=disagree, 3= neutral, 4=agree, 5= disagree). This particular employ due to its nuance, easy use and suitability for quantitative analysis. This research utilized 18 measurement items: 5 for supply chain sustainability performance, 4 for big data analytics, 4 for internet of things 3 for artificial intelligence and 4 for block chain. These factors relate to sustainable supply chain performance.

#### 3.4.1 Measurement Items

Table 1:

Construct	Items Code	Items	References
Internet of Things	IoT <sub>1</sub>	Internet speed and bandwidth	<i>Kumar et al. (2024)</i>
	IoT <sub>2</sub>	Low-cost sensors	
	IoT <sub>3</sub>	Integration Capabilities	
	IoT <sub>4</sub>	Assentation of Privacy	
Block Chain	BC <sub>1</sub>	Transection cost of supply chain operations will be reduced by using supply chain.	<i>Juma's.(2023)</i>

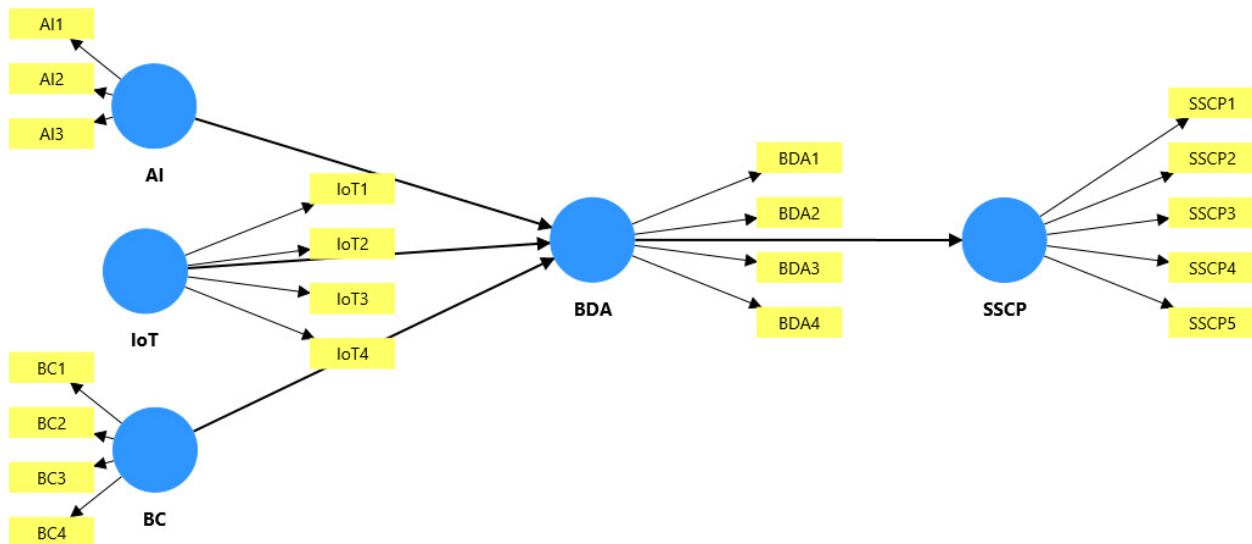
Artificial Intelligence	BC <sub>2</sub>	Level of services provide to the customers will be improved by using block chain.	<i>Rashid, Rasheed &amp; Ngah. (2024)</i>
	BC <sub>3</sub>	Speed of supply chain operations will be improved by using block chain.	
	BC <sub>4</sub>	Value creation in the supply chain will be improved using block chain.	
	AI <sub>1</sub>	Recycling options has increased by leveraging BDA-AI.	
	AI <sub>2</sub>	Experts lead the BDA-AI projects and everyone	
	AI <sub>3</sub>	follows the timelines strictly. BDA-AI project goals and are reviewed regularly based on the dynamics business environment.	
Big Data Analytics	BDA <sub>1</sub>	We have excellent expertise to process structural data	<i>Shamim et al. (2020)</i>
	BDA <sub>2</sub>	Our analytics personnel (i.e., team) actively get insights from unstructured data	
	BDA <sub>3</sub>	We effectively use real-time information for day-to-day operations	
	BDA <sub>4</sub>	The programming skills of our personnel greatly helps us to get analytical insights from the large datasets produced from smart-devices	
Sustainable supply chain Performance	SSCP <sub>1</sub>	The firm provides on-time delivery	<i>AL-KHATIB &amp; Ramayah. (2022)</i>
	SSCP <sub>2</sub>	The firm focuses on reducing waste in operational processes within the SC	
	SSCP <sub>3</sub>	The firm makes efforts to reduce transportation costs	
	SSCP <sub>4</sub>	The firm's SC can deliver flawless products to end customers	
	SSCP <sub>5</sub>	The firm can reduce inventory throughout the SC	

## Chapter 4

### RESULT ANALYSIS

#### 4.1 Pilot Study

While during the thesis analysis, using Smart PLS 4, items were cautiously reviewed to make sure the reliability and validity of the items are according to the limits. The elimination process was followed according to the guidelines of Hair et.al., (2020). The outer loadings, composite reliability (CR) and average extracted variance (AVE) were not up to the mark. These items were removed because the outer loading was below 0.060. This process improved the composite reliability (CR) and average variance extracted (AVE). Following the criteria IoT eliminate from the study because of its lean input and low outer loading. BC4 was also excluded for the reason that negligible effect was observed and correlation with other block chain indicators. BDA4 was also removed as it overlapped with the other BDA indicators and after removing the BDA4 marginal enhancement in AVE. SSCP 4, and SSCP 5evince negative outer loading and hence removed to make the results more reliable and valid.



*Figure 2: Conceptual Model*

## 4.2 Descriptive Statistics

*Table 2*

Constructs	Mean	Standard Deviation	Minimum	Maximum
BC	3.78	0.69	1.00	5.00
IoT	3.74	0.71	1.00	5.00
AI	3.81	0.67	1.00	5.00
BDA	3.89	0.65	1.00	5.00
SSCP	3.92	0.63	1.00	5.00

The descriptive Statistics indicates that the mean value shows the variable effect toward the Block chain, AI, IoT, Big Data Analytics and Sustainable Supply Chain performance and standard deviation shows the consistent response with a limited variability. The maximum value of all the variables are 5 and the minimum value of all the variables are 1.

## 4.3 Frequency and Percentage Distribution of the Items

### 4.3.1 Blockchain (BC)

*Table 3*

Response Category	Frequency	Percentage %
Strongly Disagree	9	4.1
Disagree	18	8.3
Neutral	42	19.4
Agree	86	39.6
Strongly Agree	62	28.6

Block chain results shows the mostly positive response toward the Block chain, a majority of the respondent agreed or strongly disagree. Only a small portion show the disagreement highlight the acceptance of block chain in the industry.

### 4.3.2 Internet of Things (IoT)

Table 4

Response Category	Frequency	Percentage %
Strongly Disagree	11	5.1
Disagree	20	9.2
Neutral	46	21.2
Agree	78	35.9
Strongly Agree	62	28.6

The majority of respondents agreed or strongly disagreed with the IoT, according to the results, and there was minimal opposition to its use.

### 4.3.3 Artificial Intelligence (AI)

Table 5

Response Category	Frequency	Percentage %
Strongly Disagree	8	3.7
Disagree	16	7.4
Neutral	39	18.0
Agree	90	41.5
Strongly Agree	64	29.5

AI results indicates a robust validation toward the AI practice and minor shows the norm of AI

### 4.3.4 Big Data Analysis (BDA)

Table 6

Response Category	Frequency	Percentage %
Strongly Disagree	7	3.2
Disagree	14	6.5
Neutral	36	16.6

Agree	92	42.4
Strongly Agree	68	31.3

BDA outcomes shows the strong endorsement towards the BDA model. The minority of the respondent in the organization show the opposition of it use

### 4.3.5 Sustainable Supply Chain Performance (SSCP)

Table 7

Response Category	Frequency	Percentage %
Strongly Disagree	6	2.8
Disagree	12	5.5
Neutral	33	15.2
Agree	96	44.2
Strongly Agree	70	32.3

The results show the sturdy countersignature toward the SSCP and only a few individuals designate the resistance.

### 4.4 Measurement Model

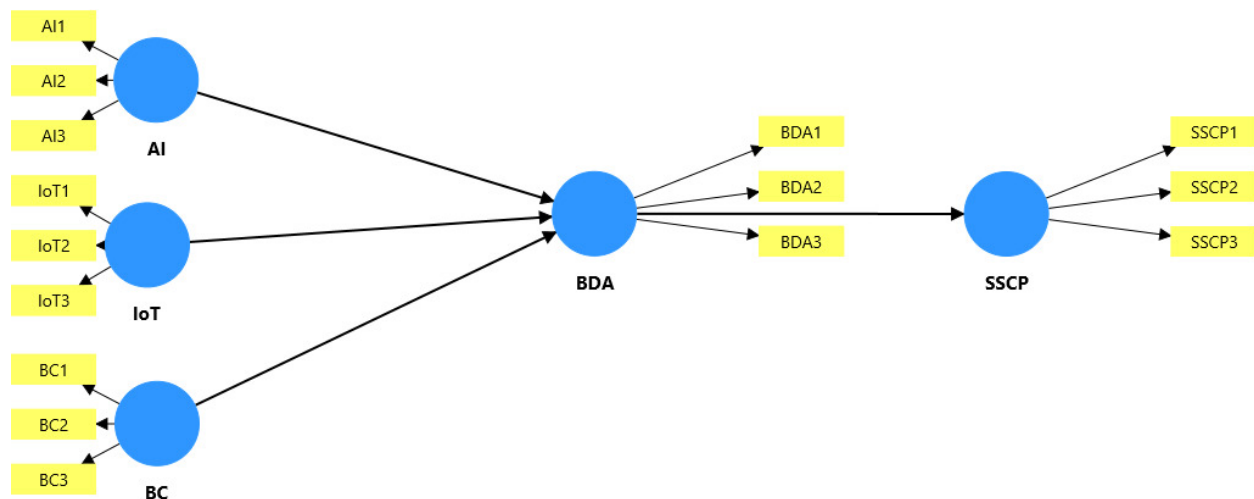


Figure 3: Measurement Model

#### 4.4.1 Indicator Loadings and Indicator Reliability

By looking at each measurement item's outer loadings on its corresponding latent construct, indicator reliability was evaluated. The degree to which an observed variable shares variation with its underlying construct is reflected in indicator reliability. PLS-SEM standards state that outer loadings of 0.70 or above are optimal, meaning that the indicator accounts for at least 49% of the latent variable's variance. However, loadings between 0.60 and 0.70 may be kept in exploratory and applied research settings as long as composite reliability and AVE values are within reasonable bounds.

*Table 8*

<b>Construct</b>	<b>Indicators</b>	<b>Outer Loadings</b>
BlockChain	BC <sub>1</sub>	0.78
	BC <sub>2</sub>	0.81
	BC <sub>3</sub>	0.74
Internet of Things	IoT <sub>1</sub>	0.80
	IoT <sub>2</sub>	0.77
	IoT <sub>3</sub>	0.72
Artificial Intelligence	AI <sub>1</sub>	0.83
	AI <sub>2</sub>	0.79
	AI <sub>3</sub>	0.76
Big Data Analytics	BDA <sub>1</sub>	0.85

	BDA <sub>2</sub>	0.82
	BDA <sub>3</sub>	0.78
Sustainable Supply Chain Performance	SSCP <sub>1</sub>	0.88
	SSCP <sub>2</sub>	0.84
	SSCP <sub>3</sub>	0.80

The findings show that most indicators in all constructs Blockchain (BC), Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA), and Sustainable Supply Chain Performance (SSCP) display outer loadings above the suggested threshold of 0.70, indicating strong indicator reliability. The results of the empirical data support the reliability of the retained indicators in the ability to reflect their latent constructs, thus making them amenable to further structural model analyses.

#### **4.4.2 Internal Consistency Reliability.**

Internal consistency reliability measures were used to evaluate the consistency of measures within the indicators in each construct to measure a similar construct. According to Hair et al. (2021), internal consistency should be standardized with the help of Cronbach alpha ( $\alpha$ ), Composite Reliability (CR), and rho A by using partial least square structural equation modeling (PLS-SEM). In PLS-SEM, composite Reliability and rho A are the most preferable because they consider variability in outer loadings, unlike the Cronbachs alpha which gives a lower limit based on an assumption of the identical loadings of indicators. The three diagnostics are all presumed to indicate sufficient internal consistency when coefficients get as high as 0.70 or higher.

Table 9

Construct	Cronbach's Alpha	Composite Reliability (CR)	Rho A
BC	0.79	0.86	0.80
IoT	0.77	0.84	0.78
AI	0.81	0.88	0.82
BDA	0.84	0.90	0.85
SSCP	0.86	0.91	0.87

The findings suggest that the values of Cronbachs Alpha, Composite Reliability and rho A of the constructs of Blockchain (BC), Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA), and Sustainable Supply Chain Performance (SSCP) are above the recommended value at 0.70. This suggests that each construct's indications are highly consistent with one another. Since none of the constructs have reliability ratings that are abnormally high (above 0.95), multicollinearity or item redundancy may not be an issue. Overall, the results show that the measurement scales employed in this investigation are trustworthy and internally consistent, offering a solid basis for additional convergent and discriminant validity testing as well as for later structural model assessment.

#### 4.4.3 Convergent Validity (AVE)

The degree to which the indicators of each construct converge or share a substantial proportion of variance in evaluating the same underlying notion was evaluated using convergent validity. The Average Variance Extracted (AVE), which shows the average amount of variance that a latent construct explains in its indicators relative to the variance related to measurement error, is frequently used in PLS-SEM to assess convergent validity. Adequate convergent validity is defined by recognized norms as an AVE value of 0.50 or above, which means that the construct explains at least 50% of the variation of its measurement items.

Table 10

<b>Construct</b>	<b>AVE</b>
BC	0.59
IoT	0.56
AI	0.63
BDA	0.67
SSCP	0.72

The results suggest that the Average Variance Extracted (AVE) values of all the investigated constructs, Blockchain (BC), the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA), and Sustainable Supply Chain Performance (SSCP) are more than 0.50, which is the recommended threshold. Therefore, the indicators that are related to each construct have a high enough level of shared variance, thus, being a reliable and all-embracing representation of each latent construct. The satisfactory AVE values also provide further empirical evidence to the effect that the variance that could be attributed to each construct is not significantly blinded by measurement error. Taken together these findings support the existence of convergent validity, hence testify to the statistical strength of the measurement model, and its suitability in future tests of structural relationships and discriminant validity.

#### **4.4.4 Discriminant Validity (HTMT)**

Discriminant validity was assessed by using the Heterotrait-Monotrait ratio of correlations (HTMT), which has been demonstrated as a more severe and reliable criterion of assessing discriminant validity in Partial Least Squares Structural Equation Modeling (PLSSEM) than other traditional methods. The procedure of HTMT is used to ascertain whether constructs are empirically distinct or not by calculating inter-construct correlations to intra-construct correlations. The set guidelines say that a conceptually dissimilar constructs should be associated with an HTMT value less than 0.85, however, in loose or exploratory studies, a value of less than 0.90 can be considered.

Table 11

<b>Construct</b>	<b>HTMT</b>
BC-IoT	0.72
BC- AI	0.70
BC BDA	0.74
BC-SSCP	0.76
IoT-AI	0.73
IoT-BDA	0.78
IoT-SSCP	0.79
AI-BDA	0.81
AI-SSCP	0.80
BDA-SSCP	0.83

Based on the results, all of the HTMT values of Blockchain (BC), Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA), and Sustainable Supply Chain Performance (SSCP) are below the conservative threshold value of 0.85, which implies that the constructs do not display too much overlap and retain specific attributes within the conceptual framework. These effects help alleviate anxieties over multicollinearity and construct redundancy, and this gives strong grounds that each latent variable represents a distinct theoretical construct. In its turn, the HTMT findings support the strength of the measurement model, and the consequent evaluation of the structural model, as it validates sufficient discriminant validity.

## **4.5 Structural Model**

### **4.5.1 Direct Effect and Path Coefficient**

The structural model was tested in order to explore the suggested relationships between the latent constructs. Path coefficients (them denoted by) and t-values and p-values were estimated using the procedure of bootstrapping in PLS-SEM. Bootstrapping is a non-parametric resampling technique that gives accurate estimates of the significance values and standard errors. In conventional norms, the path is considered statistically significant when the p-value is below 0.05 and the t-value is equal or above 1.96.

Table 12

Hypothesis	Path	B	t-Value	p-value	Lower Limit (LL)	Upper Limit (UL)	Decision
H <sub>1</sub>	BC→ BDA	0.29	4.12	0.00	0.15	0.43	Supported
H <sub>2</sub>	IoT→ BDA	0.27	3.78	0.01	0.13	0.41	Supported
H <sub>3</sub>	AI→ BDA	0.31	4.56	0.01	0.18	0.44	Supported
H <sub>4</sub>	BDA→ SSCP	0.48	6.34	0.03	0.33	0.63	Supported

The empirical results conclude that Blockchain (BC), the Internet of Things (IoT), and artificial intelligence (AI) have a positive and statistically significant effect on the Big Data Analytics (BDA). Therefore, the process of supply chain analytical capability augmentation heavily depends on the implementation of such digital technologies. Moreover, BDA significantly influences Sustainable Supply Chain Performance (SSCP) and this tendency is rather powerful and statistically significant, which indicates the key role of the latter in transforming digital competencies into sustainability achievements. In general, the studies present solid support to BDA as an important channel in which digital state-of-the-art technologies can contribute to the sustainability of a supply chain and, accordingly, provide significant empirical evidence to support the theoretical assumptions made.

#### 4.5.2 Model Explanatory Power

In assessing the explanatory power of the structural model, the coefficient of determination (R<sup>2</sup>) was utilized. The R<sup>2</sup> measures the extent or proportion of variability of an endogenous construct which can be attributed to explanations by its antecedents. Traditionally, a R<sup>2</sup> of 0.25, 0.50, and 0.75 can be said to be weak, moderately and robustly explained, respectively, according to accepted standards. The findings indicate that Sustainable Supply Chain Performance (SSCP) and

Big Data Analytics (BDA) achieve moderate to high values of R<sup>2</sup> hence suggesting that the model captures a significant proportion of variance in the endogenous constructs.

*Table 13*

<b>Endogenous Construct</b>	<b>R<sup>2</sup></b>
BDA	0.61
SSCP	0.64

*Table 14*

<b>Path</b>	<b>f<sup>2</sup></b>	<b>Effect Size</b>
BC→BDA	0.14	Medium
IoT→BDA	0.12	Small
AI→BDA	0.18	Medium
BDA→SSCP	0.36	Large

The measure of importance of all exogenous constructs was the effect size (f<sup>2</sup>). Findings of the analysis of f<sup>2</sup> show that the influence of Big Data Analytics (BDA) on Sustainable Supply Chain Performance (SSCP) is statistically significant, which implies its strategic significance; meanwhile, Blockchain (BC), Internet of Things (IoT), and Artificial Intelligence (AI) have a moderate to medium influence on BDA.

### **4.5.3 Indirect Effect**

The mediation analysis of the impact of the use of BC and IoT and AI on SSCP mediated through BDA was conducted. The mediation effect was evaluated using a bootstrapping procedure of the Partial Least Squares Structural Equation Modeling (PLS -SEM) framework due to its strong nature and no distributional assumptions. Indirect effect is considered to be statistically significant when the p-value that has undergone bootstrapping is less than the standard 0.05 level.

Table 15

Path	$\beta$	t-value	p-value	Lower Limit (LL)	Upper Limit (UL)	Mediation Type
BC→BDA→SSCP	0.14	3.87	0.00	0.07	0.22	Partial Mediation
IoT→BDA→SSCP	0.13	3.45	0.00	0.06	0.21	Partial Mediation
AI→BDA→SSCP	0.15	4.12	0.00	0.08	0.24	Partial Mediation

The findings support the mediating function of big data analytics by showing that BC, IoT, and AI have favorable and statistically significant indirect effects on SSCP through BDA. This implies that digital technologies by themselves do not directly improve sustainability performance; rather, their influence is felt when they are successfully incorporated into analytics-driven decision-making procedures. Moreover, partial mediation is shown by the direct effects' continued significance when the mediator is present. This suggests that digital technologies may have some direct impact on performance, even though BDA is essential in transferring their effects to sustainability results.

#### 4.5.4 Predictive Relevance (Q<sup>2</sup>)

Table 16

Construct	Q <sup>2</sup>
BDA	0.42
SSCP	0.47

The blindfolding process was used to evaluate predictive relevance (Q<sup>2</sup>). The model's satisfactory predictive relevance is confirmed by the fact that all Q<sup>2</sup> values are greater than zero. All of these results show that the suggested model is both predictive and explanatory.

## Chapter 5

### DISSCUSION & THEORATICAL IMPLICATIONS

#### 5.1 Discussion.

The goal of this chapter is to deliberative upon the empirical findings in the light of the proposed objectives, theoretical framework, and Literature review. This paper examined how the digital technologies BC, IoT, AI, and BDA influence Sustainable SSCP in the beverages industry of Pakistan. The results from the PLS-SEM analysis derive useful insights into how digital transformation improves sustainability outcomes through analytics-driven decision making. The present discussion relates results with past studies and theories and the result in context of Pakistani beverage industry.

Its findings also testify to the statistically significant and positive impact of blockchain technology on big-data analytics. As a result, the hypothesis that the adoption of blockchain makes supply-chain analytics more effective is justified. The research also reveals how information quality is a crucial factor of successful analytics work of big data, and that this quality can be enhanced by blockchain technology. Product identity, quality, and regulatory compliance are important forces behind the brand equity in the beverage industry. In such a way, the results support the Resource-Based View (RBV) according to which blockchain is a strategic organizational resource that enhances analytical capacity and efficiency of operations. With its concept of mutable and in real-time data exchange with the supply-chain partners, blockchain mediates the enhancement of data quality and availability, thus, amplifying predictive and prescriptive analytics. Previous studies have supported the fact that information-based supply-chain visibility and performance are enhanced by blockchain use, especially in the context of economic growth in developing countries with a lack of trust and information asymmetry. In the beverage sector of Pakistan where supply chains entail the involvement of various intermediaries and the complexity of regulations may be involved, the use of blockchain-based analytics can improve sourcing, logistics, and sustainability reporting decision-making.

Therefore, the analytical findings confirm that blockchain has a strategic role in the development of data analytics. The effect of the IoT on the big-data analytics is also considerable, which proves hypothesis that the implementation of IoT can improve the analytical capacity. Implementation of

IoT can allow gathering information on all levels of production, storage, and distribution through sensors, RFID tags, and intelligent devices. These data streams are continuous, operational, environmental, and logistical among other parameters, which form the basis of the big-data analytics. The latter outcome holds true to the Technology-Organization-Environment (TOE) model, according to which technological preparedness is one of the major predictors of adoption. IoT offers organizations a better-placed position to prepare better in terms of big-data analytics by offering more data availability, velocity and variety. In the past, as reported in literature, the IoT approach of data acquisition supports the responsiveness of supply chains, forecasting, and sustainability. The IoT use in temperature control, inventory management and transportation optimization are especially useful to the Pakistani beverage industry where the products sold are perishable. The findings of the study show that organizations that deploy IoT technologies are in a greater position to use big-data analytics in achieving sustainability effects, such as waste minimization and energy efficiency.

The strongest positive impact of Artificial Intelligence in big-data analytics can be highlighted, and one should state the fact that this aspect is the key to building analytical capabilities. Machine learning and other AI-based tools facilitate the processing of complicated data more strongly. Under the RBV paradigm, AI is an asset of value, scarcity, and non-imitable at the firm level which can enable firms to convert raw data into actionable insights. AI helps in pattern distinction, predicting demand, and controlled supply-chain procedures. The literature confirms the existence of this relationship, especially in manufacturing and process industries where AI-driven analytics can improve the performance of efficiency and sustainability. The extent to which AI is used in the beverage industry of Pakistan is still young; however, the results show that those organizations that invest in the integration of AI technologies have much greater analytic maturity. It means that AI will be able to facilitate digital transformation, transforming firms into predictive and prescriptive decision-makers.

Moreover, big-data analytics shows a high and profound influence on sustainable supply-chain performance, which testifies to the ability of digital technologies to be converted into sustainability results. The results indicate that companies can use analytics capabilities to expand their resources, which will lead to the reduction of environmental footprints, and social and economic improvement. The use of big-data analytics would allow tracking the emissions, energy

consumption, waste, and the performance of suppliers in real-time, which is consistent with the principle of the triple bottom line perspective on sustainability. Supply chains that are analytic-based are found to increase sustainability through increased transparency and informed decision-making, as proven through former studies. Using big-data analytics would enable the beverage industry of Pakistan to be more sustainable without weakening efficiency in the age of increased scrutiny and rivalry. However, studies point out that it is not just digital technologies which ensure improvements in sustainability.

The most crucial discovery of the research is the substantial mediating effect of big-data analytics between the issues of digital technologies; blockchain, IoT, and AI, and sustainable supply-chain performance. The mediation analysis shows that there is a partial mediation effect with digital technologies having a direct and indirect effect on sustainability and analytics capability respectively. The analysis presented suggests that meaningful improvement of performance, when implementing data generating technologies, cannot be founded without analytical capabilities. The results are consistent with the previous empirical data that puts analytics as a key mechanism with the help of which organizations shift between digitalization and sustainability. The mediation effect further strengthens the theoretical integration of RBV and TOE by showing how technological resource transformation into performance advantages is enabled by organizational capabilities. The results have significant ramifications for beverage companies in Pakistan to invest in the analytics infrastructure along with the digital technologies for optimizing sustainability.

## **5.2 Theoretical Implications**

This research paper presents a number of useful practical implication to managers, practitioners, as well as policymakers in the beverage industry. First of all, top managers should understand that their investments in the technologies, including blockchain, the Internet of Things (IoT), and artificial intelligence (AI), should be supported by effective analytical systems. Even though the organizations might hoard data, failure to analyze and interpret the same will bar substantive gains in sustainability. Digital technology alone is not enough as regards to investment. As a result, companies will have to invest in analytics infrastructures, data management and governance programs, and staff training measures. In its turn, the managerial personnel should note the strong impact of AI on BDA. This ability provides demand prediction and inventory optimization as well as sustainability tracking instruments. The analytics made possible through AI will be able to help

beverage firms to lower inventory levels, maximize energy consumption and become more responsive. These findings can be used by policy makers and regulators in the industry to foster fortification of digital and analytical powers within the industry. Sustainable supply-chain transformation in the beverage sector will be made possible through digital-skills programmers, the incentives towards the use of analytical devices, and investment into data infrastructure.

### **5.3 Limitations of The Study**

This research has various limitations that are essential to handle. First, the cross-sectional design limits the ability of the study to cause causation. Though the analysis demonstrates a strong statistical relationship through PLS-SEM, the addition of longitudinal data would allow one to explore the nature of digital technologies and analytics capabilities development more thoroughly through the course of time and, finally, increase the performance of sustainability. The data obtained through self-reports survey answers might be subject to common-method bias and subjectivity of respondents. While the use of procedural remedies was modified in the construction of the questionnaire, it may be important for future studies to also use performance indicators or secondary data, which would likely validate the survey data. Third, the entire research focused on the beverage industry of Pakistan. Therefore, this may limit its findings to Pakistan's beverage industry only. There may be differences in supply chain structures, regulatory environments and technological maturity across sectors and countries. Ultimately, although this paper studied Big Data Analytics as a mediating factor, the model did not include other organizational determinants, such as leadership support, organizational culture, and digital skills. To investigate sustainability outcomes, further investigation on whether these factors are important is necessary.

### **5.3 Future Research Recommendations**

Based on the restrictions of the conducted study, many future researches are suggested. Going ahead prosperous to the opportunity of longitudinal research design(s) to evaluate the interactive nature of digital technologies and analytics capabilities on sustainability performance over time. It would allow studying the feedback processes and the influences of technological maturity. In addition, scientists can enrich the suggested model with more mediators or moderators, which include organizational culture, technological preparedness, environment regulation, top-management support and such variables to explore the circumstances the model presumed to cause

the creation of sustainability benefits. Another third option is to provide comparative research across the industries such as pharmaceuticals, textiles and manufacturing to know whether the relationships revealed in the beverage industry are only sector specific or generalizable. Fourth, objective measures of sustainability performance (carbon footprint, energy consumption or reduction of waste) can be used in future studies to add to what the perceptual survey data covers and improve empirical rigor. Finally, a policy should seek to adopt mixed-method strategies that embody the complexity of decisions of managers and the difficulties related to the implementation of digital technology and analytics in the supply chains in developing nations.

## **5.4 Conclusion**

The main aim of the study was to investigate the effects of digital technologies i.e. Blockchain (BC), Internet of things (IoT) and Artificial Intelligence (AI) upon Sustainable Supply Chain Performance (SSCP) in beverages sector of Pakistan with Big Data Analytics (BDA) as mediating mechanism. By using a quantitative research methodology and employing Partial Least Squares Structural Equation Modeling (PLS-SEM), the study empirically tests the suggested relationships based on data obtained from 217 supply chain experts in the beverage industry.

Results of the study provide robust evidence that owing to the positive and statistically significant effect of the Blockchain, IoT, and AI on Big Data Analytics. Tech adoption promotes effectiveness of organizations to gather, control and process large volumes of supply chain data. Artificial intelligence (AI) exhibited the most effect. Therefore, it is central to the increase of sophistication of the Big Data Analytics (BDA) predictive modeling, automation, and intelligent decision-making processes. Furthermore, the results affirm that BDA has major and positive impact on Sustainable Supply Chain Performance (SSCP) to reaffirm that concept that digital investment is a value with not indispensable price to applications on sustainability. Organizations can use insights obtained with the aid of analytics in order to streamline their management of resources, reduce losses, increase efficiency of operations, and improve supply-chain visibility. The claim regarding the necessary analytical capacities that should be present alongside the digital technologies in order to achieve the sustainability goals is more than ever.

One of the main findings of this study is that BDA has a mediating effect which was confirmed. The mediation analysis suggests that BDA has a partial mediating effect on the effect of digital

technologies on SSCP. It means that despite the direct influence of digital technologies, their major impact on the sustainability performance is the way, which should manifest through BDA. Based on this; BDA is being placed as a strategic capability that creates a connection between digital shift projects and sustainability results.

Conclusively, sustainable supply-chain operation in the Pakistani beverage sector can be boosted by the integration of digitalization and the use of BDA. The findings provide meaningful information to researchers and practitioners who wish to comprehend the role of digital transformation in taking sustainability in the Global south to the next level.

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