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Modeling the impact of BDA-AI on sustainable innovation ambidexterity and environmental performance

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Abstract

Data has evolved into one of the principal resources for contemporary businesses. Moreover, corporations have undergone digitalization; consequently, their supply chains generate substantial amounts of data. The theoretical framework of this investigation was built on novel concepts like big data analytics—artificial intelligence (BDA-AI) and supply chain ambidexterity's (SCA) direct impacts on sustainable supply chain management (SSCM) and indirect impacts on sustainable innovation ambidexterity (SIA) and environmental performance (EP). This study selected employees of manufacturing industries as respondents for environmental performance, sustainable supply chain management, big data analytics, artificial intelligence, and supply chain ambidexterity. The results from this study show that BDA-AI and SCA significantly affect SSCM. SSCM has significant associations with SIA and EP. Finally, SIA has a significant impact on EP. According to the results indicating the indirect impacts, BDA-AI has significant indirect relationships with SIA and EP by having SSCM as the mediating variable. Furthermore, SCA has significant indirect associations with SIA and EP, with SSCM as the mediating variable. Additionally, both BDA-AI and SCA have significant indirect associations with EP, while SIA and SSCM are mediating variables. Finally, SSCM has an indirect association with EP while having SIA as a mediating variable. The findings of this paper provide several theoretical contributions to the research in sustainability and big data analytics artificial intelligence field. Furthermore, based on the suggested framework, this study offers a number of practical implications for decision-makers to improve significantly in the supply chain and BDA-AI. For instance, this paper provides significant insight for logistics and supply chain managers, supporting them in implementing BDA-AI solutions to help SSCM and enhance EP.

Keywords: Big data analytics—Artificial intelligence, Sustainable supply chain management, Sustainable innovation ambidexterity, Supply chain ambidexterity, Environmental performance

Introduction

Data has evolved into one of the foremost substantial resources for contemporary businesses [1–3]. Moreover, corporations have embraced digitalization; consequently, their supply chains are generating extensive data [4]. However, unlike investments, large data has no utility without the necessary tools to derive better insights [5]. The managers with the most knowledge and comprehension of their data [6] can leverage it to establish corporate benchmarks [7]. Big data, along with predictive analytics, enables enterprises and organizations to cut costs [5], manufacture items more quickly [8], and develop innovative services and products to satisfy clients' evolving demands [9]. The evolution of supply chain digitalization will be propelled by the ability to conduct predictive analytics on large amounts of data enabled by artificial intelligence [10]. Consequently, applications like big data analytics (BDA), machine learning (ML), and artificial intelligence (AI) applications in the field of management have garnered more attention [11], leading organizations to spend more on sustainable technologies related to these technologies to obtain a competitive advantage [5, 6]. Big data, in association with AI, plays a major role in the management of sustainable supply chain management (SSCM) by reducing nonsynchronous information and handling complicated data related to the environment [12]. BDA-AI presents implications for decision-makers regarding the enhancement of SSCM and ecological performance [13]. Scholars have acknowledged the role of BDA-AI in the internal ecological integration of a number of supply chain tasks, for instance, warehousing, manufacturing, and disposal management, to boost the ecological efficiency of firms [14]. BDA-AI also plays a role in external supply chain tasks, including the selection of supply chain partners and environmental design [15]. In addition, BDA-AI aids in greening the supply chain tasks and collaboration with supply chain partners which in turns helps in the reduction of waste and carbon emissions [16]. Notwithstanding the previous research, the association between BDA-AI and SSCM is still inadequate and needs further attention by researchers [17, 18]. Therefore, this investigation intends to examine the link between BDA-AI and sustainable supply chain management (SSCM) [6].

Firms may encounter challenges when redesigning their sustainable supply chain if any of the supply chain partners exit the supply chain or a new supply chain partner is added to the supply chain [19]. Hence, organizational flexibility and ambidexterity become crucial in navigating these dynamic changes in the supply chain [20]. Ambidexterity theory advocates for the simultaneous use of two opposing management techniques, skillfully balanced to ensure organizational success [21]. Thus, the two core management concepts, including exploration and exploitation, are treated as a pair of internal capabilities together rather than using either one of them [22, 23]. Firms must strive for a harmonious balance between exploitation as well as exploration, preventing uncertainties associated with exploration procedures and the reliance on outdated exploitation processes [24]. Supply chain ambidexterity (SCA) involves simultaneously reaping the incentives of exploration and exploitation throughout the supply chain [25, 26]. Previous studies have explored the responsibilities, roles, and impact of organizational ambidexterity on different critical concerns, including the discovery of new knowledge [27], the improvement in the performance of companies [28], and the design and production of creative goods [29]. While the theoretical nature of institutional ambidexterity and innovation has been investigated [30], several studies have focused on the concept of relative ambidexterity [31]. SSCM is recognized for promoting organizational sustainability through activities that address environmental issues, including the reduction of hazardous contaminants, air pollution, power consumption, and related concerns [26, 32]. SSCM policies also contribute to improved business operations [33]. The successful and efficient application of SSCM tasks like sustainable procurement (SP), sustainable manufacturing (SM), sustainable distribution (SD), and sustainable logistics (SL) can be aided by SCA [26]. Hence, this research aims to investigate the association between SCA and SSCM.

Previous studies indicated that the implementation of SSCM was high cost and had no significant impact on enhancing the performance of organizations [34, 35]. It was also found that only a few managers had employed SSCM in their firms [36, 37]. However, SSCM was discovered to have a significant impact on sustainable innovation, enhancing the sustainable innovation of firms [38]. Organizations began to adopt and implement SSCM and sustainable innovation due to external stakeholder pressure to improve overall firm performance [39]. In addition, this research supports innovation activities that might practically increase the sustainable inventive nature of firms, offering a comprehensive appraisal of the significance of sustainable modernization at the SSCM stage. The results enhance SSCM and sustainable innovation ambidexterity (SIA) when organizational ecological performance is analyzed. The research emphasizes that direct evaluations are insufficient and give inadequate comprehension and assessment. For instance, the relationship of SSCM with SIA remains an open question, particularly in underdeveloped nations. There is a strategic relationship between SSCM and SIA regarding the importance of the product life cycle in boosting environmental performance [38]. Similarly, the majority of studies centered on the association between the notions of sustainable innovation and sustainable sourcing, including their influence on competitive benefits and sustainable strategies [40, 41]. Therefore, there is a connection between SIA and SSCM procedures [42]. Consequently, this study analyses the effects of SSCM and SIA.

SSCM has been implemented by manufacturing industries to cope with the demand of customers for ecological products manufactured with environment-friendly procedures in compliance with government regulations [43]. SSCM practices require manufacturing industries to collaborate with customers and suppliers to enhance sustainability. The employment of SSCM tasks is found to boost the environmental performance (EP) of firms, assured by the reduction in waste, pollution, and usage of toxic substances [44, 45]. Sustainability encompasses notions of EP, economic, and social performance [46]. The sustainability literature is highly developed. This study is primarily concerned with the EP aspect of sustainability. Environmental management has shifted its emphasis from the company level to the supplier chain [45]. It has been suggested that SSCM is now a competitive requirement as a result of customer demands for ecologically sustainable products and processes that are developed and operated to increase environmental sustainability. Previous research identified a correlation between the use of SSCM and enhanced EP [47]. Furthermore, it was discovered that strong ties and close supplier collaboration in industrial environments result in enhanced EP [48]. Based on anecdotal information, it is possible to assert that green procurement and supply policies will likely result in enhanced EP [43]. SSCM techniques are designed to enhance the EP of manufacturers. Practices including SP, customer cooperation, eco-design, and capital recovery are intended to significantly influence EP [45]. Consequently, this study examines the relationship between SSCM and EP. Additionally, SIA is associated with a strict environmental management objective, and SIA promotes EP [49–51]. Consequently, this study investigates the effects of SIA and EP.

The study aims to enrich the empirical contributions related to the impacts of BDA-AI, SCA, SIA, and EP. The first objective of this research is to provide a theoretical framework to measure the impacts of BDA-AI on SIA and EP of firms. The second objective of this research is to enhance the existing literature on BDA-AI and offer new discussion insights based on the study results. Furthermore, this paper provides several theoretical contributions to researchers in BDA-AI and ambidexterity literature. It also offers practical contributions by providing significant insights for logistics and supply chain managers, supporting them in implementing BDA-AI solutions to help SSCM and enhance EP.

The remaining sections of the study are explained as follows. Section "Literature review" of the study explains the theoretical background. Section "Hypothesis development" represents the development of hypotheses. The methodology of the study is described in "Methodology" Section. Furthermore, the data analysis of the study is presented in "Data analysis" Section. In addition, "Discussions" Section of the study represents the data analysis discussions. Sections "Theoretical implications", "Managerial implications", and "Policymakers implications" describe the study's theoretical, practical, and policy implications. Lastly, "Further research directions" and "Limitations" Sections describe the future research directions and limitations of the research.

Literature review

BDA-AI

AI is the study of constructing intelligent machines that use different algorithms to assist computing machines in resolving issues humans could solve [52]. In terms of its historical development, artificial intelligence was conceived between 1943 and 1955 and was born in the Dartmouth laboratory in 1956 [53]. Unfortunately, there was an AI winter from the late 1960s until the late 1970s. This occurred for a variety of reasons, including Prof. James Lighthill's negative study on the status of AI in the UK [54]. Subsequently, research related to AI faced much criticism in the United States Congress, and funding for neural-net research declined progressively [55].

Nonetheless, beginning in the 1980s, the exploitation of intelligent systems in private organizations became apparent [56, 57]. In 1995, AI technologies like robots were introduced, and in 2001, Big Data (BD) emerged. It has considerably boosted AI, allowing search engines to be driven by AI, e-commerce, as well as digital support [58]. Consequently, AI research has expanded into the subject of marketing science. Evaluating massive data sets derived from a variety of demographics as well as sources enables marketers to determine how to enhance marketing performance. BDA shows themes as well as patterns that artificial intelligence can utilize to enhance the effectiveness of initiatives related to marketing [57, 59].

The implementation of BDA-AI has been recently enhanced in many industries [60]. The utilization of BDA-AI has yielded several benefits for these industries, enhancing operations and reducing resource usage and costs [61]. Furthermore, BDA-AI opens up numerous research opportunities for research in various fields. For instance, in the medical field, BDA-AI was found effective in designing new drugs [60]. Hence, BDA-AI efficiently manages the information flows required to efficiently plan the resources and forecast the needs of firms for specific periods. In addition, BDA-AI is found to be effective in managing the supply chain and assisting firms with decision-making practices for the development of sustainable policies. Despite the benefits offered by BDA-AI, many firms have yet to embrace it in the context of SSCM [17]. Hence, the present study proposes integrating BDA-AI within sustainability concepts to enable organizations to make decisions in an ecologically friendly way [18, 62].

Supply chain ambidexterity

Ambidexterity is a combination of exploiting and exploring. The former refers to steps taken to adjust or alter the company's current methods, while the latter alludes to activities designed to produce new creative ideas and plans [63]. Scholars unanimously agree on the crucial importance of balancing exploitation and exploration techniques [64]. While prior research suggested an option to choose between exploitation and exploration projects [65], current research indicates that corporations manage both initiatives concurrently [66]. According to Raisch et al. [67], exploitation is defined as a corporation's capability to modify present resources and exploration as its capacity to discover new prospects.

Ambidexterity in the technological concept comprises management techniques for organizations to adapt to the dynamic environment [68]. The ability of organizations to adapt can be linked to their innovation [69] and is centered on their capabilities to engage in exploration and exploitation activities [70]. Hence, it can be inferred that ambidexterity is closely tied to the dynamic abilities of organizations [65], aiming to enhance innovation and, in turn, boost their overall performance [28, 68].

Kristal et al. [25] expounded on the notion of ambidexterity within the context of the SC. The approaches and capacities of a firm to change and enhance the efficacy of its current SC initiatives are classified as exploitation of the supply chain system. On the contrary, exploitation of the SC or the distribution was defined as the organization's competencies and processes for designing and implementing innovative SC solutions [71]. Companies can achieve supply chain exploration by upgrading and eliminating redundant supply chain processes while achieving supply chain exploitation by conducting experiments and discovering workable ideas for supply chain issues [25]. Researchers have emphasized the significance of ambidexterity in the framework of SC operations. A study found that SC partners engaged in ambidexterity study client requirements and adapt the company's environment accordingly, thereby reducing the supply chain issues experienced by the company and increasing its efficiency [72]. Additionally, ambidexterity has been linked to both internal and exterior integration. Internal integration includes and participates in a company's internal elements, whereas external amalgamation entails exchanging information and networks between customers and suppliers [73].

Sustainable supply chain management

The forward and backward stream of cash, goods, services, and knowledge from a company's initial supplier partners up to the end-users is referred to as a supply chain [26]. Considering that the SC consists of a variety of partners and connections, it is crucial to effectively manage these relationships for businesses to safeguard an effective supply chain [74]. The activities of the SSCM's framework that promote a company's sustainability have gained popularity in recent times [32]. SSCM efforts facilitate the management of sustainability concerns, such as energy conservation, poor air quality, use of hazardous chemicals, etc. Additionally, adherence to these regulations may lead to the establishment of a competitive benefit [33]. Companies must be specialists in incoming and outbound logistics to achieve an efficient SSCM system. Outbound logistics refers to operations relating to client requests, the company's reputation, and performance. Inbound logistics refers to policies and initiatives related to the internal supply chain [75]. By enhancing the sustainability and financial standards relating to the partners in the supply chain, SSCM efforts significantly enhance the efficiency of the entire firm. Initiatives for SSCM are focused on the business's financial, sustainable, and social components [76]. In addition, SSCM is dedicated to managing the connections between supply chain participants, employing a TBL methodology that incorporates sustainability goals such as enhancing social, economic, and environmental factors [77]. SSCM strategies not only support companies in managing ecological challenges but also in achieving a targeted share of the market and profit margin [78].

SSCM includes the management of all activities in a sustainable way, ranging from the management of raw materials to the end-user [79]. SSCM comprises sustainability practices and endeavors that can contribute to enhancing the EP of many supply chain partners in the same supply chain [80]. According to Zhu and Sarkis [47], SSCM includes management support, ISO 14001 verification, sustainability inspections, collaboration for sustainability, trading of scrap, and a decrease in the usage of hazardous materials. This study employs Khan et al.'s [26] SP, SM, SL, and SD framework to examine SSCM.

Sustainable innovation ambidexterity

Sustainable innovation is related to the generation of ecologically friendly processes and products [81] via the implementation of sustainable practices, for instance, the usage of sustainable materials and reduction in the usage of resources, thereby promoting eco-design [51]. Previously, it has been indicated that organizations that have employed sustainable innovation techniques experience considerable success [81]. In addition, these firms outperform their competitors significantly by efficiently addressing customers' green demands with the support of their sustainable resources [51].

March [65] introduced the idea of ambidexterity in the context of creativity. In conjunction with innovation, research must consider the current state as a result of multiple situations and the most significant modifications to the current operation. Apple effectively challenged Sony's Walkman position with its iPod, while Sony continues to market its subsequent MP3 player products. Nevertheless, Sony has persisted in this market as a competitor with a considerably lower market share [82]. Therefore, investigations should be concerned with a broader range of contemporary repercussions than only survival. Similarly, corporations do not merely respond to a significant invention when its impact on established markets and popular models is assured [83].

Innovation ambidexterity consists of two components: exploitative innovation and exploratory innovation [84]. Numerous scholars have investigated exploitative and explorative innovation [84–87]. Exploitative innovation projects are tied to the company's efforts to enhance its existing competencies [65, 86, 87]. Therefore, exploitative innovation methods concentrate on improving existing materials and technology. Alternatively, exploratory innovation projects focus on acquiring new and inventive knowledge [86, 87]. Therefore, exploratory innovation strategies give firms a fresh knowledge base [84]. This study combines innovative ambidexterity with sustainability considerations connected to environmental conservation and development, resulting in the acronym SIA. Sustainable exploitative innovation (SET) pertains to the company's initiatives to enhance its current products and technologies to make them more environmentally friendly and sustainable. On the other hand, sustainable exploratory innovation (SEP) is tied to the corporation's efforts to build innovative and creative sustainable technologies and products [88, 89].

Environmental performance

ISO 14001 defines EP as the tangible outcomes of an organization's environmental management systems when taking care of the environment based on its ecological policies and goals [90]. Its main goal is to lower the amount of pollution in the environment [45]. An organization can achieve its EP by minimizing toxic pollutants, wastewater discharge, waste products, utilization of hazardous products, and environmental mishaps [91]. EP can be improved by, among other factors, assigning ecological responsibilities to practitioners and supporting environmental training to non-environmental employees, in addition to environmental specialists [90]. Researchers examine EP in terms of the organization's environmentally responsible policies and practices, operational effectiveness, reduced emissions, and proper waste disposal [90, 92].

EP is based on organizational activities to cope with the demands of society and stakeholders concerning the ecological situation [93]. EP includes all the ecological impacts caused by the organizational processes and resource usage that are in best compliance with the legal ecological regulations [94]. Previously, it has been suggested that EP is associated with the quality of sustainable products and processes. Furthermore, it is also related to the inclusion of sustainability concerns in manufacturing and operations [51, 94, 95].

Hypothesis development

BDA-AI and sustainable supply chain management

In corporate research, big data is typically processed utilizing AI algorithms capable of handling massive amounts of data. Despite ample research to understand the relationship between BDA and AI, it is rarely applied to developing supply chain processes and sustainable green practices [96]. This research focused on the effects of BDA-AI in enhancing EP [18]. Recently, practitioners and academics have recognized the importance of BDA in SSCM [97, 98], which means the use of comprehensive environmental issues in supply chain management [35]. BDA facilitates the mining of environmental data throughout the supply network and the generation of SSCM-enhancing insights [99].

However, despite high hopes for BDA, many companies could not capitalize on the advantages it offered for SSCM [97]. Specifically, the ineffective use of BDA to eliminate information asymmetry frequently results in difficulty measuring the greenness of providers [15]. BDA isn't used well because people don't know what kinds of BDA techniques can be used and what kinds of SSCM areas BDA can help with [99, 100]. AI-based BDA is a key part of SSCM because it keeps information from being out of sync and helps manage complex ecological data [12]. It gives information to help decision-makers improve SSCM and EP [13, 18].

Previous literature strongly indicates that employment of BDA-AI aids in the improvement of SSCM integration and management of information [101]. SSCM includes collaboration with supply chain partners to improve the sustainability of products and procedures [18]. The collaborations between supply chain partners often represent a barrier to achieving sustainable outcomes [102]. Hence, it can be indicated that SSCM can be enhanced by the employment of sustainable practices according to the demands of customers [103]. BDA-AI has been found to benefit the sustainability of product designs with the help of its smart technologies [62], in turn enhancing the SSCM of firms. The employment of BDA-AI in the context of SSCM has expanded significantly over the past several years [104]. A strong association between BDA-AI and SSCM has been found by researchers [6, 18, 99]. Centered on the above discussion, this research postulates the following hypothesis.

Hypothesis 1. BDA-AI has a substantial effect on SSCM.

Supply chain ambidexterity and sustainable supply chain management

SCA can help ensure eco-friendly supply chain actions like buying raw materials, producing green products, using green packaging, and recycling are done well and quickly [26, 105]. SM, SP, SL, and SD are all important parts of SSCM practices that industries need to do well in terms of sustainability [106]. Greening a supply chain means taking care of many things, like purchasing and managing raw materials, implementing marketing plans, and ensuring eco-friendly reverse supply chain approaches are in place [107]. Recently, researchers have been investigating the significance of SCA literature. Partanen et al. [38] talked about SCA in terms of SMEs in their study. Their results showed a weak connection between SCA and performance [38].

Previously, SCA has been studied in various contexts, including supply chain performance, firm performance, and product development [108–110]. Aslam et al. [71] studied SCA in association with supply chain resilience and identified a significant correlation between them. In a recent research, SCA was found to significantly correlate with supply chain dynamic capability [19]. In addition, Munir et al. [111] conducted research on SCA in emerging countries like India, Pakistan, and Bangladesh and found a significant association between SCA and sustainability. Another study in an emerging country found a significant relationship between SCA and SSCM [26]. Research shows that SCA can figure out what green customers want and adapt to a changing organizational environment so that SSCM processes run smoothly in the company [72]. Even though SSCM practices are important, only a small amount of study has been conducted on them, and sometimes the results are contradictory [26, 112]. The existing research gap in the current research is a greater interpretation of how SCA affects SSCM and the causation relationships involved. Therefore, this research postulates the following hypothesis.

Hypothesis 2. SCA has a substantial effect on SSCM.

Sustainable supply chain management & sustainable innovation ambidexterity

Two notions support the relationship of SSCM approaches with sustainable innovation. The first is co-creation, while the second is innovation through natural selection [113]. These concepts suggest that the interaction among partners or owners involved in the supply chain method of a corporation would develop additional sustainable inventive ideas to withstand the extreme coercions from external forces, particularly official and state control [38]. Suppliers that are sustainable foster supplementary eco-friendly advancements, showing that SSCM strategies are among the primary driving forces behind the development of sustainable invention techniques [42]. Various studies demonstrated the significance of SSCM in forming SIA [114]. Accelerating SIA by sustainable relations of enterprises with their essential suppliers to develop a modern, technologically innovative, and green product [40]. Several studies suggest that strengthening the suppliers will substantially affect sustainable innovation [114, 115]. In addition, research conducted in Taiwanese indicates that corporate sustainability administration, such as SSCM, is strongly associated with sustainable procedures and product innovations. This association aligns with the fundamental concept given the correlation of SSCM with SIA [42]. Growing fear related to sustainability initiatives and expressed concerns from numerous stakeholders, such as the community, the consumers, as well as the suppliers, drive firms to coordinate and collaborate with them during the product development process [116]. Relationships between these stakeholders and firms will surely be very beneficial in terms of business innovation, developing the design structure of the product and the method of their production, as well as enhancing compliance with ecological regulations [38]. SSCM can be implemented more effectively with the assistance of the SIA concept by offering producers creative proposals, processes, and capabilities for the creation of new products. The SIA is intended to provide continuous innovative methods in each phase related to the supply chain to gain an advantage over competitors and alleviate the industry's sustainable problems [42, 117].

Hence, it can be indicated that SSCM plays a major role in the SIA [42]. Employment of both SSCM and SIA will be advantageous for organizations in terms of complying with the sustainability policies related to the manufacturing of products [41]. According to a recent study by Novitasari and Agustia [39] conducted in the context of the Indonesian industries, SSCM was found to impact the sustainable innovation of firms significantly. A similar study conducted in an emerging country found a positive association between SSCM and SIA [42]. Hence, it can be indicated, based on previous research, that SSCM and SIA are significantly correlated in a synergistic association [38, 118]. Consequently, this research postulates the following hypothesis.

Hypothesis 3. SSCM has a substantial effect on SIA.

Sustainable supply chain management and environmental performance

Previously, sustainability was integrated into procurement, and it was found that SP of SSCM has a significant impact on the EP [41, 119]. Furthermore, a study targeting the manufacturing industries of China found a significant association between SSCM and EP of firms [120]. In another investigation by Muma et al. [90] concentrating on Korea's tea industry, it was revealed that SSCM significantly impacted the EP of firms.

Choi and Zhang's [121] topic of research on SL and business performance was based on China. They also revealed that some companies had achieved a harmonious balance between ecological concerns and financial gains. SSCM contributes to mitigating the environmental impacts of industrial activity, hence boosting EP [122]. Green et al. [45] created an SSCM model emphasizing the practices of industrial enterprises, aiming to ascertain whether SSCM methods might enhance EP. Their findings demonstrated that SSCM contributed positively to EP [45]. A study of SSCM in China by Liu et al. [123] discovered a favorable correlation between SSCM practices and EP. The research revealed that approaches centered around commercial actors are more sustainable than regulation-oriented models for promoting SSCM practices, as they rely on mutual communication and collaboration between the primary shareholders. In addition, ideas for providing additional technical support and deploying market forces other than those required by law to achieve SSCM [123]. Also, the development of environmentally friendly goods through cooperative research and requiring suppliers to meet greater ecological requirements as ways for enhancing the participation of peripheral SSCM practices are also mentioned [90]. In Hsu and Hu's [124] study on SSCM in consumer electronics, environmental performance can be linked to constructing an ecological record of products, requesting product assessment reports, and supporting senior management. A study by Chien and Shih [92] investigating the application of SSCM procedures in electronic businesses and their impact on organizational performance determined that SP and SM could produce positive EP. Due to the restricted scope of prior studies, researchers recommend additional research on connections between SSCM practices and enterprise performance, financial results, business processes, client services, and the diffusion of effective SSCM practices [90].

Consequently, the following hypothesis is postulated.

Hypothesis 4. SSCM has a substantial effect on EP.

Sustainable innovation ambidexterity and environmental performance

Earlier studies have illustrated that companies may be ambidextrous, seeking both exploratory and exploitative innovations [125], and that ambidextrous firms tend to achieve superior success [126]. When examining SIA, whether exploratory or exploitative, relates to products or processes, along with environmentally friendly services; a procedure which involves businesses that constantly launch and promote green activities involving energy conservation, prevention of pollution, and the improvement in environment quality EP [127] to achieve financial benefits [128, 129]. Prior research suggests that SIA should not be viewed as a corporation's spontaneous response to shareholder demands but as positive organizational goals and actions to enhance EP for competitive advantage [51, 130, 131]. In this regard, SIA may be viewed as a strategy for integrating environmental concerns into businesses while enhancing their competitive edge [81] through incremental or radical innovation that can benefit their EP [129, 132]. SIA is linked to a strict environmental management objective, and SIA promotes EP [49–51, 127].

Hence, previously, SIA was indicated to have a significant association with EP [49, 50]. Earlier studies further propose that SIA should be viewed as a proactive sustainability measure by organizations rather than merely responding to stakeholder pressure to

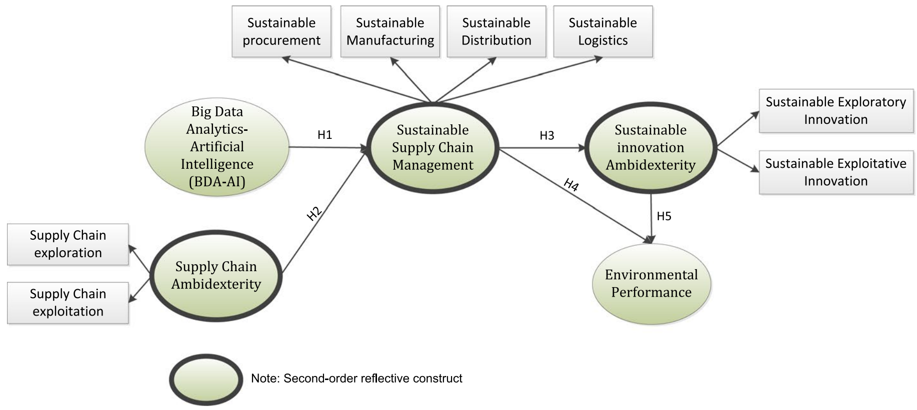

Fig. 1 Theoretical framework

enhance firm performance [130, 131]. A previous human resource research studied SIA in the context of the hotel industry and found that SIA significantly impacted EP [129]. Additionally, a study conducted by Singh et al. [51] also found significant associations between SIA and EP. Consequently, this research postulates the following hypothesis.

Hypothesis 5. SIA has a substantial effect on EP. Fig. 1. indicates the theoretical framework of this research.

Methodology

This empirical study compiles data from a range of sources from the manufacturing industry of Pakistan. The survey was conducted in the country's main industrial hub located in the capital, renowned for its technological advancements relative to other cities in the nation. The target sample for this study were top and middle-level managers possessing knowledge and decision-making power for sustainability and technological changes in their organizations. A total of 195 middle and top-level managers were chosen utilizing a convenience sampling technique. However, the data collection was completed in two rounds due to the non-response issues [133]. In the initial round, researchers managed to collect only a sample of 125 respondents, representing a response rate of 64.10 percent and a non-response rate of 35.9 percent due to the executive level and busy nature of the respondents' jobs. Therefore, researchers focused on the companies with no initial response, urging managers to participate and underscoring the importance of their responses for the study. As a result, in the second round, researchers gathered data from 70 additional respondents. Employee responses to a self-governed, constrained questionnaire were utilized to collect the data [134]. Rather than simply expressing agreement or disagreement, Likert scale questions elucidates the degree of agreement concerning the proposition. This specific research employs a Likert scale of seven points, where 7 implies strong agreement, and 1 implies strong disagreement. Neutrality is indicated by 4.

The items for measuring BDA-AI were adopted and then altered from Bag, Gupta, et al.'s [57] research. The items in Khan, Chen, Lu, et al.'s [26] research were utilized to evaluate SSCM & SCA. The variables used to evaluate the EP were adapted from

Benzidia et al.'s [18] research. However, SIA was assessed using the items proposed by Khan, Chen, and Hung's [84] research.

The study utilized a two-step quantitative methodology of PLS-SEM (partial least squares structural equation model) proposed by Anderson and Gerbing [135]. According to this approach, the measurement research model is evaluated in two steps. The validity and reliability tests of the research framework are employed in the first step of evaluation. The second step includes the evaluation of the research framework's path relationships and their significance [135].

PLS-SEM has been utilized to evaluate the gathered data. The study employed PLS-SEM because of the study's small sample size [136] and to calculate the complex framework of the research uncomplicatedly [137]. The analysis is separated into two sections. In the initial phase of the research, the constructs' validity and reliability were tested, and in the next phase, the casual orientations of the constructs and path coefficients were identified [138]. PLS is the most effective method for retaining specified linkages and calculating complex research frameworks [139]. PLS can be used to assess outcomes with an irregular distribution, owing to the presence of useful indicators for handling randomness in a study's data. The research explored dynamic approaches [140, 141].

Data analysis

Reliability and validity of the measurement model

Convergent validity

Cronbach's Alpha, Rho_A, AVE, and CR are utilized for the examination of the convergent validity of this investigation. Cronbach's alpha was employed to validate internal reliability, whereas CR and Rho_A represented reliability metrics. The Rho_A evaluates the tool's dependability through the assessment of the weights rather than the loadings [142]. To be considered credible, Rho A and Cronbach's Alpha must be above 0.70 [143].

As projected, Table 1 indicates that all constructs exhibit Rho A and Cronbach's alpha values greater than 0.7. The instrument shows internal validity because all components have CR values over 0.70 [144]. Moreover, the outcomes correspond with the results in

Table 1 Construct validity and reliability

Constructs	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
BDA-AI	0.955	0.957	0.961	0.712
EP	0.949	0.949	0.975	0.951
SD	0.987	0.988	0.989	0.919
SCEP	0.941	0.942	0.953	0.773
SCET	0.958	0.958	0.967	0.855
SL	0.916	0.920	0.947	0.857
SM	0.921	0.922	0.950	0.864
SP	0.954	0.956	0.965	0.845
SEP	0.884	0.885	0.920	0.743
SET	0.879	0.882	0.918	0.737

EP Environmental Performance, *BD-AI* Big Data Analytics—Artificial Intelligence, *SCET* Supply Chain Exploitation, *SCEP* Supply Chain Exploration, *SET* Sustainable Exploitative Innovation, *SD* Sustainable Distribution, *SEP* Sustainable Exploratory Innovation, *SM* Sustainable Manufacturing, *SP* Sustainable Procurement, *SL* Sustainable Logistics

Table 2 Fornell-larcker criterion

Constructs	BDA-AI	EP	SD	SCEP	SCET	SL	SM	SP	SEP	SET
BDA-AI	0.844									
EP	0.268	0.975								
SD	0.241	0.219	0.959							
SCEP	0.173	0.441	0.431	0.879						
SCET	0.190	0.451	0.444	0.888	0.925					
SL	0.531	0.324	0.483	0.377	0.322	0.925				
SM	0.559	0.345	0.545	0.361	0.339	0.798	0.930			
SP	0.733	0.300	0.362	0.262	0.237	0.768	0.794	0.919		
SEP	0.427	0.235	0.306	0.254	0.248	0.512	0.498	0.384	0.862	
SET	0.444	0.186	0.318	0.241	0.209	0.470	0.518	0.400	0.784	0.858

BD-AI Big Data Analytics-Artificial Intelligence, *EP* Environmental Performance, *SCEP* Supply Chain Exploration, *SCET* Supply Chain Exploitation, *SEP* Sustainable Exploratory Innovation, *SET* Sustainable Exploitative Innovation, *SD* Sustainable Distribution, *SL* Sustainable Logistics, *SM* Sustainable Manufacturing, *SP* Sustainable Procurement

Table 1. The composite reliability is determined by using the average variance of every factor, which is one of the components of the AVE. This construct exhibits strong convergent validity only when the number is higher than 0.5 [145]. As revealed in Table 1, the AVEs of the hypothetical construct variables vary between 0.712 and 0.951, indicating a significant level of convergence.

Discriminant validity

This signifies the degree to which two constructs vary from each other. Discriminant validity of the research is determined utilizing the criteria of Fornell and Larcker. The square root of the AVE is utilized to identify the latent variables [146]. Table 2 illustrates that the components are much more efficient than the competing constructs in characterizing the variance, given that the adjusted variance estimates' (AVEs) square root is higher than for competing variables.

Discriminant validity assesses the distinction between the different constructs as well as research items. Table 3 demonstrates that the indices utilized to evaluate these constructs possess sufficient discriminant validity. Each indicator representing a specific construct has a value for the factor loading, which is higher than that of every subsequent latent construct. The greatest value of every indicator is indicated by bold text in Table 3 [147].

Examination of the internal (Structural) model

Empirical results

A path analysis of the study framework was performed utilizing the Smart PLS. Calculation of the Inner model was performed throughout this stage. A p-value and a t-value are used to calculate the internal model's parameters. When the t-value surpasses 1.96 and also the p-value is less than 0.05, then the hypothesis is supported.

The path coefficient findings are indicated in Table 4 and Fig. 2. Data from this study shows that BDA-AI ($\beta = 0.538$, t-value = 3.956) and SCA ($\beta = 0.297$, t-value = 2.917) have significant effects on SSCM. This indicates that organizations leveraging BDA-AI

Table 3 Cross loadings

Constructs	BDA-AI	EP	SD	SCEP	SCET	SL	SM	SP	SEP	SET
BDAI1	**0.845**	0.223	0.229	0.214	0.203	0.444	0.466	0.614	0.299	0.395
BDAI2	**0.875**	0.258	0.202	0.160	0.195	0.443	0.498	0.669	0.370	0.393
BDAI3	**0.864**	0.196	0.208	0.129	0.147	0.451	0.452	0.686	0.343	0.380
BDAI4	**0.888**	0.197	0.162	0.067	0.093	0.448	0.455	0.682	0.327	0.368
BDAI5	**0.875**	0.232	0.200	0.139	0.159	0.481	0.464	0.707	0.397	0.413
BDAI6	**0.862**	0.209	0.201	0.185	0.185	0.535	0.523	0.640	0.347	0.386
BDAI7	**0.776**	0.276	0.167	0.146	0.158	0.418	0.402	0.533	0.356	0.390
BDAI8	**0.774**	0.183	0.198	0.093	0.134	0.336	0.409	0.478	0.296	0.253
BDAI9	**0.835**	0.239	0.262	0.152	0.168	0.449	0.534	0.557	0.382	0.345
BDAI10	**0.836**	0.249	0.199	0.161	0.157	0.458	0.497	0.587	0.480	0.407
EP1	0.275	**0.975**	0.214	0.429	0.454	0.311	0.312	0.288	0.233	0.183
EP2	0.247	**0.975**	0.213	0.432	0.426	0.322	0.361	0.298	0.224	0.180
SD1	0.225	0.224	**0.959**	0.407	0.417	0.443	0.520	0.332	0.290	0.301
SD2	0.236	0.203	**0.977**	0.420	0.439	0.472	0.533	0.349	0.311	0.311
SD3	0.216	0.209	**0.967**	0.418	0.432	0.457	0.519	0.332	0.309	0.299
SD4	0.241	0.234	**0.972**	0.423	0.428	0.494	0.525	0.355	0.319	0.319
SD5	0.229	0.213	**0.961**	0.417	0.432	0.479	0.517	0.346	0.302	0.319
SD6	0.242	0.202	**0.969**	0.403	0.415	0.460	0.532	0.353	0.314	0.317
SD7	0.215	0.168	**0.913**	0.407	0.406	0.421	0.495	0.352	0.211	0.258
SD8	0.241	0.223	**0.947**	0.413	0.431	0.478	0.536	0.362	0.285	0.308
SCEP1	0.177	0.430	0.411	**0.869**	0.861	0.336	0.354	0.261	0.251	0.256
SCEP2	0.157	0.316	0.391	**0.847**	0.725	0.370	0.320	0.238	0.285	0.271
SCEP3	0.132	0.358	0.357	**0.862**	0.710	0.330	0.283	0.196	0.204	0.178
SCEP4	0.180	0.397	0.359	**0.900**	0.723	0.334	0.355	0.251	0.260	0.259
SCEP5	0.129	0.402	0.385	**0.895**	0.812	0.316	0.301	0.219	0.183	0.168
SCEP6	0.137	0.416	0.372	**0.902**	0.840	0.305	0.295	0.217	0.162	0.147
SCET1	0.157	0.442	0.423	0.800	**0.914**	0.279	0.290	0.202	0.224	0.218
SCET2	0.174	0.418	0.416	0.824	**0.938**	0.254	0.279	0.199	0.207	0.156
SCET3	0.170	0.435	0.384	0.824	**0.914**	0.308	0.326	0.207	0.257	0.202
SCET4	0.188	0.404	0.422	0.820	**0.937**	0.345	0.361	0.257	0.269	0.236
SCET5	0.190	0.390	0.407	0.836	**0.922**	0.303	0.310	0.232	0.193	0.157
SL1	0.511	0.336	0.468	0.340	0.307	**0.941**	0.757	0.729	0.475	0.431
SL2	0.513	0.360	0.462	0.368	0.299	**0.955**	0.757	0.736	0.469	0.434
SL3	0.449	0.197	0.410	0.338	0.288	**0.879**	0.701	0.665	0.480	0.441
GM1	0.566	0.276	0.406	0.331	0.283	0.804	**0.906**	0.815	0.478	0.518
GM2	0.506	0.327	0.541	0.346	0.339	0.738	**0.951**	0.720	0.473	0.466
GM3	0.487	0.359	0.571	0.331	0.323	0.684	**0.932**	0.680	0.437	0.462
SP1	0.619	0.293	0.406	0.340	0.279	0.784	0.817	**0.911**	0.377	0.429
SP2	0.665	0.311	0.331	0.256	0.245	0.701	0.759	**0.931**	0.363	0.353
SP3	0.677	0.244	0.324	0.212	0.196	0.673	0.686	**0.915**	0.340	0.350
SP4	0.718	0.259	0.289	0.172	0.163	0.691	0.705	**0.930**	0.311	0.330
SP5	0.697	0.271	0.307	0.211	0.198	0.672	0.668	**0.909**	0.372	0.369
SEP1	0.368	0.116	0.296	0.239	0.250	0.419	0.435	0.318	**0.814**	0.694
SEP2	0.322	0.282	0.247	0.230	0.218	0.466	0.428	0.327	**0.900**	0.666
SEP3	0.386	0.265	0.267	0.256	0.239	0.525	0.436	0.363	**0.891**	0.678
SEP4	0.396	0.141	0.245	0.148	0.149	0.351	0.415	0.316	**0.840**	0.665
SET1	0.384	0.125	0.259	0.180	0.169	0.355	0.436	0.320	0.637	**0.870**
SET2	0.380	0.198	0.303	0.207	0.201	0.384	0.474	0.345	0.678	**0.912**
SET3	0.359	0.146	0.216	0.240	0.186	0.361	0.394	0.281	0.700	**0.887**
SET4	0.402	0.169	0.315	0.200	0.162	0.522	0.478	0.436	0.676	**0.755**

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Table 4 Path coefficients

Hypotheses	Path coefficients (β)	T Values	P Values
H1: BDA-AI—> SSCM	0.456	3.726	0.000
H2: SCA—> SSCM	0.292	2.946	0.003
H3: SSCM—> SIA	0.437	7.695	0.000
H4: SSCM—> EP	0.172	2.668	0.008
H5: SIA—> EP	0.382	5.073	0.000

BD-AI Big Data Analytics—Artificial Intelligence, *EP* Environmental Performance, *SCA* Supply Chain Ambidexterity, *SIA* Sustainable Innovation Ambidexterity, *SSCM* Sustainable Supply Chain Management

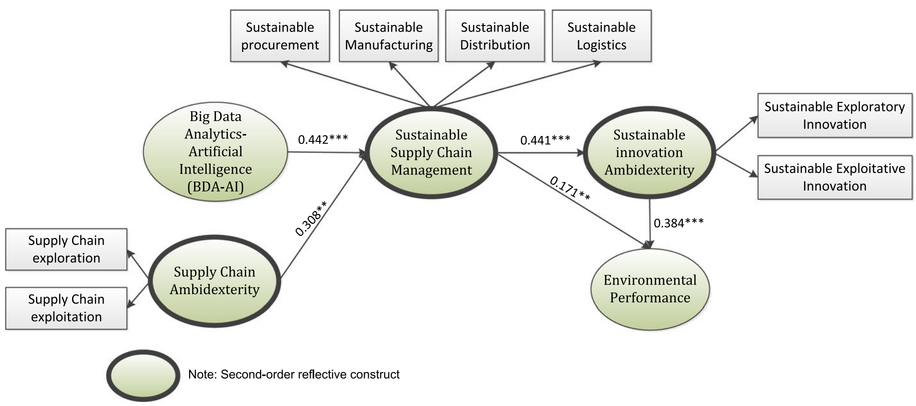

Fig. 2 Path coefficients. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

technologies and SCA are more likely to enhance their sustainable supply chain management practices. SSCM significantly correlates with SIA (β = 0.441, t-value = 7.391) and EP (β = 0.169, t-value = 2.701). This indicates that organizations with robust SSCM practices are better positioned to foster SIA and EP. Finally, SIA significantly impacts EP (β = 0.386, t-value = 4.985). This implies that organizations that prioritize SIA are more likely to achieve superior EP outcomes. Figure 3 of the study describes the software image of SmartPLS. The indirect relationships of the study are provided in Table 5.

Indirect effects of the study

The current study analyzed the indirect impacts offered by SMARTPLS. According to the results, BDA-AI has significant indirect relationships with SIA (β = 0.200, t-value = 3.312) and EP (β = 0.079, t-value = 2.040) by having SSCM as the mediating variable. Furthermore, SCA has significant indirect associations with SIA (β = 0.127, t-value = 2.811) and EP (β = 0.049, t-value = 2.082), with SSCM as the mediating variable. Additionally, BDA-AI (β = 0.077, t-value = 2.509) and SCA (β = 0.049, t-value = 2.224) have significant indirect associations with EP while having SIA and SSCM as mediating variables. Finally, SSCM indirectly associates with EP (β = 0.169, t-value = 3.597) while having SIA as a mediating variable.

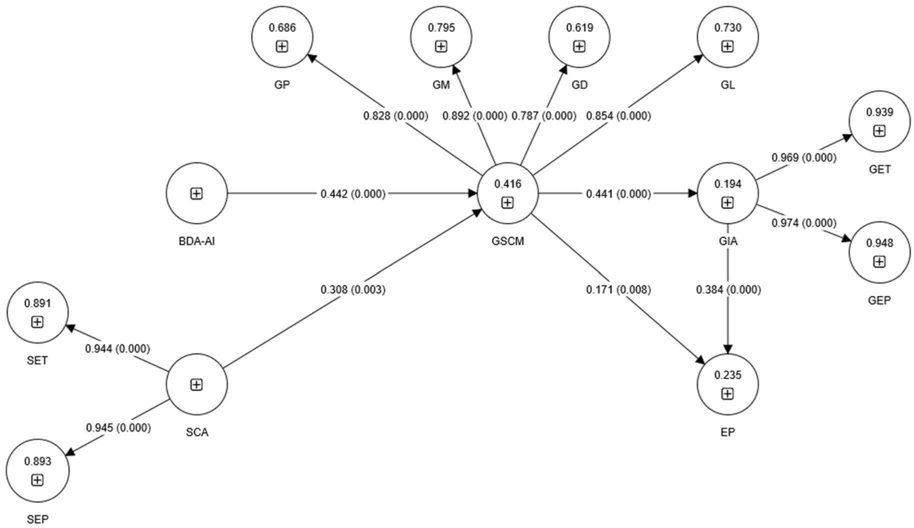

Fig. 3 Smart PLS empirical results

Table 5 Specific indirect effects

Indirect relationships	Path coefficients (β)	T Values	P Values
BDA-AI—> SSCM—> SIA	0.200	3.312	0.001
BDA-AI—> SSCM—> EP	0.079	2.040	0.042
SCA—> SSCM—> SIA	0.127	2.811	0.005
SCA—> SSCM—> EP	0.049	2.082	0.038
BDA-AI—> SSCM—> SIA—> EP	0.077	2.509	0.012
SCA—> SSCM—> SIA—> EP	0.049	2.224	0.026
SSCM—> SIA—> EP	0.169	3.597	0.000

BD-AI Big Data Analytics-Artificial Intelligence, *EP* Environmental Performance, *SCA* Supply Chain Ambidexterity, *SIA* Sustainable Innovation Ambidexterity, *SSCM* Sustainable Supply Chain Management

Discussions

The theoretical framework of this investigation was based on BDA-AI and SCA's direct impact on SSCM and their indirect impacts on SIA and EP. This research aims to cover several research gaps. It explores the relationship between BDA-AI and SCA on SSCM. Second, it examines the impact of SSCM on SIA and EP. Third, it discovers the association between SIA and EP. Finally, this research explores the various indirect associations of BDA-AI and SCA with other constructs.

According to the conclusions of this research, BDA-AI was found to have a significant influence on SSCM. The results of this study are somewhat similar to earlier research [6]. The result can be more precisely compared to a study by Benzidia et al. [18]. Benzidia et al. [18] utilized the theory of organizational information processing by including BDA-AI as well as asserting e-learning as the mediator of the SSCM. Utilizing the technique of PLS, the conceptual framework to examine a data sample from 168 French hospitals was created. The results demonstrated that the use of BDA-AI solutions has a substantial impact on SSCM as well as the environmental process integration. Additionally, the research indicated that SSCM collaboration and the environmental process integration substantially affect EP. Hence, based on the present result, it can be indicated that BDA-AI technologies planning, training, and implementation can effectively aid in greening the supply chain of firms. The present result also supports the theoretical frameworks of various earlier research proposing the employment of BDA-AI technologies in efficient collaboration of supply chain partners [17, 18].

Furthermore, corresponding to the conclusions of this research, SCA and SSCM were found to have a significant association. This result aligns with a previous study by Khan, Chen, Lu, et al. [26]. The main objective of Khan, Chen, Lu, et al.'s [26] study was to investigate how SCA provides support for SSCM and to improve on prior research by analyzing how networking capability helps to clarify the effect of SCA upon SSCM. The emphasis of the research was the top executives of Pakistani manufacturing enterprises. Through cluster sampling, 34 manufacturing industries were picked altogether. The information recorded from the 125 top executives was evaluated using the PLS technique, and the moderation evaluation was carried out using an analysis of variance. Initially, SCA had a positive effect on SSCM. Nonetheless, networking capabilities do not mitigate the association of SCA with SSCM. The present study's results suggest that firms must continually adapt to the dynamic market environment, consistent with previous empirical studies indicating that SCA efficiently aids firms in enhancing their current operations and adapting to dynamic market variations [148, 149]. Furthermore, it is indicated that SCA boosts supply chain partnerships, sustainability, innovation, and adaptability to adjust to dynamic changes [111].

In addition, according to this research's outcomes, SSCM substantially impacted SIA. The results are comparable to an earlier study conducted by Khan, Chen, Suanpong, et al. [42]. Their work contributed to the development of SIA, SSCM, corporate social responsibility (CSR), and second-order social capital (SOSC). Their study developed a theoretical framework focused on the theory of social exchange, Carroll's CSP model, and social capital theory to examine CSR effects upon SSCM, SIA, and SOSC. In addition, the mediating implications of SSCM as well as SOSC on the association of CSR with SIA were investigated. In addition, in their research, a model was presented to describe the effect of SSCM as well as SOSC upon SIA. It was focused on the senior executives of many Pakistani industrial firms. The study selected a combination of 42 manufacturing companies using the convenience cluster sampling methodology. Corresponding to the outcomes of their study, CSR had a positive effect on SIA, SSCM, and SOSC. Furthermore, both SOSC and SSCM exhibited a significant association with SIA. Ultimately, both SOSC and SSCM moderated the connection of CSR with the SIA. The present research result indicated that implementing SSCM through the selection of environmentally concerned suppliers has the ability to enhance SIA. These findings align with the previous empirical framework that advocates for the role of SSCM in enhancing SIA [38]. Furthermore, it is also indicated that the SP of green materials significantly impacts the success of SIA in firms [39].

Additionally, as per the results, SSCM was in a significant association with EP. These results bear some resemblance to an earlier study conducted by Stefanelli et al. [80]. As per Stefanelli et al.'s [80] research, the significance of SSCM rises as it may assist in the enhancement of enterprises' EP. Their research aimed to provide the findings of an analysis done on 80 micro as well as small and medium-sized Brazilian suppliers of the bioenergy industry. These outcomes suggested that SSCM techniques improve the EP of enterprises within the industry. Therefore, their study contributes to the existing body of knowledge by exploring the relationship between SSCM and EP in a field that has not been extensively studied, specifically sugarcane and ethanol production. The present findings propose that close collaboration with supply chain partners will enhance the EP of firms. This finding is also theoretically consistent with previous empirical frameworks indicating that collaborative, sustainable policy implementation will aid firms in maintaining associations with supply chain partners and enhance EP [103, 150].

Moreover, corresponding to the research results, SIA was substantially associated with EP. These findings align with a previous study conducted by Úbeda-García et al. [129]. The goal of Úbeda-García et al.'s [129] study was to examine the connection between green high-performance work systems (GPWS) and EP via the mediation of SIA. The study utilized a variance-based PLS on a sample of Spanish hotel companies. The findings revealed that GHPWS aided the emergence of SIA and that this factor contributed to enhanced EP. Hence, based on the previous discussion, firms with the ability to implement SEP and SET strategies can achieve high levels of SIA. This research result is also in collaboration with the previous theoretical framework supporting organizational ambidexterity's role in enhancing EP [151], and this study also proposes that sustainable innovation in products and processes enhances EP [129].

Consequently, this study also discovered significant indirect relationships between variables while using SSCM as a mediating variable. The indirect findings are somewhat similar to an earlier study conducted by Green et al. [45]. The objective of Green et al.'s [45] study was to significantly contribute to the initial phase of empirical investigations into the impact of SSCM on performance. Additionally, their study aimed to theorize and empirically evaluate a complete SSCM and performance framework. Their study evaluated the data from 159 managers. Data provided by manufacturing managers demonstrated the limit to which their firms cooperate with suppliers as well as consumers to strengthen the ecological responsibility of the distribution network. Adopting SSCM principles by manufacturing firms typically results in enhanced EP and economic strength, thereby benefiting operational performance. Organizational performance is improved through operational performance. The present study theoretically signified the mediating role of SSCM, indicating that implementing SSCM practices will improve the SIA and EP of firms. Sustainability issues have led companies to employ SSCM practices, where they are concerned regarding procurement of raw materials from supply chain partners that are environmentally friendly and possess the ability to adopt sustainable innovation for enhancing the performance of firms [39].

Finally, the study also discovered indirect impacts between the constructs of the study while employing SIA as a mediating variable. The indirect results can be compared to research conducted by Singh et al. [51]. Singh et al.'s [51] study, which drew from the resource-based perspective and the ability-motivation-opportunity theory, the investigation focused on how green human resource management (GHRM) influences the relationships between green transformational leadership (GTL), SIA, and EP. The research gathered triadic data from 309 production industry small and medium-sized businesses using a questionnaire survey (SMEs). Covariance-based SEM was utilized to test this research's hypotheses. The results indicated that GHRM moderates the association between GTL and SIA. Research also discovered that GHRM indirectly regulates EP via GIA. The study concludes that the HRM-performance link does not solely depend on the increased concentration of GTL and SIA as antecedents and mediators, respectively, nor on their interactive effect. Instead, it relies on a combination of both forms to impact company EP. Hence, the present study confirmed the mediating role of SIA, which was previously indicated by studies, especially in the indirect relationship between SSCM and firm performance [39, 41].

Theoretical implications

The theoretical implications of this study are significant. Firstly, the empirical validation of the proposed theoretical framework advances knowledge in supply chain management, sustainability, and innovation. Integrating concepts from BDA, AI, SCA, and sustainability theory offers a comprehensive understanding of modern supply chains. Moreover, the findings underscore the mediating role of SSCM, highlighting its significance in leveraging BDA-AI and SCA for SIA and EP. This validation establishes a robust foundation for future research, facilitating deeper exploration of the complex relationships between these constructs and their implications for organizational sustainability and innovation strategies.

This work integrates BDA-AI with SCA to better comprehend decision-making in favor of the SSCM. This study demonstrates that making decisions built on groundbreaking technology enhances the data-handling capabilities of a company's operations. This conclusion bolsters the notion that enterprises with technology resources and analytic intelligence capabilities may manage the risks associated with the interconnectedness of their units and their dynamic environment. The findings also align with the literature's assessment of the requirement for a supporting IT architecture to foster collaborative stakeholder relationships [18].

Regarding the concept of ambidexterity, researchers in the field of ambidexterity have divergent points of view. The most significant distinction is between the static and dynamic perspectives of ambidexterity. Research academics who view ambidexterity as a static process assert that corporations simultaneously participate in exploitation and exploration endeavors [152]. Others argue that a corporation will traverse a temporal cycle of exploration and exploitation. They consider ambidexterity to be a dynamic and sequential process [26, 153]. This study contributes to the literature on organizational ambidexterity. It portrays ambidexterity as a constant approach in this research, being aware that respondents were asked to indicate their level of disagreement and agreement regarding their organization's exploitation and exploration supply chain processes. Organizations may have been utilizing their existing resources or skills while also investigating innovative methodologies to enhance the productivity of a supply chain. This investigation adds to the sparse literature on the impact of SIA on organizational EP. This study provides evidence that SIA increases EP. That is how the study contributes to the knowledge base by confirming that the SIA enhances EP and also that the development and enhancement of ecological expertise play an essential role in manufacturing industries [129, 154].

Managerial implications

The practical implications of this study hold significant value for managers aiming to boost sustainability and innovation within their organizations. The positive correlation between BDA-AI and SSCM underscores the potential of BDA-AI technologies in streamlining supply chain operations and fostering sustainability. Leveraging BDA-AI tools enables organizations to analyze extensive datasets, extracting actionable insights to enhance EP throughout the supply chain. Moreover, the study highlights the necessity of cultivating an innovative culture within organizations, with SIA identified as a pivotal driver of EP. Managers can encourage the exploration of sustainable technologies and practices, fostering a proactive approach to environmental sustainability initiatives. Additionally, promoting SCA bolsters overall resilience, empowering organizations to adeptly address environmental challenges and disruptions.

This study has a number of managerial and decision-making consequences. Decision-makers can utilize their existing technology capabilities in BDA-AI to establish a proactive environmental strategy that encompasses all company supply chain activities. Utilization of BDA-AI tech enables executives to deploy modern measurements and indices in real-time for improved visualization and understanding of ecological balance facts. That accomplishment may contribute to the circular economy concept as well as policy [18]. This study highlights the necessity of sustainability at the supply chain level and presents data supporting the need for industrial enterprises to adopt SSCM practices in collaboration with consumers and suppliers. Supply chain practitioners have had to acquire SSCM skills, capabilities, and organizational administration expertise and abilities. To improve EP, supply chain practitioners must now concentrate on enhancing the supply chain.

Nevertheless, production supervisors are held accountable for the effectiveness of their organization from a purely pragmatic standpoint. Supervisors will adopt this approach if improving the production chain and satisfying end-users ultimately leads to enhanced performance [45]. This analysis indicates that the firms' EP depends on SIA firms. Therefore, it is recommended that SIA be a proactive approach to reduce or avoid negative environmental consequences to improve EP [129].

Policymakers implications

Regarding the implications for policy makers, researchers have signified the role of BDA-AI in SSCM [155]. SSCM has become an important concern for various policymakers due to sustainability issues, ranging from chemical spills, global warming and poisonous pollutants [156]. Hence, to promote sustainability issues, emerging economies like China and India employ smart detection technologies to detect ecological concerns within firms and between other firms. For instance, Jiangsu, China, employed a smart detection technology to collect millions of unstructured environmental data [6]. In the aforementioned situation, policy makers can employ BDA-AI technologies to further enhance the unstructured data and provide various insights for decisions regarding sustainability concerns in emerging economies [103, 157]. Furthermore, policy makers are suggested to focus on the micro-level determinants, including the local firms' current policies and supplier practices, the intermediate-level industrial operations, and the macro level determined by institutions to design new policies related to sustainable innovation. In addition, policy makers also need to take into account the security and privacy aspects related to BDA-AI when designing policies related to the implementation of SSCM practices. Supply chains based on data can improve the products' traceability and in turn, aid in the ecological impact evaluation [158].

Further research directions

Future studies are recommended to explore the antecedents of the acceptance and integration of BDA-AI techniques in various SSCM initiatives, as well as the internal mechanisms behind the connection between BDA-AI and SSCM to provide new insights. Furthermore, future academics can approach SCA as a first-order concept to conduct a relatively more comprehensive investigation of SCA. Regarding the concept of ambidexterity, scholars hold contradictory opinions. In addition, future researchers can utilize a large sample size from a wider cross-section of businesses to increase the model's universality. Future researchers can also employ this framework in a developed country and conduct a comparative analysis with the present study's results related to emerging economies to offer new research insights. Finally, future researchers can employ a longitudinal study approach to enhance the reliability of results further and offer new insights.

Limitations

This study focused primarily on the direct effects of BDA on GSCM. There is a shortage of knowledge regarding the factors that influence firms' deployment of BDA-AI in SSCM and the processes by which BDA-AI influences SSCM. Research limitations further hindered SCA measurement in this study. It was unable to examine the differential influence of SCA on SSCM due to the possibility that SCA's impact is not equally distributed between exploitation and exploration. By treating SCA as a single concept, this study cannot report the degree of distinction between the exploitation and investigation of SCA. Lastly, the sample size for this research was limited, but it was still substantial enough to deliver sufficient power to examine the hypotheses and was focused on the manufacturing industry.

Appendix A

Questionnaire

Sustainable Supply Chain Management (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [26]	
Sustainable Procurement	
SP1	We follow the principles of the 3Rs: reuse, recycle, and reduce in the process of green procurement in terms of paper and parts containers (plastic bag/box)

Sustainable Supply Chain Management (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [26]	
SP2	We place purchase orders through email (paperless)
SP3	We use eco-labeling on our products
SP4	We ensure our suppliers possess environmental compliance certifications
SP5	We conduct audits on suppliers' internal environmental management
Sustainable Manufacturing	
SM1	We, as a manufacturer, design products that facilitate the reuse, recycling, and recovery of parts and material components
SM2	We avoid or reduce the use of hazardous products within the production process
SM3	We minimize the consumption of materials as well as energy
Sustainable Distribution	
SD1	We use strategies to downsize packaging
SD2	We use "green" packaging materials
SD3	We promote recycling and reuse programs
SD4	We cooperate with vendors to standardize packaging
SD5	We encourage and adopt returnable packaging methods
SD6	We minimize material uses and time to unpack
SD7	We use a recyclable pallet system, and lastly
SD8	We save energy in warehouses
Sustainable Logistics	
SL1	We collect used products and packaging from customers for recycling
SL2	We return packaging and products to suppliers for reuse
SL3	We require suppliers to collect their packaging materials
Big data—Artificial Intelligence (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [57]	
BDA-AI1	Our organization has access to unstructured and structured data sets
BDA-AI2	Our organization amalgamates internal and external data for value analysis in the business environment
BDA-AI3	We apply advanced analytical techniques for decision-making
BDA-AI4	We use computing techniques for the processing of large data sets
BDA-AI5	We use data visualization methods to decode complex data
BDA-AI6	Our management has approved the budget for the big data and artificial intelligence project
BDA-AI7	We give BDAI training to our employees
BDA-AI8	We appoint persons with long experience in handling BDAI
BDA-AI9	We have collaborated with organizations and universities to implement BDAI projects
BDA-AI10	Our BDAI team coordinates effectively with other departments and stakeholders
BDA-AI11	AI bots can assist the sales team by automating certain steps of sales and improving the capabilities of the sales force
Green Innovation Ambidexterity (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [84, 129]	
Green exploitative innovation	
SET1	We usually strive to improve the environmental quality of our existing products
SET2	We often try to reduce the production cost of existing products (services) by choosing low-energy-consuming materials
SET3	We often adjust our product structure to make our products (services) more environmentally friendly
SET4	We often try to improve our business processes to make our products (services) more environmentally friendly
Green exploratory innovation	
SEP1	We often try to create or introduce new green products (services)

Green Innovation Ambidexterity (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [84, 129]	
SEP2	We often try to introduce new environmental protection technology
SEP3	We often try to develop new green products (services) in emerging markets
SEP4	We actively adopt new green products, processes, and services
Environmental Performance (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [18]	
EP1	Our organizational policies help increase compliance with global environmental regulations
EP2	Our organizational policies help reduce environmental accident risks such as waste leakage, poisoning, or radiation emissions
Supply Chain Ambidexterity (scaling from "strongly disagree" to "strongly agree" on a seven-point scale) [26]	
Supply Chain Exploitation	
SCET1	To stay competitive, our supply chain managers focus on reducing operational redundancies in our existing processes
SCET2	Leveraging our current supply chain technologies is important to our firm's strategy
SCET3	In order to stay competitive, our supply chain managers focus on improving our existing technologies
SCET4	Our managers focus on developing stronger competencies in our existing supply chain processes
Supply Chain Exploration	
SCEP1	We proactively pursue new supply chain solutions
SCEP2	We continually experiment to find new solutions that will improve our supply chain
SCEP3	To improve our supply chain, we continually explore new opportunities
SCEP4	We are constantly seeking novel approaches to solve supply chain problems

Abbreviations

BDA-AI Big data analytics—artificial intelligence
SSCM Sustainable supply chain management
SIA Sustainable innovation ambidexterity
SCA Supply chain Ambidexterity
EP Environmental performance
SP Sustainable procurement
SM Sustainable manufacturing
SD Sustainable distribution
SL Sustainable logistics
PLS Partial least square
SEM Structural equation model
CSR Corporate social responsibility
SOSC Second-order social capital
GHRM Green human resource management
GTL Green transformational leadership

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