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Paving the way to environmental sustainability: A systematic review to integrate big data analytics into high-stake decision forecasting[☆]

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ABSTRACT

Big Data Analytics (BDA) is increasingly gaining interest in supply chain management due to the incorporation of digital technology in a range of operations. It facilitates the movement of commodities and data efficiently. However, despite the numerous benefits associated with BDA, there has been limited research on the extent to which BDA can improve environmental sustainability in supply chains. In an attempt to assess the depth of our knowledge, this study undertakes a bibliometric analysis in which 155 relevant articles are retrieved. The assessment discloses the various factors driving, limiting, and stimulating the adoption of BDA in the digital supply chain through analysis and discussion. Additionally, it suggests a framework linking the factors to achieve environmental sustainability. The outcomes of the evaluation indicate that the adoption of BDA could help in realizing an eco-friendly supply chain by reducing the carbon footprint, increasing product life cycles, minimizing the cost of transportation, and reducing transport-related emissions. This research suggests that policymakers should support BDA technology adoption for the reasons identified - it assists in boosting innovation and resilience in the increasingly competitive, ever changing market and the chaotic economic conditions of some industries. Many decisions made regarding environmental sustainability call for policies that will encourage BDA use to address climate, resources, energy management and sustainability factors.

1. Introduction

In the modern world, most sectors face a plethora of challenges that can impede their growth and financial sustainability (Ghosh et al., 2023; Shahi and Sinha, 2021). Various challenges can arise from different factors such as increased competition, changing market trends, emerging client needs, and poor economic conditions (Hanelt et al., 2021). Big data analytics (BDA) is an increasingly popular strategic tool adopted by industries to overcome these challenges (Hajek and Abedin, 2020; Kumar et al., 2022a). It is an analytic methodology used to extract valuable information from vast datasets using advanced tools and techniques (Belhadi et al., 2019; Talwar et al., 2021). Large amounts of data provide the means to analyse customer behavior, market trends and potential weaknesses of a business (Maheshwari et al., 2021; Mariani and Fosso Wamba, 2020). The information obtained is used to identify growth direction, cost reduction opportunities, process and performance optimisation (Huynh et al., 2023). However, one of the major challenges remaining is the ability to make fast, informed decisions (Munirathinam, 2020). In the global business world, firms must be able to make quick and reliable decisions in order to remain competitive (Brinch et al., 2021; Nudurupati et al., 2022). Through BDA, businesses can make decisions based on data driven insights instead of gut feelings, allowing planning for real time feedback (Amankwah-Amoah and Adomako, 2019). In addition, large quantities of data are being produced every

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day, creating enormous problems for companies in terms of storage and analysis (Abawajy, 2015). Managing such data can be very cumbersome if the right tools and techniques are not in place (Siriwardhana et al., 2020). Ram and Zhang (2022) state that BDA assist industries to create detailed analysis of voluminous amounts of data so that new capabilities can be achieved leading to innovation and growth.

The big data era of quick growth offers more opportunities with regard to environmental sustainability and the related challenges of businesses and industries (Li and Huang, 2023). Wang et al. (2016) claim that the appropriate potential of sustainable practice implementation in various industries and further solutions to environmental problems is available within the domain of this data-driven strategy. Similar research is reported by Chang et al. (2022) concerning the importance of the use of the huge amount of data generated every day for new approaches towards environmental sustainability. Pollution, global warming, resource depletion, and biodiversity loss are the main related problems; however, the interactions among them can be determined (Li and Huang, 2023). To be more precise, one of the practical uses is the corresponding monitoring of air and water quality with the help of sensors and IoT technologies. In this way, the real-time nature of such analysis and the potential for immediate response to environmental threats are provided. Big data offers the possibility of sustainable innovation for many organisations (Fang et al., 2022). Researchers claim that by studying consumer behavior, companies can produce environmentally friendly goods or dispose of excess packaging into waste while planning more streamlined supply chains. Data analysis can help in monitoring and improving transport routes, resulting in less greenhouse gas emissions. Recently, the introduction of big data has influenced decision making processes in almost every discipline, including environmental sustainability (Li et al., 2022). Indeed, BDA appear to be essential in a seminal decision-making context such as environmental sustainability (Ram and Zhang, 2022). Experts are able to analyse and interpret deep information sets that deliver clear answers for decisions on key environmental topics - climate change, natural disasters and resource management (Papadopoulos and Balta, 2022). This approach allows decision makers to address potential challenges in their respective sectors ahead of time, devise efficient strategies to ameliorate the issues, and make sure that the given environment will remain sustainable for the current generation and the next (Zamani et al., 2022). As big data triggers a range of transformative changes across industries and, to a considerable degree, society, the environmental sector may also be viewed as a stakeholder which has an opportunity to achieve significant advances by using BDA (Bhatti et al., 2022). BDA allow organisations to explore the needs of the environment in greater detail and develop steps that are best suited to meeting them (Benzidia et al., 2021). Some of the real advantages of using BDA in industry are the Management of Natural Resources (Shah et al., 2021), the Real-time Monitoring of the Environment (Lee et al., 2021), Optimization of Renewable Energy Sources (Mohamed Nazief Haggag Kotb Kholaif et al., 2022), Waste Reduction in Production (Gupta et al., 2019), and Modelling of the Impacts of Climate Change (Sun et al., 2022).

There are several conditions prompting the emergence and expansion of this study. Firstly, environmental sustainability issues have become more complicated and pressing, impacting ecosystems, biodiversity, and human health. Thus, the incidence of environmental problems and sustainability efforts make the study very relevant (Mondal and Palit, 2022). Secondly, the inability of decision makers and other parties involved to fully understand sustainability leads to a lack of more appropriate systems (Bakhsh et al., 2024). Even though multiple attempts to embrace the issue have been undertaken, it is impossible to achieve sustainability due to the constraints of traditional decision forecasting systems (Bibri et al., 2024; Lund et al., 2018). Extant models are not scalable as they do not allow for real-time adjustment of decisions. This is especially applicable to high-stake decision forecasting since the requirements for results to be absolutely correct are exceptionally high due to the enormous value of these stakes. Lastly, numerous decision forecasting techniques as applied to environmental sustainability are available (Ascough et al., 2008; Savun-Hekimoğlu et al., 2021), but not one of them integrates BDA. Therefore, it is reasonable to state that the conditions prompting the expansion of this study are primarily related to the research opportunities provided by business analytics. Overall, these conditions are closely interconnected; no department ever develops without being influenced by external conditions that make it necessary.

This paper aims to contribute to better and deeper research into the area of environmental sustainability. By systematically reviewing existing literature, it is hoped to identify disadvantages in existing methodologies and propose a framework to seamlessly apply BDA in decision forecasting. The research contributes to resolving an improved and more systematic comprehension of the role of big data concepts in addressing the problem of environmental sustainability more deeply and efficiently. This paper seeks to delve into the role of BDA in high-stake decision forecasting for environmental sustainability, shedding light on both the advantages and challenges associated with this approach. Therefore, the study addresses the following research questions (RQ):

RQ1. What are the challenges, barriers, and drivers of adopting BDA in high-stake decision forecasting for environmental sustainability?

RQ2. What are the future opportunities for adopting BDA in high-stake decision forecasting for environmental sustainability?

To address the above RQs, this study presents a review study of 155 relevant articles that provide a thorough understanding of the enablers, challenges, and barriers in the adoption of BDA in decision forecasting through content analysis. Identification of BDA enablers can help practitioners utilise BDA to optimise resources, enhance decision-making, and develop strategies to adopt BDA. Similarly, identifying the barriers and challenges associated with BDA adoption will help industrial practitioners develop strategies to overcome those challenges.

The present study is unique in that it investigates the incorporation of BDA into decision forecasting geared towards environmental sustainability. This research fills a substantial gap in the present body of literature. The research investigates 155 relevant studies to explore the constraints that restrict the growth and financial sustainability in varied industries and to evaluate the rising potential of BDA as a strategic system to overcome these challenges. This research shows the substantial role played by BDA in addressing environmental issues such as climate change and the problem of managing resources; it underlines the significance of BDA in the context of high-stake decision making. Moreover, a substantial contribution to our field of knowledge is made as a result of the systematic review conducted as part of the investigation. This allows us not only to identify factors that facilitate, hinder, and present difficulties in adopting and promoting BDA but also provides a detailed framework for the implementation of BDA in decision forecasting. In addition, this research offers a substantial resource for practitioners as it will allow them to achieve better outcomes, maximize available resources, improve the effectiveness of decision making, and solve the issues related to the integration and implementation of BDA in different settings. It also develops a clear argument that emphasizes the relationship between BDA and environmental sustainability. This may serve as a source of inspiration for researchers and professionals in both the academic and industrial contexts, promoting further research in this field. Overall, this research develops a solid scientific base that has tangible implications for further development of successful policy and industrial practice by stimulating creative and well-informed decision-making with a view to ensuring a sustainable future. The research implications are manifold and extensive. The present framework consolidates various perspectives and helps in understanding the ways in which BDA can help overcome environmental challenges from a theoretical standpoint. Also, the paper leads businesses to understand the potential of BDA to improve resource allocation and decision-making and to facilitate sustainable business development. This accountability-driven approach allows managers to implement BDA to adapt to market dynamics and environmental uncertainty, which aids in the enhancement of their operations. Furthermore, the study provides an argument to enact policies where BDA is a mandatory part of the sustainability plan. Guidelines from the paper can aid policymakers in understanding the main obstacles, drivers, and future potential of BDA incorporation, eventually allowing for a more sustainable multidisciplinary future.

The remainder of the paper is structured as follows. Section 2 describes the research methodology used in the study. Section 3 discusses the barriers and challenges in the adoption of BDA. Section 4 discusses the enablers of BDA adoption. Section 5 presents a discussion along with the proposed research framework. Section 6 presents the implications of the study. Finally, conclusions are presented in section 7.

2. Research methodology

The paper is based on a two-fold research methodology taking into account bibliometric analysis and literature content analysis. “Bibliometric analysis is a valuable method to explore the past trends of the corpus of the literature of any specific domain” (Muhuri et al., 2019). The literature content analysis includes the stages of the process of identifying articles along with their topics (Saihi and Ben-Daya, 2023). In this way, crafting this article consists of four major stages - the development of the search approach, the selection of papers for the research, the identification of topics for bibliometric analysis, and the formulation of research questions for the literature review. The following sections of the article provide the detailed descriptions of each of the steps.

2.1. Search approach

The following strings are incorporated into the search strategy:

String 1: “big data” OR “big data analytics” OR “BDA” OR “large data” OR “Hadoop”, *String 2:* “environment” OR “sustainability” OR “ecolog*”, *String 3:* “supply chain” OR “Logistic*” OR “distribution channel” OR “decision forecast”, *String 4:* “driver” OR “barrier” OR “enabler” OR “roadblocks” OR “challenge”.

These strings are inserted into the Scopus and web of Science database in December 2023 using the abstract title keyword search option. A total of 290 articles are identified based on the inserted keywords. Only journal articles written in the English language are considered for shortlisting. 155 articles are ultimately selected for final analysis. The

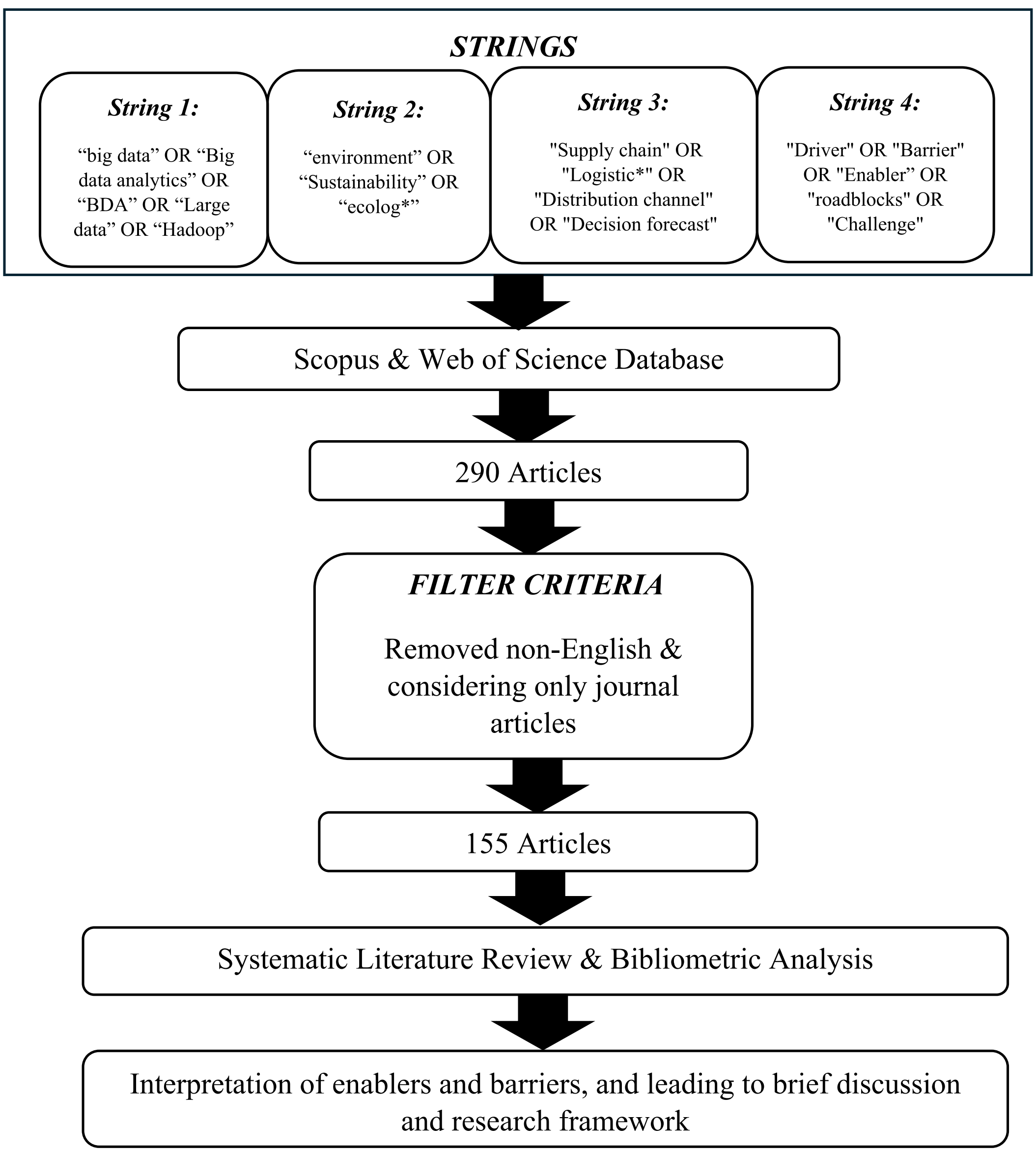

Fig. 1. Research flow diagram.

detailed screening of the articles is shown in Fig. 1.

2.2. Bibliographically important topics

In this bibliometric study, we focus on the following areas:

- Trends in publication: to confirm the number of articles that are published each year throughout the years.
- Most relevant country: to confirm the number of articles that are published throughout the years.
- Most relevant corresponding author's region: to verify the region where the author works in the relevant field.
- Most prominent country: to confirm the maximum number of citations per article received by various countries.
- Most prominent journal: to verify the journals where articles are published.

2.3. Bibliometric analysis

To ensure a rigorous bibliometric analysis, we meticulously select 155 articles; each is systematically downloaded, and the bibliographic details are gathered to allow for examination. To conduct the bibliometric analysis, we employ the advanced capabilities of the Biblioshiny application within the R package, a powerful and dependable open-source software. The decision to utilise the R package stemmed from its robustness and reliability in handling complex analysis. Through the application of this sophisticated tool, this study extracts and analyses key bibliometric details, allowing for a comprehensive and data-driven exploration of the selected literature, as presented in the sub-sections below.

2.3.1. Trends in publication

During the last decade, there has been a significant increase in the number of studies examining enablers and barriers, emphasising the adoption of BDA to provide environmental sustainability. Fig. 2 is a line graph depicting the total number of unique articles. There are three distinct epochs to consider: early, middle, and late stages of evolution. In the first stage, between 2012 and 2015, only three articles are published, which may indicate that the context of adapting BDA to ensure environmental sustainability was not frequently examined during this time. Compared to the total time analysed, the next four years (2016–2019) show only a modest output (25 publications) on this topic. The third and final stage begins with a surge of 24 articles in 2020 and continues to the current day with a total of 125 articles. Increased academic interest in improving the interaction between digital technologies and the environment, as well as increasing public awareness of the negative effects of these technologies, may be the reasons for this trend.

2.3.2. Country profile

This section discusses prominent countries and their contributions to the publication of relevant articles. Fig. 3 illustrates the top 20 countries in terms of significant contributions to publishing articles related to the role of enablers and barriers in the adoption of BDA for environmental sustainability. The outcomes from Fig. 3 indicate that China has published most articles (23) in the relevant context. India (19), the UK (11), the USA (11), and France (9) are the other countries that have contributed most articles published. The statistics shown in Fig. 3 suggest that Europe has contributed most published articles in the relevant context. The most likely reason for this could be the increased use of digital technologies due to a better developed structure in this area.

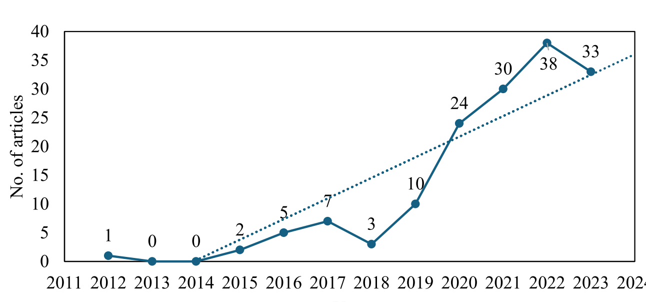

Fig. 2. Trends of article over the years.

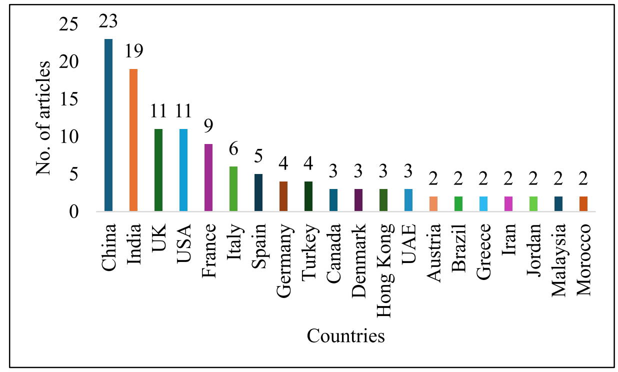

Fig. 3. Most relevant corresponding author's country.

2.3.3. Author profile

This section details the contributions of prominent authors in publishing articles, focusing on enablers and barriers to adopting BDA in delivering environmental sustainability. The information is given in Table 1. The findings in Table 1 indicate that Kumar V (5) and Kumar A (4) are the authors who have contributed most articles. In addition, this section focuses on the most cited articles region wise. The results in Table 1 indicate that the UK is the most prominent country with 1148 citations, followed by the USA (961), China (529), Germany (493), India (445), and New Zealand (380). The information given in Table 1 indicates that most of the cited articles are from Europe.

Finally, this section focuses on the top journals that have published most articles related to the role of enablers and barriers in the adoption of BDA to achieve environmental sustainability. Table 1 indicates that "Sustainability" from Switzerland has published most articles (12), followed by "Business Strategy and the Environment" (5), "Applied Sciences" (4), and "IEEE Access" (4). The outcomes relevant to journal production show that most articles are published in Europe-oriented journals. This could be a reflection of the awareness and more frequent use of journals related to developed countries.

3. Review of the barriers to adopting BDA to achieve environmental sustainability

The selected articles underwent a thorough review to pinpoint the barriers hindering the adoption of BDA in decision forecasting for environmental sustainability. Barriers are divided into five categories: technological barriers, financial barriers, cultural barriers, process-related barriers, institutional and regulatory barriers. Categorisation helps to organise the barriers more efficiently and systematically, collecting them within groups based on common characteristics or themes. As a result, the complexities and commonalities between challenges are clearer and easier to understand for researchers, decision-makers, and practitioners. The main advantage of categorisation is the provision of a strategic context, as different barriers can be recognized in connection to one of the following aspects - technological, financial, cultural, process-related, institutional/regulatory. This advantage is critical for the development of effective strategies and tactics that are needed to overcome obstacles to BDA implementation.

Table 1
Most relevant authors, countries, and journals.

Authors	Articles	Most cited countries	Citations	Highest production journals	Articles
Kumar V	5	UK	1148	"Sustainability (Switzerland)"	12
Kumar A	4	USA	961	"Business Strategy and The Environment"	5
Bag S	3	China	529	"Applied Sciences (Switzerland)"	4
Bui TD	3	Germany	493	"IEEE Access"	4
Gunasekaran A	3	India	445	"Annals of Operations Research"	3
Kang K	3	New Zealand	380	"Computers and Industrial Engineering"	3
Luthra S	3	Canada	248	"Environmental Science and Pollution Research"	3
Mangla SK	3	France	236	"Production Planning and Control"	3
Raut RD	3	Spain	233	"Resources, Conservation and Recycling"	3
Singh R	3	Denmark	221	"Sensors"	3
Tseng ML	3	Norway	208	"Technological Forecasting and Social Change"	2
Agrawal R	2	Malaysia	205	"Benchmarking"	2
Benyoucef L	2	Hong Kong	200	"Computers in Industry"	2
Chang AY	2	South Africa	193	"Energies"	2
El Ouadghiri Md	2	Italy	133	"Expert Systems with Applications"	2
Gupta S	2	Belgium	130	"Frontiers in Public Health"	2
Hassoun A	2	Turkey	90	"International Journal of Information Management"	2
Huang Y	2	UAE	54	"International Journal of Operations and Production Management"	2
Jagtap S	2	Austria	52	"International Journal of Production Economics"	2
Kamble SS	2	Qatar	46	"Journal of Cleaner Production"	2

3.1. Technological barriers

BDA has significantly impacted the decision-making process across industries, in particular concerning environmental sustainability (Pappas et al., 2018). In the particular context of high-stake decision forecasting for environmental sustainability, one of the major public policies that can facilitate the adoption of BDA is the technological barrier. A technological barrier implies various technical issues caused by the complexity and diversity of BDA technologies, such as software, hardware or infrastructural technologies (Ahmed et al., 2023). The involvement of the entire system affects the system level, as it diminishes the scalability, reliability, and interoperability of BDA systems, hindering their integration (Konanahalli et al., 2022).

This section identifies technological barriers from an implementation point-of-view on applying BDA in high-stake decision forecasting for environmental sustainability. The discussion can be summarized by the respective components shown in Table 2. An in-depth knowledge of and a pre-emptive action on these technological constraints is the bedrock for any organisation willing to move towards BDA supportive of environmental sustainability. Mitigating these challenges enables better predictions, policy and environmental outcomes.

3.2. Financial barriers

In the context of high-stake decision forecasting, financial barriers act as another major bottleneck to integrating BDA for environmental sustainability (Abedin et al., 2021). BDA can be used to analyse large amounts of data, helping to discover hidden patterns and making decisions based on past experience (Rudin, 2019). Nevertheless, a number of economic and financial factors have substantial impact on investment towards the application of BDA in high-stake decision forecasting. This section examines the financial constraints on BDA choice in particular areas of interest. Different kinds of financial barriers are explained in Table 3. Knowing the impact of these barriers is vital for stakeholders who may be considering investment in BDA towards sustainability.

3.3. Cultural barriers

In the practice of high-stake decision forecasting for environmental sustainability, another important hindrance to the adoption BDA is the cultural barrier. The culture of an organisation influences its propensity to innovate with new technology, work across different departments and make data-driven decisions (Ojha et al., 2023). Cultural barriers can in some cases be more demanding than financial ones. Cultural barriers are discussed in Table 4.

3.4. Process-related barriers

In the context of high-stake decision forecasting for environmental sustainability, the adoption of BDA is typically hampered by not only financial and cultural barriers but process-related barriers as well. It is vital that all process-related barriers that may arise during the stages of implementation and integration of BDA systems are dealt with through existing organisational processes (Spaltini et al., 2024). In turn, failing to address these obstacles can affect the usability and effectiveness of BDA systems and impede their successful adoption. In this regard, the current section focuses on process-related barriers to the adoption of BDA as part of high-stake decision forecasting for environmental sustainability. Specifically, this section discusses a range of process-related barriers in Table 5. Organisations can benefit from addressing the identified process-related barriers, thus improving the effectiveness of BDA systems.

3.5. Institutional and regulatory barriers

Institutional and regulatory barriers provide another challenge to the adoption of BDA in environmental sustainability high-stake decision forecasting. Institutional barriers relate to problems affecting organisational structure and policies (Alalawneh and Alkhatib, 2021), while regulatory barriers pertain to issues on legal or regulation frameworks guiding data gathering, storage, and processing operations (Georgiadis and Poels, 2021). The existence of these barriers affects the accessibility, security and privacy aspects towards data; this slows down adoption of BDA. We discuss different institutional and regulatory barriers in Table 6. Overcoming these barriers will allow organisations to tackle legal and policy-related obstacles in relation to using BDA for the sake of environmental stability; this will ultimately result in more efficient decisions and better environmental performance.

Table 2
Technological barriers.

S. No.	Barriers	Description	References
1	Data privacy and security (TB1)	One of the key challenges with data privacy is that BDA involves collecting and analysing large amounts of data. Therefore, even if personal information is anonymised, it can still be identified through the use of advanced data analytics techniques.	(Mangla et al., 2022; Perçin, 2023; Pishdar et al., 2018)
2	Lack of data scalability (TB2)	In the context of BDA, it is essential to have a system that can handle large amounts of data without slowing down or crashing. The lack of data scalability can make it difficult for organisations to leverage the power of BDA fully.	(Mangla et al., 2022; Perçin, 2023; Pishdar et al., 2018)
3	Complexity of data integration and management (TB3)	In the context of BDA, data integration can be a complex and time-consuming process. This is because big data often comes from a variety of sources, including structured and unstructured data, and can be stored in different formats.	(Bag et al., 2022; Perçin, 2023; Villa-Henriksen et al., 2020)
4	Poor management of data generated from multiple sources (TB4)	Today, businesses generate lots of data from various outlets such as sensors, market research, social media, and customer transactions. This data can be both structured and unstructured, making it challenging to manage and analyse; this can negatively impact the decision-making process.	(Bag et al., 2022; Park et al., 2018; Verma et al., 2022)
5	Multiple formats of data (TB5)	Data can be structured or unstructured and comes in many different formats, including text, audio, video, and images. Each format requires different analytical tools and techniques, making it difficult to integrate the data for analysis.	(Bag et al., 2022; Park et al., 2018; Verma et al., 2022)
6	Lack of technological development (TB6)	Lack of technological development creates a significant barrier to the adoption of BDA. Without the necessary tools and technologies, organisations may struggle to manage and analyse their data effectively, limiting their ability to make informed decisions.	(Khan, 2022; Mangla et al., 2022; Moktadir et al., 2019)
7	Data heterogeneity (TB7)	Analysing data from different sources and formats requires specialized skills and expertise. Integrating and analysing data effectively can be challenging, and may lead to inconsistencies, inaccuracies, and errors.	(Ardagna et al., 2016; Vassakis et al., 2018; Villa-Henriksen et al., 2020)
8	Data quality and availability (TB8)	If data is inaccurate, incomplete, or inconsistent, the insights gained from the analysis may be unreliable, leading to incorrect decisions. Similarly, if data is unavailable when needed, the analysis may be delayed, hindering the decision-making process.	(Moktadir et al., 2019; Soylu et al., 2022; Villa-Henriksen et al., 2020)
9	Data storage issues (TB9)	Storing and managing large volumes of data can be expensive and time-consuming, particularly if the data needs to be stored for long periods. Storage issues can create significant barriers to the adoption of BDA.	(Alharthi et al., 2017; Pishdar et al., 2018; Raut et al., 2021a)
10	Propagation losses (TB10)	BDA often relies on the use of sensors and other devices to collect data. However, as the signal travels from the sensor to the device or system that processes the data, it can experience propagation losses. These losses can result in incomplete, inaccurate, or unusable data, reducing effectiveness of the analysis.	(Jia et al., 2020; Kamilaris et al., 2017; Villa-Henriksen et al., 2020)

4. Review of enablers of adopting BDA to achieve environmental sustainability

A similar procedure is followed for categorising enablers where literature articles are analysed critically. Enablers are grouped into five categories: sustainability-oriented, supply-chain-oriented, management decision-oriented, technology-oriented, and stakeholder-oriented.

4.1. Sustainability-oriented enablers

The infrastructure and mechanisms necessary to enact sustainability practices in SC can be developed by sustainability-oriented enablers (Mesquita et al., 2023). By so doing, companies can potentially reduce their environmental footprint and improve their sustainability performance (Zkik et al., 2023). An illustration of this is in the utilization of green forms of energy like wind and solar power as opposed to traditional, polluting types. The reduction in pollution can be triggered with a payoff of chain electricity use through BDA environmental sustainability adaptability (Gawusu et al., 2022). With supply chain participants (suppliers and manufacturers) and customer enthusiasm, it becomes easier to make BDA adoption towards environmental sustainability (Bag et al., 2020). A corporate sustainability strategy helps in BDA integration into the supply chain to achieve superior environmental performance. Specific sustainable goals and benchmarks, after BDA operationalization, can lead to locating a site for potential implementation of big data applications that provide sustainability improvement. A complete overview of sustainability-oriented enablers for better BDA adoption to induce environmental support is given in Table 7.

Table 3
Financial barriers.

S. No.	Barriers	Description	References
1	Lack of financial resources (FB1)	Companies usually need to make investments in advanced hardware and software infrastructure as well as hire specialized resources that can gather, process and analyse data for business development. Such expenses might be unaffordable for small businesses or those with limited budgets; such companies may not be able to use BDA as a tool of growth and innovation.	(Bag et al., 2022; Perçin, 2023; Raut et al., 2021a, 2021b)
2	Return on investment (ROI) issues (FB2)	A central concern regarding BDA is that it can be hard to measure the return on investment (ROI) of its use within an organisation. Hence measuring the direct impact of BDA on a company's bottom line can be quite complex.	(Arunachalam et al., 2018; Perçin, 2023; Raut et al., 2021a, 2021b)
3	Major investment costs (FB3)	Large investment costs for BDA are barriers that some businesses face; this means that they may fall short of competitors who have already reconciled it.	(Ada et al., 2021; Kumar et al., 2022a; Moktadir et al., 2019)
4	Revenue and affordability (FB4)	The central issue, concerning both revenue and affordability, is that BDA can be a high-investment initiative which takes time to pay off in the form of added value; it requires considerable resources, both monetary and personnel. Many organisations may not have enough disposable income to invest in implementation.	(Alharthi et al., 2017; Bhattarai et al., 2019; Villa-Henriksen et al., 2020)

Table 4
Cultural barriers.

S. No.	Barriers	Description	References
1	The traditional mindset of existing employees (CB1)	Employees who have worked in an organisation for many years may be afraid of changes in new technology or working routines. Employees often do not have technical backgrounds in terms of data science, or BDA; they therefore cannot comprehend the whole potential of BDA.	(Bag et al., 2022; Doukas, 2022; Pugna et al., 2022)
2	Difficulty in changing organisational culture across the entire organisation (CB2)	Changing an entire organisation's culture requires planning and communication, training, and ensuring it is cost effective.	(Bag et al., 2022; Kache and Seuring, 2017; Shah, 2022)
3	Hesitant company culture (CB3)	There may be a lack of understanding of technology and the benefits that can result from it. In the case of BDA, many employees may not understand the potential of the technology, while others are not technically competent enough to apply it.	(Ada et al., 2021; Kirchherr et al., 2018; Kumar et al., 2022a)
4	Fear of new technology (CB4)	New technologies can be scary for some people to learn for the first time. Unfortunately, fear of data is what prevents most people and organisations from taking advantage of BDA; this happens even when they can benefit greatly.	(Bag et al., 2022; Kumar et al., 2022b; Yasir et al., 2022)

4.2. Supply chain-oriented enablers

In addition to concerns about sustainability, various enablers in the supply chain could be adopted to assist with the integration of BDA to enhance environmental sustainability (Xu et al., 2021). Businesses can concentrate on these sectors by gathering transportation, sourcing and production data from disparate sources of their supply chains through BDA. Organisations could then look into where sustainability can be upgraded, such as, for example, by improving resource use, environmental risk management throughout the SC process or developing collaboration among SC partners through better communication. The application of BDA in this way enables organisations to mitigate their environmental footprints and can thus lead to substantial enhancement in an organisation's overall sustainability performance (Raj et al., 2023). Table 8 summarises the different supply chain-oriented enablers identified in the literature analysis.

4.3. Management decision-oriented enablers

Major drivers dealing with management decisions are the most important factors for BDA adoption in supply chains to reach environmental sustainability (Fantazy and Tipu, 2023). These factors include the establishment of a sustainable and measurable objective framework, integration of sustainability considerations into the decision-making process and BDA to support management decisions related to sustainability. By establishing sustainability goals and metrics, organisations can monitor their progress towards these objectives (Movilla-Pateiro et al., 2021). These sustainability factors form an important part of promoting priorities in a company; it is necessary to consider these priorities within day-to-day operations and their impact on sustainable decision-making. BDA can help to track and analyse real-time data related to performance on sustainability, leading to decision-making becoming more rational. Table 9 describes the various management decision-oriented enablers identified from literature.

4.4. Technology-oriented enablers

The progress of BDA in the supply chain for environmental sustainability is largely dependent on technology-oriented facilitators (Li et al., 2023). Drivers include the means to access data, the implementation of advanced analytical tools, and the ways in which technology is used, such as the Internet of Things (IoT) or blockchain (Richey et al., 2023). IoT can help companies collect vast amounts of data on supply chain operations and analyse this data to identify where they can achieve better sustainability performance. Advanced analytics tools can model and simulate different scenarios to signify to decision-makers how their choices can positively influence sustainability performance. IoT can also be used to collect real-time data on environmental parameters, such as temperature, humidity, and quality of air; this allows companies to better understand their environmental impact and make immediate corrections where needed (Tsipis et al., 2020). Blockchain can ensure the highest level of transparency and traceability in the supply chain,

Table 5
Process-related barriers.

S. No.	Barriers	Description	References
1	Lack of collaboration among stakeholders (PB1)	The obstacles related to process usually arise from the fact that different stakeholders may have conflicting interests; it may be difficult to encourage them to work together towards a common goal. As a result, decision-making is usually delayed, resources are wasted or not allocated correctly; this may hinder the adoption of BDA.	(Ada et al., 2021; Kavre et al., 2022; Khan, 2022; Perçin, 2023)
2	Insufficient training and education (PB2)	Employees with limited training and knowledge of BDA tools may not have the skill sets to use them efficiently; this results in poor or no adoption.	(Bag et al., 2022; Khan, 2022; Perçin, 2023)
3	Lack of skills for proper data processing and correct interpretation (PB3)	The complexity of BDA can be a struggle for employees who lack experience, knowledge or the necessary skills. Problems may arise in getting to know which features are the most useful sources of data for employees' specific tasks; choosing between different algorithms used in processing data or drawing the correct conclusions from interpreting analysis results is challenging.	(Bag et al., 2022; Kumar et al., 2022a; Perçin, 2023)
4	Information sharing (PB4)	BDA does not fulfil its mission if the data used within its silos is limited by a failure to share across the organisation. The absence of information sharing results in possible data duplication and inconsistency that may affect an organisation in understanding operations and performing efficiently across their systems.	(Bag et al., 2022; Khan, 2022; Mangla et al., 2022)
5	Communication protocols (PB5)	Utilizing BDA effectively demands cooperation and communication throughout different teams and departments. However, this becomes difficult when there are no defined communication methods to share data and findings. This may cause misunderstanding and misinterpretation of data when communication protocols are non-existent.	(Sharma et al., 2022; Villa-Henriksen et al., 2020; Xindong et al., 2014)

Table 6
Institutional and regulatory barriers.

S. No.	Barriers	Description	References
1	Weak environmental regulations (IRB1)	Environmental regulations can impact the availability and quality of data, particularly in industries that generate large amounts of data. Weak regulations can result in inconsistent data quality, making it difficult to trust insights gained from analysis.	(Farooque et al., 2019; Kazancoglu et al., 2021; Perçin, 2023)
2	Lack of top management support (IRB2)	Without leadership support, employees may not prioritise the use of data in decision-making, or they may not have the necessary training to use the technology effectively. This can result in incomplete or inaccurate data analysis, hindering the ability of the business to make informed decisions.	(Alharthi et al., 2017; Perçin, 2023; Raut et al., 2021a)
3	Infrastructure unreadiness (IRB3)	BDA requires a robust and scalable infrastructure capable of processing and managing large volumes of data. Businesses need high-speed networks, cloud-based storage, and powerful computing resources; some may lack the necessary infrastructure to support BDA.	(Bag et al., 2022; Kache and Seuring, 2017; Perçin, 2023)
4	Lack of focus in installing modern management practices (IRB4)	BDA can be effectively managed and used only by means of modern management practices - agile methodologies, data governance and data quality management. Yet, a lot of second language businesses may not have the knowledge/skill set or focus to follow these practices accordingly. Without proper data governance, a business may experience issues with guaranteeing both the accuracy and completeness of their data.	(Bag et al., 2022; Kache and Seuring, 2017; Kar and Kushwaha, 2021)

meaning companies can scrutinize their suppliers' sustainability performances and be absolutely assured that established rules and norms are being followed (Venkatesh et al., 2020). By adopting these technology-oriented factors, organisations can improve sustainability performance and reduce their environmental impact. Technology-oriented enablers are described further in Table 10.

4.5. Stakeholder-oriented enablers

The incorporation of stakeholder-oriented enablers is vital in the successful implementation of BDA to reinforce environmental sustainability. Crucial factors include active relations with stakeholders, generating trust and transparency; this encourages stakeholder input for the improvement of sustainability performance (Guo et al., 2024). Organisations which interact effectively with suppliers, customers and regulators, gain a more accurate understanding of their sustainability metrics to identify areas for improvement (Richey et al., 2023). Trust and transparency with stakeholders guarantee an organisation's accountability with regard to sustainability performance, while keeping stakeholders informed and engaged with the organisation's sustainability processes (Masiero et al., 2020). In addition, stakeholder feedback can be used to identify areas for improvement which can be integrated into the priority list for further development. The adoption of stakeholder-oriented aspects can support the organisation in reinforcing

Table 7
Sustainability-oriented enablers.

S. No.	Enablers	Description	References
1	Green design and disposal system (SE1)	BDA can assist green design and disposal systems to identify areas where waste is created and where environmental impact can be minimised.	(Maksimovic, 2018; Yadav et al., 2020; Zhao et al., 2017)
2	Adoption of sustainable energy resources system (SE2)	By implementing sustainable energy resources and using BDA to analyse energy usage data, companies can identify areas where energy consumption can be reduced and optimise their operations to minimize energy usage.	(El-Haddadeh et al., 2021; Gangwar et al., 2023; Sahebi et al., 2022)
3	Educating customers for sustainability (SE3)	Educating customers about sustainability is a great way to lead an effective global campaign so that it brings a positive impact to the market, as people understand more and make choices accordingly. Through tracking customer preferences and behaviours, this data allows companies to use BDA to analyse information gathered, pinpointing which areas could be remodelled to enhance sustainability.	(Cicculo et al., 2022; Côrte-Real et al., 2019; Jamwal et al., 2021)
4	Adoption of industrial ecology initiatives (SE4)	Industrial ecology projects are those that utilise the principles of ecological systems in designing industrial processes which aim to close material loops, minimize waste and enhance environmental performance. Using these to capture waste, improve resource usage and other environmental metrics through data collection means that companies are able to use BDA in order to identify areas where a difference can be made.	(Côrte-Real et al., 2019; Jamwal et al., 2021; Yadav et al., 2020)
5	Continuous monitoring of reduction emission (SE5)	Monitoring ongoing emissions reduction involves regularly collecting and analysing data on emission sources such as production process, transportation (shipment) or energy use. To decide where it can make changes to reduce its carbon footprint, BDA allows a company firstly to collect data regarding emissions from various sources and analyse them later.	(Bibri, 2018; Maksimovic, 2018; Yadav et al., 2020)
6	Adoption of effective process optimisation techniques (SE6)	Process optimization strategies refer to looking at and improving the way you do something in order to make it more efficient; the aim is to reduce waste as well as minimize environmental impact. By collecting data related to the processes involving production, transport and other activities, BDA can analyse this information to identify where changes can be made for sustainability.	(Bibri, 2018; Sestino et al., 2020; Yadav et al., 2020)
7	Understanding the implications of sustainability (SE7)	Using BDA, companies can analyse data to understand the impact sustainability could have on their operations and then make better decisions about which initiatives they should focus their efforts on.	(Côrte-Real et al., 2019; Jamwal et al., 2021; Jum'a et al., 2022)

relationships with their stakeholders and improve the sustainability performance that defines a more sustainable and resilient supply chain. An overview of stakeholder-oriented enablers is shown in Table 11.

5. Discussion

We use a systematic literature review method, allowing us to rigorously review 155 relevant articles using pre-established inclusion and exclusion criteria. This enables targeting to identify high-quality research evidence regarding the adoption of BDA in decision forecasting for environmental sustainability. We also conduct a content analysis of the chosen articles to identify potential themes, challenges and enablers that may be present. These methodologies confirm the reliability and legitimacy of our investigation. For the purposes of validating our research findings, we compare and contrast results with similar studies to determine how this paper is relevant in widening the discussion on the BDA transformative role regarding environmental issues. What makes our research unique is the focus on how BDA may be absorbed in high-stake choice forecasting for environmental sustainability, providing stakeholders with applicable insights. Our study's findings are in line with earlier studies that emphasise the potential importance of BDA regarding ecological concerns (Li and Huang, 2023; Ram and Zhang, 2022). However, our contribution is original in investigating the challenges along with barriers and enablers alongside their impact on BDA into decision forecasting. The established framework is another novelty that gives practical recommendations for managers and policymakers that can inform practice. We present a unique approach that integrates BDA into decision forecasting for environmental sustainability. Critical stakeholders can use this framework to develop a holistic approach to overcome barriers, leveraging key enablers and taking advantage of various opportunities and thus improving their application of BDA in real scenarios. From the systematic review, we identify several enablers and barriers to BDA in decision forecasting for environmental sustainability. This will help practitioners and policymakers prepare to address potential barriers and take advantage of opportunities to make sustainability a reality.

The integration of BDA into decision forecasting also addresses the potential market disaster of urban-rural (U-R) conflicts. Thus, the essence of the research is that real-time monitoring of environmental and socioeconomic indicators allows a timely response to evolving challenges, thereby improving market stability and resilience in U-R conflict-prone areas. During the COVID-19 era, BDA was a key solution to market disasters and resilience building. By examining BDA's role in the pandemic regarding infection rates, healthcare capacity, and

Table 8
Supply chain-oriented enablers.

S. No.	Enablers	Description	References
1	Reducing stock and wastage across the SC (SCE1)	The adoption of BDA in the supply chain ensures more accurate analysis of data. Data analysis helps to minimize stock, optimise production processes, reduce transportation emissions, and lower waste generation.	(Akbari and Hopkins, 2022; Côrte-Real et al., 2019; Khan et al., 2022)
2	Better supply chain response times (SCE2)	By using BDA to monitor supply chains and respond quickly to potential environmental risks, companies can minimize waste generation and conserve resources such as water and energy.	(Bahrami et al., 2022; Bamel and Bamel, 2021; Lamba and Singh, 2018)
3	Supply chain transparency (SCE3)	By making their supply chains more transparent, companies can gather more detailed data on sustainability performance and identify areas for improvement. This data can then be analysed using BDA to identify trends and patterns that can help to optimise supply chain processes.	(Bai et al., 2022; Lamba and Singh, 2018; Mageto, 2021)
4	Supply chain contract management (SCE4)	Supply chain contract management can help organisations to integrate sustainability into their supply chain operations and drive the adoption of BDA to enhance environmental sustainability.	(Akbari and Hopkins, 2022; Gupta et al., 2021; Lamba and Singh, 2018)
5	Improve supplier and supply chain collaboration (SCE5)	By collaborating closely with suppliers, organisations can collect and analyse the data necessary to make informed decisions and take action to reduce environmental impact.	(Akbari and Hopkins, 2022; Bamel and Bamel, 2021; Gupta et al., 2021)
6	Supply chain digitisation (SCE6)	By digitising supply chain processes, organisations can collect and analyse data in real-time, identify environmental sustainability challenges, and take timely action to reduce environmental impact.	(Agrawal and Narain, 2023; Gupta et al., 2021; Kunkel et al., 2022)

economic indicators, policymakers can make well-informed decisions about public health responses, resource deployment and economic recuperation processes. Another significant advantage of BDA is the potential to identify market trends and characteristics that make a successful business. As a result, businesses can rapidly respond to shifting market patterns to minimize the economic impacts of a disruption. In general, this research paper demonstrates that business data analysis has immense potential to address issues of environmental sustainability and avert market disasters. In this regard, this study is critical for providing intervention strategies and a structural BDA strategy to promote viable development and survival amidst complex socio-environmental dynamics. Further, we offer a separate discussion on barriers and enablers identified from the research findings in the following subsections.

Table 9
Management decision-oriented enablers.

S. No.	Enablers	Description	References
1	Recognition of new sales and market opportunities (ME1)	By identifying new sales and market opportunities, organisations can develop new sustainability-focused products and services that meet customer demands and drive environmental sustainability.	(Akbari and Hopkins, 2022; Côrte-Real et al., 2019; Urbinati et al., 2019)
2	Better targeted marketing (ME2)	By leveraging data analytics, organisations can develop more effective marketing strategies that promote sustainable products and services, reach environmentally conscious customers, and encourage changes in behavior.	(Côrte-Real et al., 2019; Grover et al., 2018; Hallikainen et al., 2020)
3	Create new business opportunities/ competitive advantages (ME3)	To gain an edge in the market, businesses may use BDA to discover untapped possibilities and create long-term, sustainable fixes.	(Akbari and Hopkins, 2022; Côrte-Real et al., 2019; Verma, 2017)
4	Improved administration, record keeping reliability and accuracy (ME4)	Improving administration, record-keeping reliability, and accuracy can help companies make better decisions, improve efficiency, and reduce waste, all of which contribute to a more sustainable supply chain.	(Akbari and Hopkins, 2022; Côrte-Real et al., 2019; Lamba and Singh, 2018)
5	Top management support and leadership, change of leadership style (ME5)	By providing resources, creating a data-driven culture, developing a clear vision, encouraging collaboration and leading by example, top management can help promote sustainable practices throughout the organisation.	(Barlette and Baillette, 2022; Côrte-Real et al., 2019; Lamba and Singh, 2018)
6	Government and policy support (ME6)	Government and policy support can help promote adoption of BDA in the supply chain to enhance environmental sustainability by providing incentives, promoting standardisation, funding research, facilitating collaboration and raising public awareness.	(Akbari and Hopkins, 2022; El-Haddadeh et al., 2021; Yang et al., 2023)
7	Management engagement towards sustainability adoption (ME7)	By setting sustainability goals, investing in technology and personnel, encouraging data-driven decision-making, creating a system of accountability, and collaborating with supply chain partners, management can promote sustainable practices throughout the organisation.	(Bag et al., 2021; Mangla et al., 2021; Yadav et al., 2020)

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Table 9 (*continued*)

S. No.	Enablers	Description	References
8	Policies of rewards and incentives for sustainability adoption (ME8)	By encouraging adoption, improving performance, promoting collaboration and enhancing reputation, policies of rewards and incentives can incentivise companies to invest in BDA technology and encourage personnel to support sustainability initiatives.	(Gupta et al., 2021; Wong et al., 2016; Yadav et al., 2020)

5.1. Discussion on barriers

BDA have been employed as a decision-making tool in many fields including environmental sustainability (Awan et al., 2021). With such a vast amount of environmental data and the variation in its patterns, BDA can be adopted as an analysis trend model for appropriate predictions on which decisions have to be made (Feng et al., 2019). Therefore, high-stake forecasting in environmental sustainability is a possible new way of addressing whatever big problems the environment may face; this can be greatly improved with the use of BDA. BDA can process and analyse a variety of data from many sources, thus making it hugely influential. Data from sensors, satellites and social media or any other resources can be collected and trends identified (Ford et al., 2016). With an understanding of this, decision-makers will be better equipped to make more informed decisions that ultimately drive improved environmental performance. Secondly, BDA are useful in forecasting the impact of any interventions made to the environment (Benzidia et al., 2021). Analysis can be made, for example, to predict the impact of climate change and appropriate policies developed to mitigate or adapt impact. But we must remember that when the stakes are high, BDA cannot be totally relied upon for forecasting; there are a range of difficulties - financial, process, technological, institutional and regulatory, cultural plus systemic barriers in particular (Bag et al., 2022; Mangla et al., 2022; Perçin, 2023; Villa-Henriksen et al., 2020). To surmount these barriers, organisations should develop appropriate strategies. For example, they remove the financial problems of initial investment and maintenance cost by using cloud-based solutions (Sharma et al., 2023). Dealing with cultural barriers can be tackled by developing a data-driven culture that is both cooperative and transparent (Robinson, 2020). Technological barriers can be swept aside by investing in BDA solutions that are scalable, flexible and interoperable (Reddy et al., 2022). Institutional and regulatory barriers can be addressed by implementing the correct policies and procedures that make companies or departments comply with all relevant data privacy/security regulations, while also incorporating a culture that promotes data sharing among departments as well as with other organisations (Olawuyi, 2020).

A research framework (Fig. 4) is suggested to aid the proposition of BDA effectiveness in making high-stake decision forecasts for environmental sustainability. This framework has the prevalent nuances of BDA in high-stake decision-making, addressing driving and restricting factors responsible for influencing decisions towards acceptance or rejection. The figure shows how barriers limit the successful use of BDA in high-stake forecasting. These barriers could range from data security concerns and privacy issues to the complexities associated with handling large-scale datasets. The drivers and barriers within this figure provide a holistic view, enabling stakeholders to weigh the potential benefits of BDA against these challenges. This facilitates informed decision-making in the pursuit of environmental sustainability and effective resource management. Table 12 proposes some questions for future researchers.

Table 10
Technology-oriented enablers.

S. No.	Enablers	Description	References
1	Virtual work environment (TE1)	By reducing travel, improving efficiency, increasing data accessibility, providing flexibility and reducing resource consumption, virtual work environments can help supply chain partners to collaborate more effectively and make more sustainable decisions.	(Akbari and Hopkins, 2022; Gupta et al., 2021; Sestino et al., 2020)
2	Enterprise strategic management and new technology coordination (TE2)	By aligning sustainability goals with business objectives, facilitating technology adoption, providing resources and training and encouraging collaboration, companies can effectively leverage BDA tools to support sustainability initiatives throughout the supply chain.	(Espinosa and Armour, 2016; Mandal, 2018; Sestino et al., 2020)
3	Analysis and management of big data (TE3)	By identifying environmental impacts, monitoring performance, performing predictive analytics, optimising supply chain operations and benchmarking against industry standards, companies can effectively leverage BDA tools to support sustainability initiatives throughout the supply chain.	(Akbari and Hopkins, 2022; Khan and Vorley, 2017; Sestino et al., 2020)
4	IT infrastructure (TE4)	By supporting data collection and management, data analysis and processing, data security, integration with existing systems and real-time monitoring and reporting, companies can effectively leverage BDA tools to support sustainability initiatives throughout the supply chain.	(Bamel and Bamel, 2021; Bertello et al., 2021; Lamba and Singh, 2018)
5	Adoption of cyber-physical system (TE5)	By enabling real-time data collection and analysis, predicting maintenance needs, optimising resource usage, developing autonomous vehicles and improving supply chain visibility, companies can effectively leverage BDA tools to support sustainability initiatives throughout the supply chain.	(Agrawal and Narain, 2023; Babiceanu and Seker, 2016; Yadav et al., 2020)
6	Adoption of a machine learning system (TE6)	By enabling predictive analytics, demand forecasting, product quality control, supply chain optimisation, and energy efficiency, companies can	(Lamba and Singh, 2018; Sestino et al., 2020; Yadav et al., 2020)

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Table 10 (*continued*)

S. No.	Enablers	Description	References
		effectively leverage BDA tools to support sustainability initiatives throughout the supply chain.	
7	Digitisation of supply chain activities (TE7)	Organisations may successfully employ BDA systems to back up sustainability goals throughout the supply chain by providing real-time data gathering, greater supply chain transparency, enhanced traceability, optimised inventory management, and increased customer involvement.	(Gupta et al., 2021; Lamba and Singh, 2018; Queiroz et al., 2021; Shajalal et al., 2023)
8	Real-time tracking of suppliers (TE8)	By enabling enhanced transparency, environmental impact assessment, compliance monitoring, risk management and supplier engagement, companies can effectively leverage BDA tools to support their sustainability initiatives.	(Bamel and Bamel, 2021; Gupta et al., 2021; Yadav et al., 2020)

5.2. Discussion on enablers

In recent years, sustainability has risen to prominence as a major concern in the global economy. Neglect of considering environmental factors has meant losses and eventual closure for many factories. Sustainability in manufacturing is however, something that industrialised countries have generally mastered. Yet, developing countries have a far lower adoption rate of sustainable practices (Yadav et al., 2020). New technologies such as BDA are currently available because of the way businesses are trending. These technologies may be classified under the Industry 4.0 umbrella when applied to the industrial sector (Yang et al., 2022). It is crucial to recognize the direct or indirect ways in which such cutting-edge innovations help in environmental preservation (Yadav et al., 2020). For this reason, learning more about the enablers that pave the way for widespread sustainability adoption is important.

While competing on a global scale, it is crucial to provide environmentally friendly goods. A legal need is to consider environmental and social impacts while making products (Gbededo et al., 2018). Therefore, businesses are looking for innovative solutions to meet sustainability goals (Bendul and Blunck, 2019). BDA give a means of bolstering industrial, service, and healthcare institutions (Seuring et al., 2019). Certain businesses in advanced economies, such as Germany, the United States of America and the United Kingdom, have already achieved sustainability by embracing cutting-edge technology, as noted in a number of studies (Dima et al., 2022). BDA serve as an essential mechanism for the success of the supply chain (Hazen et al., 2016). Massive volumes of information are created throughout a supply chain, from the manufacturer to the end customer (Wang et al., 2016). BDA help businesses to become more responsive to market changes, more accurate with their forecasts, and more perceptive in regard to spotting new sales opportunities and marketing possibilities (Efat et al., 2022). BDA also encourage the development of novel CE business models. All these elements profoundly affect sustainable targets (Wang et al., 2016). Authors such as Tortorella and Fettermann (2018) and Moeuf et al. (2020) have published a generic set of enablers for Industry 4.0 technologies that pave the way to sustainability; however, the relevance of these enablers is debatable in developing countries. Two major studies, Yadav et al.

Table 11
Stakeholder-oriented enablers.

S. No.	Enablers	Description	References
1	Greater product customisation (STE1)	By leveraging BDA tools to analyse customer data, companies can better understand customer preferences and offer customised products and services that meet their needs while minimizing environmental impact.	(Gunasekaran et al., 2018; Lehrer et al., 2018; Strange and Zucchella, 2017)
2	Improved performance of existing tasks (STE2)	Improving performance of existing tasks using BDA can help identify inefficiencies, enhance process optimisation, monitor environmental impact, enable predictive maintenance, and reduce inventory waste.	(Akbari and Hopkins, 2022; Jagatheesaperumal et al., 2022; Lehrer et al., 2018)
3	Real-time fraud and risk management (STE3)	Real-time fraud and risk management present challenges; BDA can help identify fraudulent activities, ensure compliance with environmental regulations, reduce risks, enhance supply chain transparency, and improve waste management.	(de Assis Santos and Marques, 2022; Eltweri and Faccia, 2021; Hajek et al., 2023)
4	Use digital technology for new product innovation, intelligence (STE4)	The use of digital technology for new product innovation and intelligence can leverage BDA to support sustainability initiatives in the supply chain.	(Akbari and Hopkins, 2022; Lamba and Singh, 2018; Sestino et al., 2020)
5	Advanced information sharing systems (STE5)	Advanced information sharing systems can help improve the inclusion of BDA in the supply chain to enhance environmental sustainability by facilitating real-time data collection and sharing, data analytics, collaboration, and decision-making.	(Bibri, 2018; Jha et al., 2020; Khan and Vorley, 2017)
6	Adoption of health and safety modules (STE6)	Adopting health and safety modules can indirectly help adopt BDA in the supply chain to enhance environmental sustainability by promoting a culture of safety and environmental consciousness.	(Jamwal et al., 2021; Thibaud et al., 2018; Yadav et al., 2020)
7	Adoption of sustainability supportive policies (STE7)	The adoption of sustainability supported policies can help in the adoption of BDA to enhance	(Côrte-Real et al., 2019; El-Haddadeh et al., 2021; Lai et al., 2018)

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Table 11 (*continued*)

S. No.	Enablers	Description	References
		environmental sustainability by creating a culture that prioritises sustainability initiatives, increases investment in technology, promotes collaboration, and ensures regulatory compliance.	
8	Supplier commitment for sustainable procurement (STE8)	Supplier commitment for sustainable procurement can help in the adoption of BDA to enhance environmental sustainability by providing accurate data, promoting collaboration, managing risk, and ensuring regulatory compliance.	(Agrawal and Narain, 2023; Wong et al., 2016; Yadav et al., 2020)

(2020) and Akbari and Hopkins (2022), show insightful work on identifying the numerous enablers that can assist in adopting BDA into a business to offer environmental sustainability (see Table 1 to Table 5). Yadav et al. (2020) identify 32 Industry 4.0 technology enablers from different literature searches. Akbari and Hopkins (2022) suggest 40 enablers from various past studies. At the same time, businesses should take preventative action against environmental degradation by reducing emissions (Nujoom et al., 2019).

Different stakeholders play a crucial role in an organisation's capacity to remain viable throughout time (Seuring et al., 2019). For sustainability initiatives to be successfully implemented, management must play a vital role and be fully committed to the cause (Koplin et al., 2007). To achieve organisational objectives however, one must first grasp sustainability's central advantages and far-reaching consequences, as stated by Moktadir et al. (2018). The policies that promote sustainability should be fully understood by managers (Luthra et al., 2019). Several key enablers are identified by Koplin et al. (2007) as central to the contribution of management in adopting sustainability practices. Management exerts tight control over budgetary choices made to further an organisation's mission (Piyathanavong et al., 2019). As a result, it is essential to distribute funds among the organisation's many branches wisely. Industry IoT promotion allows businesses to monitor worldwide development and implement sustainable practices across all stages of their operations (Ahmad and Wong, 2019).

Conversely, supply chains and logistics profoundly influence both operational and financial performance (Mani and Gunasekaran, 2018). Therefore, to maintain global competitiveness, it is crucial to digitalise supply chain processes since doing so will allow more precise real-time supplier monitoring. According to Xu et al. (2016), if you want to make a sustainable product, you must ensure that your raw materials come from a reputable source. Reverse logistics allow businesses to save money on research and development while increasing their profits (Gmelin and Seuring, 2014). Therefore, enablers are seen to be important players to help improve the adaptation of BDA for delivery of environmental sustainability. Table 13 proposes questions for future researchers.

5.3. *Economic benefits from the perspective of theoretical, empirical and marginal economic effects*

The implementation of BDA to forecast high-stake decisions regarding environmental sustainability is a novel approach, constituting

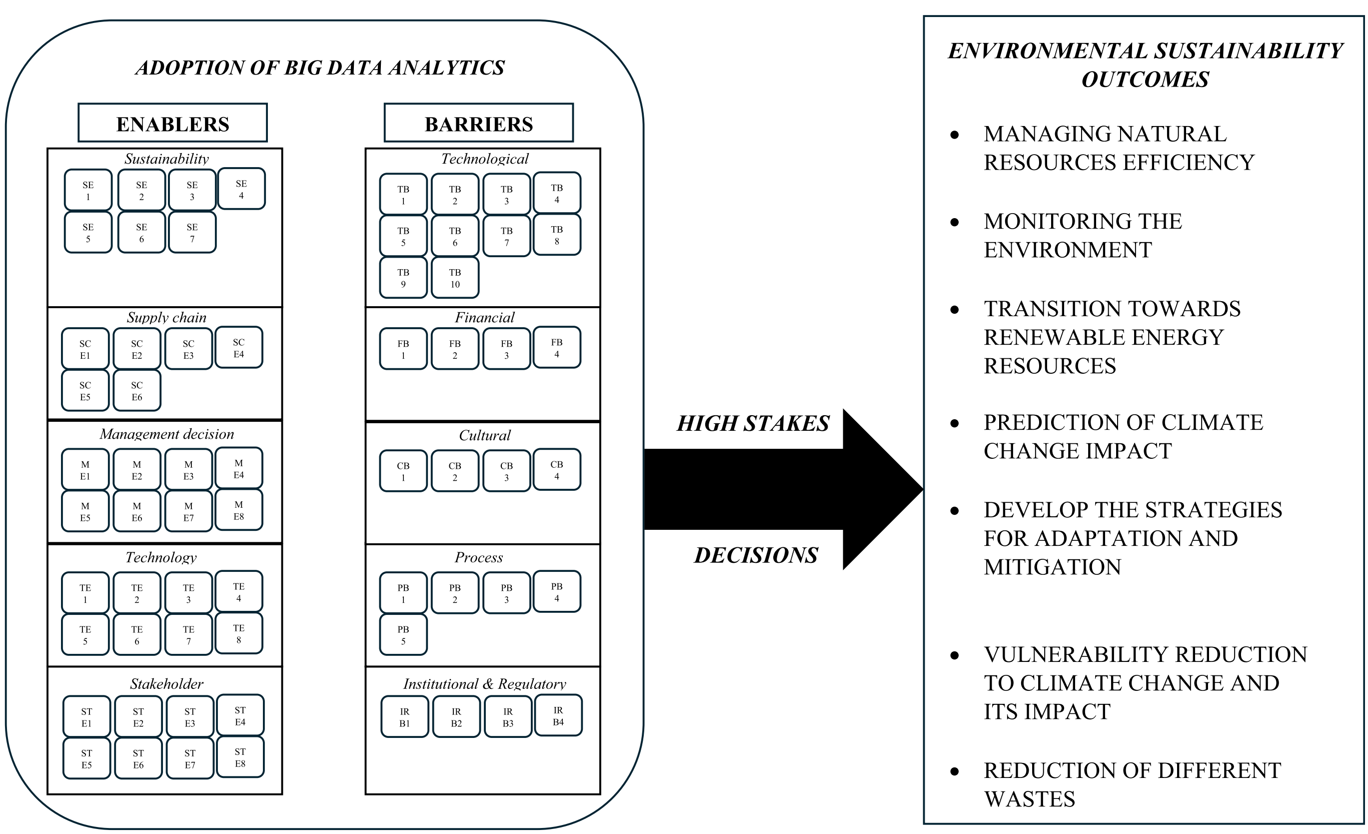

Fig. 4. Future research framework for integrating BDA in high-stake decision forecasting for environmental sustainability.

Table 12
Propositions of future research questions drawn from the literature assessment on barriers.

Direction of discussion	Future research questions (FRQs)
• Barriers are categorised into various types according to their similarities. • By identifying these barriers, firms can navigate the process of overcoming them and thus improve decision-making related to environmental sustainability. • Organisations can devise different strategies for implementing environmental aspects within a company after identifying the different barriers. • A requirement for effective communication techniques is needed to ensure that all stakeholders and decision-makers have a thorough understanding of BDA outcomes and ethical aspects such as data protection and security.	**FRQ1.** What technological and design hurdles must be overcome in order to make BDA tools and technologies more user-friendly and accessible in order to increase their adoption for environmental sustainability decision-making? **FRQ2.** How do barriers to BDA change when comparing companies, industries, and countries? **FRQ3.** How can we secure the trustworthiness and integrity of decision-support systems by addressing the major issues and problems related to data quality, privacy, and security in the setting of BDA for high-stake environmental decision-making? **FRQ4.** How can we best take advantage of the political, cultural, and social aspects that affect the spread of BDA for use in environmental sustainability decision-making? **FRQ5.** How can BDA be used with local knowledge, professional judgement, and citizen science to make environmental decisions that are more robust and relevant? **FRQ6.** What are the ethical and legal consequences of identifying, assessing, and mitigating the possible bias and limits of BDA in the setting of high-stake environmental decision-making? **FRQ7.** How can we identify and cultivate the most important knowledge and abilities for using BDA in high-stake environmental decision-making? **FRQ8.** How can we assure the scalability and sustainability of decision-support systems by identifying and addressing the economic and organisational elements that impact the acceptance and dissemination of BDA for environmental sustainability decision-making? **FRQ9.** How can organisations and sectors tailor best practices and recommendations for applying BDA in high-stake environmental decision-making to their own requirements and contexts? **FRQ10.** To make sure that decision-support systems are legitimate and effective, how do we learn what effects BDA will have on the administration, legislation, and reporting aspects of environmental decision-making?

Table 13
Propositions of future research questions drawn from the literature assessment on enablers.

Direction of discussion	Future research questions (FRQs)
• Enablers are categorised into various types according to their similarities. • By identifying these enablers, firms can navigate the process of promoting them and improve decision-making related to environmental sustainability. • Emphasise the environmental advantages that may result from using BDA. • The importance of multidisciplinary work and stakeholder participation in BDA implementation to achieve environmental sustainability is discussed.	**FRQ1.** How might we best go about creating the technical foundation for the widespread use of BDA in ecologically responsible policymaking? **FRQ2.** How can organisations maximize the benefits of organisational facilitators of BDA adoption, such as buy-in from top management and sufficient funding? **FRQ3.** How can security, confidentiality, and responsibility issues related to BDA be successfully addressed, and how can the resulting ethical and legal frameworks be applied in environmental decision-making settings? **FRQ4.** To successfully use BDA for environmental decision-making, how can cultural and social elements be utilised, and what are the best practices for controlling these factors? **FRQ5.** How can the return on investment (ROI) of BDA-based decision making be successfully quantified and communicated, and what are the primary financial facilitators of BDA adoption for environmental decision making? **FRQ6.** How can the efficacy and usefulness of BDA systems for environmental decision-making be maximised, and what design principles should be applied to do so? **FRQ7.** How can stakeholder participation be handled efficiently, and what methods have been most successful in enlisting their support for BDA‘s role in environmental decision-making? **FRQ8.** To make sound BDA-based decisions based on accurate and trustworthy environmental data, how can best practices in data governance and management be put into place? **FRQ9.** How may BDA-based outcomes be communicated to decision-makers and stakeholders in the context of environmental sustainability, and which communication techniques are most successful for doing so? **FRQ10.** In regard to making environmentally responsible decisions, how can BDA systems make use of cutting-edge technology such as edge computing, artificial intelligence, and machine learning?

a profound paradigm shift. In theoretical terms, BDA have the potential to contribute to the improvement of the decision-making process by analysing the vast amount of data derived from sensors, satellites, social media, and a range of other sources. As a result, outcomes regarding the environment should theoretically improve as well, with environmentally sound decision-making, strategic management of resources and opportunities being facilitated by this novel form of analysis.

On a practical level, Awan et al. (2021), Feng et al. (2019), and Ford et al. (2016) have conducted empirical studies that demonstrate the tangible economic benefits of the use of BDA in the context of environmental sustainability. These empirical results correspond with theoretical developments, suggesting that BDA is capable of analysing and predicting environmental trends and, as a result, provides decision-makers with the necessary input to make informed choices (Benzidia et al., 2021). The resulting empirical evidence reinforces the economic argument for the use of BDA in decision-making regarding environmental sustainability. The application of BDA can also be used to predict the potential impact of decision implementation, for example climate change impact prediction and strategies for its mitigation and/or adaptation. Throughout its use, we can observe incremental improvements in the measures of sustainability, waste reduction, as well as intuitive resource management.

There are still several barriers to the comprehensive economic implementation of BDA for environmental sustainability. The existing financial, cultural, process-related, technological, institutional, and regulatory limitations must be overcome in order to realize the economic benefits of this approach. Cloud-based solutions should be adopted, a data-driven culture should be developed, a scalable solution implemented, and a data privacy and security policy developed. The application of these strategies allows stakeholders to implement BDA to its full extent. Additionally, the research framework described in this paper considers both drivers and barriers, providing decision-makers and stakeholders with a comprehensive view of the topic based on which, informed choices can be made. From this perspective, it can be observed that the role of sustainability has never been greater in the context of current globalized economic conditions. Although supportive of an environmentally friendly way of living, the case for applying BDA is not limited only to assessing how environmentally friendly one's decisions are. The technology can also be used to improve the efficiency of supply chain decisions, financial outcomes, and a broad range of other business issues, correlating with the determinants discussed in earlier studies (Yadav et al., 2020; Akbari and Hopkins, 2022). As a result, the economic benefits of applying BDA concerning environmental sustainability can be viewed as ranging from theoretical justification to existing empirical evidence promoting implementation with some minor improvements.

6. Implications of the study

6.1. Managerial and practical implications

This article is a systematic review on the adoption of BDA in the field of high-stake decision forecasting to reach environmental sustainability. By leveraging vast amounts of data, BDA can help decision-makers accurately predict and manage the impact of their decisions on the environment (Chatterjee et al., 2023). BDA can improve the accuracy and reliability of environmental forecasting models (Benzidia et al., 2021). The decision-makers can build more comprehensive forecasting models with the help of large datasets (Nisar et al., 2021). In addition, this study can help decision-makers to expose potential risks and assess opportunities. Thirdly, the implementation of BDA increases the validity of forecasts. This method can help decision-makers to make more reasonable and, therefore, more sustainable choices (Wong-Parodi et al., 2020). Besides, BDA can alert us to links between substances and different chemicals that may impact environmental conditions. Finally, the use of BDA allows identification of the causes of environmental issues and the possible ways to resolve them (Kauffmann et al., 2020).

BDA can determine those areas where it is most likely that using a specific intervention will be most effective. This can help to build adaptive management approaches (Raj et al., 2023). By continuously monitoring and scrutinizing the environmental data, BDA can help decision-makers to recognize the changes and troubleshoot strategies in good time (Settembre-Blundo et al., 2021). For instance, it can assist in detecting those areas where it is possible to control the emission of greenhouse gases in the most eco-friendly way possible and the ways to manage water resources most effectively. It will also allow stakeholders who are interested in environmental monitoring and protection to use BDA to analyse data and look for patterns and trends to develop preparedness measures (Ahmed et al., 2023). For example, modern BDA can provide prediction models with real-time data to predict the development of a natural catastrophe or the deterioration of an environmental situation in a particular area (Merz et al., 2020). Industrial stakeholders can benefit from adhering to industrial sustainability policies based on data analysis and resident requirements. For example, the production of various manufacturing units may be better optimised, which in turn minimizes waste and other pollutants, thus reducing the environmental footprint (Amjad et al., 2021). In addition, living conditions of inhabitants from urban and rural areas are subject to significant improvements when specific policies are implemented timely. Thus, waste management may become more efficient, air can be made cleaner, and urban areas better planned.

6.2. Policy implications

Adaptive management strategies can be enabled through BDA. Continuous monitoring, and analysis of environmental data, such as satellite remote sensing technologies, can alert decision-makers to changes in ecosystems. This enables any need for intervention with strategies that would serve to ensure the sustainable outcomes of their decisions (Settembre-Blundo et al., 2021). Investing in data infrastructure can support monitoring and detection of environmental impacts quickly. Such infrastructure can enable decision-makers to take timely actions that maintain ecosystem health and counteract harmful environmental effects. For instance, in the Amazon rainforest, instantaneous satellite data has been used to combat illegal deforestation, enabling timely enforcement responses from the authorities (Mullan et al., 2022). BDA can also be used to enhance transparency and accountability (Agostini et al., 2023). Policymakers must ensure open-access publishing of environmental data and support collaboration between the public and private sectors on issues surrounding data integrity. This should provide accountability while empowering citizens to take part in the environmental decision-making process. An example of this already in practice is the European Union "Copernicus" program that provides free satellite data, a prototype for climate transparency and global climate cooperation (European Commission, n.d.). BDA can produce evidence that can be employed to steer species-oriented environmental policies. For example, pollution should be monitored in real time to inform policy on ecological conservation (Xu et al., 2020). Authorities must build BDA into their regulatory frameworks to monitor pollution control and ensure that policy responses are reactive to the extent needed. This may include setting up watch systems that inform specialists if corrosion surface plunging or new ecological dangers appear. One example is air quality monitoring networks set up by China in cities such as Beijing; this enables real time data to inform government decision-making and has resulted in tougher air pollution controls (Li et al., 2024). Such results highlight the potential for predictive analytics to bring about greater resource efficiency. This helps in the allocation of resources (Zhongping et al., 2023), making this relevant for governments, corporations and other organisations. It is also useful in anticipating potential future environmental disasters. There must be an emphasis on data sharing and analysis, a drive towards broader collaborative strategies around environmental sustainability and a willingness for governments, the business sector and communities to work together. The UN's Global Partnership for Sustainable Development Data works to build cooperation between governments, international organisations and private sector partners around data that can help drive progress towards SDGs (UN, 2023). Many similar initiatives are needed.

7. Conclusion

The adoption of BDA in predicting high-stake decisions for environmental sustainability can change the way we deal with our environment. With BDA, decision-makers will be able to gain access into environmental patterns and trends; they can make very accurate forecasts of what the impact a variety of interventions will be on the environment. Based on such studies, better decisions can be made to produce much improved outcomes. The overall goal of this paper is to assess how BDA can help in high-stake decision forecasts related to environmental sustainability. The adoption of BDA for environmental sustainability presents numerous opportunities and challenges. Therefore, a systematic literature review is performed, and various enablers are recognized. Challenges and barriers to BDA adoption are identified. This systematic review sheds light on the integration of BDA in high-stake decision forecasting to achieve environmental sustainability. The key findings from our review emphasise the pivotal role of data-driven insights in addressing the complex challenges associated with environmental sustainability. We highlight both the drivers of and barriers to BDA adoption, offering a comprehensive understanding of this area.

The essential approach to address these challenges is the aim of researchers. Experts and policymakers must fully ensure safe and ethical use of BDA and the provision of adequate information and education to the people who are tasked in using the technology and those influenced by it. When adequately resourced and supported, BDA can play a crucial role in equitable environmental sustainability and realization of long-term goals. This analysis, therefore, responds to the first research question by identifying the necessary and sufficient conditions that make it easier or harder to use BDA to predict high-stake decisions. The second question is answered by the framework for future research which shows how drivers and barriers of BDA interact with each other in working for environmental sustainability. This requires efficient utilization of natural resources, environmental management, predictive and preventive measures of environmental impacts, risk and climate change reduction, and waste minimization.

The methodology of systematic reviews is not immune to selection, inclusion and exclusion bias or quality assessment. The inclusion or exclusion of studies is often based on subjective judgments taken by researchers themselves, potentially influencing the findings. Future reviews should use automated tools to screen and assess studies, to reduce human bias and increase reproducibility. For example, machine learning techniques can facilitate the systematic and objective screening of relevant studies. The enablers and barriers identified and appraised are based on the views of researchers performing the review. This can mean that, depending on the interpretations of those carrying out the reviews, certain drivers or barriers may be over-represented and others under-represented. This should be validated in future studies. To address this limitation, diverse teams with multidisciplinary expertise should be introduced and application of a Delphi or consensus-building approach used to complement the work. Also, involving outside reviewers or other stakeholders can mitigate bias in the evaluation process. The article identifies data privacy, ownership and algorithmic bias as ethical concerns but is neither comprehensive nor systematic in its review. These are vital points around which trust and acceptance of BDA for environmental sustainability can be built. Further study can investigate ethical frameworks and governance mechanisms to ensure fair and proper use of BDA. Special emphasis should be placed on guidelines for data protection, participation at the design stage of algorithms and reducing bias. The study recognizes differing perspectives among stakeholder groups about factors that drive or hinder adoption of BDA, but does not investigate whether these conflicts lead to positive or negative outcomes. This collective misalignment can make the adoption of BDA into decision-making more challenging. We recommend carrying out further research in which the different views of stakeholders are included (policymakers, companies and the local community), to develop an even more complete view. Interviews and case studies can be mixed-method approaches that help researchers to understand the dynamics between stakeholders. Despite the implications of national and regional level results, some issues such as differences in BDA adoption by region, sector or industry are not duly addressed. In future, reviews should be broken down to a more granular level, such as region or industry, to identify localised challenges and opportunities. In addition, comparative analyses across regions or sectors can identify opportunities to target specific areas for policy development.

CRediT authorship contribution statement

Rohit Agrawal: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Nazrul Islam:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Ashutosh Samadhiya:** Writing – original draft, Visualization, Methodology, Conceptualization. **Vinaya Shukla:** Writing – review & editing, Visualization, Supervision, Investigation. **Anil Kumar:** Writing – review & editing, Supervision, Investigation. **Arvind Upadhyay:** Writing – review & editing, Visualization, Supervision, Investigation.

Data availability

Data will be made available on request.

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