The Role of Big Data Analytics in IoT-enabled Green Supply Chain Management: Architecture, challenges, and future perspectives

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Abstract

The integration of the Internet of Things (IoT) and Big Data Analytics (BDA) has brought about a revolution in Green Supply Chain Management (GSCM). In particular, it has enabled the optimization of many aspects of the supply chain (SC), including transportation, inventory management, and customer service. The application of BDA in IoT-enabled GSCM is receiving a lot of attention because it has the capacity to assist businesses become more cost-effective and environmentally sustainable to make more informed decisions. By identifying the inefficiencies in the supply chain and take corrective action. With the advent of the IoT, businesses are now able to get a great deal of information from sensors that are installed in different parts of their SC, including transportation vehicles, warehouses, and factories. This data can be leveraged for a variety of purposes, including optimizing the SC for sustainability and reducing its environmental impact. There are also challenges associated with BDA in IoT-enabled GSCM. The volume of data that needs to be processed presents the biggest obstacles. This requires specialized tools and expertise in data management and analytics. Despite these difficulties, technology has the power to completely alter how firms conduct their operations. This paper presents an overview about BDA in IoT-enabled GSCM. The review highlights the benefits and challenges in adopting BDA in IoT-enabled GSCM, the key technologies involved, and the various applications of BDA in IoT-GSCM. Finally, provides insights into the future directions of research in this area.

Keywords: Big Data Analytics (BDA); Internet of Things (IoT); Green Supply Chain Management (GSCM).

1. Introduction

In recent years, there has been an increasing trend towards using Big Data Analytics (BDA) in Supply Chain Management (SCM) to improve operational efficiency and decision-making [1]. Since the creation of the Internet of Things (IoT) and the expansion of sensor technology and other data-gathering devices, there is a wealth of data available in supply chain operations that can be leveraged through BDA techniques [2]. This has led to the emergence of a new field of research, known as IoT-enabled green supply chain management (GSCM) [3], which focuses on using BDA to optimize sustainability and environmental performance in SC operations. IoT-enabled GSCM involves the use of IoT devices and BDA technologies together to gather, store, and analyze a lot of data from different sources in the SC. This data includes information on product demand, inventory levels, transportation routes, fuel consumption, and other relevant factors that impact the sustainability and environmental performance of the SC [4]. By leveraging cutting-edge analytics methods like machine learning and predictive modeling, supply chain managers can gain insights into these data sets and make data-driven decisions that optimize sustainability and reduce environmental impact [5]. The use of BDA in IoT-enabled GSCM has the potential to improve SC efficiency and reduce costs, while also enhancing sustainability and environmental performance. By leveraging data from IoT devices, supply chain managers can gain a better understanding of their operations and make more informed decisions [6]. For example, they can optimize

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transportation routes to reduce fuel consumption and carbon emissions, or adjust inventory levels to minimize waste and reduce costs. Overall, the use of BDA in IoT-enabled GSCM represents an exciting opportunity for organizations to improve their supply chain operations and meet sustainability goals, while also reducing costs and improving customer satisfaction. As such, it is an area of growing interest and research in the field of SCM [7].

This research paper makes the following contributions:

1. Overview about BDA in IoT-enabled GSCM
2. The benefits and challenges in adopting BDA in IoT-enabled GSCM.
3. The key technologies involved in adopting BDA in IoT-enabled GSCM.
4. The various applications of BDA in IoT-enabled GSCM
5. Finally, provides insights into the future directions of research in this area.

The sections that precede are set in the order that follows. Section 2 presents an overview about the IoT & Big Data Analytics. Section 3 discusses the IoT-enabled GSCM process. In section 4, we discusses the Role of BDA in IoT-enabled GSCM. The future directions of research in this area are discussed in section 5. We conclude our work in section 6. Finally, list of our references.

2. IoT & Big Data Analytics Overview

IoT and BDA are two technologies that are increasingly being used together to create new applications and business models [8]. IoT is a network of physical devices, gadgets, and sensors that are linked together so they can interact and share data [9]. BDA refers to the procedure of gathering, handling, and examining enormous amounts of data in order to find patterns, insights, and trends. When these two technologies are combined, they create a powerful platform for collecting, analyzing, and utilizing data from a wide range of sources. IoT devices generate vast amounts of data, including environmental data, user behavior data, and operational data, which can be analyzed using BDA tools to gain insights that can be used to optimize processes, improve efficiency, and drive innovation [10].

2.1 IoT

IoT which is a network of physical objects or devices that are embedded with sensors, software, and connectivity to enable them to collect and exchange data with other devices and systems over the internet [11]. The goal of IoT is to create a more connected world by allowing devices to communicate and work together to automate tasks, improve efficiency, and enhance overall quality of life. IoT technology is being used in various industries, such as healthcare, manufacturing, transportation, agriculture, and smart homes. IoT devices can range from simple sensors to complex machines and appliances. These devices can collect data on various aspects of their environment, such as temperature, humidity, light, and motion [12]. This data can be analyzed and used to make decisions or automate actions. IoT also involves the use of cloud computing and data analytics to process and store the massive amounts of data generated by these devices. This allows for real-time monitoring and analysis of data, which can help identify patterns and trends and optimize processes [13].

2.1.1 IoT Architecture:

IoT architecture describes the system's layout and organization that enables the interconnectivity of devices and sensors. The architecture defines the components, protocols, and communication interfaces required for IoT devices to communicate with each other and with cloud-based platforms for data processing and analysis. There are several layers in the IoT architecture, including [14]:

- Perception layer: This layer includes physical gadgets and sensors that gather environmental data. These devices can include sensors, cameras, and other IoT devices that are embedded in the environment or attached to assets such as machines or vehicles. The perception layer is in charge of gathering unprocessed data and transmit it to the network layer.
- Network layer [15]: This layer is in charge of establishing a connection between the cloud and the perception layer's devices or other networks, enables communication between devices and the cloud, and it can use a variety of wireless technologies like cellular networks, Wi-Fi, Bluetooth to transmit data.

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- Application layer: This layer is in charge of processing and examining the information gathered by the perception layer. The application layer can include cloud computing platforms that enable data storage, analytics, and visualization. It can also include software applications that are designed to perform specific functions based on the data collected, such as machine learning algorithms, predictive maintenance systems, or automation systems.

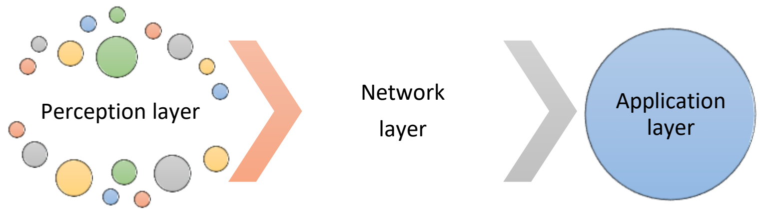

Figure 1: IoT Architecture

These three layers work together to enable the collection, transmission, and processing of data from IoT devices. The perception layer collects data from the environment, the network layer connects devices to the cloud or other networks, and the application layer processes and analyzes the data to enable intelligent decision-making and action. Figure 1 represent this architecture

2.1.2 IoT technologies:

IoT technology is being used for a variety of areas, like: Smart homes, Healthcare, Manufacturing and Security. The growth of IoT is expected to continue, with estimates of over 75 billion connected devices by 2025 [16]. The development of 5G networks is expected to further enable the proliferation of IoT, as it will provide faster and more reliable connectivity. AI and machine learning are also expected to play a significant role in the future of IoT, as they can help process and analyze the massive amounts of data generated by these devices here are some common IoT technologies [17]–[19]:

- Sensors: Sensors are devices that collect environmental data such as temp, moisture, and brightness or motion. They are essential components of IoT systems and enable the perception layer of IoT architecture.
- Connectivity technologies [20]–[23]: IoT devices use various wireless technologies to communicate with each other and the cloud. Such as Wi-Fi, Bluetooth and cellular networks such as 4G LTE and 5G.
- Cloud computing platforms [24][25], [26]: Cloud computing platforms provide the infrastructure and services required to process and store the huge volume of data generated by IoT devices. Amazon Web Services (AWS), Azure, Google Cloud Platform, and IBM Cloud are some of these platforms.
- Edge computing [27], [28]: Edge computing is a distributed computing paradigm that makes it possible to process and analyze data more closely to the data source, rather than in the cloud. This can reduce latency and enhance real-time assessment in IoT applications.
- Machine learning and artificial intelligence: Machine learning and AI are used in IoT applications to analyze data and make predictions or decisions based on that data. These technologies can enable automation, predictive maintenance, and intelligent decision-making in various industries.
- Blockchain [29], [30]: enables secure and transparent transactions between devices without the need for intermediaries. It can be used in IoT applications to enable secure data sharing and device-to-device transactions.
- Radio-Frequency Identification (RFID): uses Radio waves to automatically identify and track items. RFID tags can be attached to objects and used to collect data about their location, status, and other properties.
- Near-Field Communication (NFC) [9]: NFC is a short-range wireless communication technology that enables objects to communicate over a few centimeters enabling devices to share data. NFC can be used for a variety of IoT applications, such as contactless payments, smart ticketing, and access control.
- Data analytics and visualization tools[31]–[33]: Data analytics and visualization tools are used to process and analyze the vast amounts of data generated by IoT devices and sensors. These tools can help organizations make sense of the data and uncover insights and trends that can be used to improve business operations, reduce

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costs, and enhance customer experiences. Popular data analytics and visualization tools used in IoT include Hadoop, Spark.

There are many technologies that are used in IoT applications [34]. The combination of these technologies can enable a variety of IoT applications across different industries, like healthcare, manufacturing, and agriculture [35].

2.2 Big Data Analytics (BDA)

The term "Big Data" refers to the enormous amount of structured and unstructured data that is produced from numerous sources, including IoT devices, social media, online transactions, and more [2], [43], [44]. The growth of Big Data has been fueled by the increase in digital devices and IoT as well as the development of powerful data analytics tools that enable organizations to extract valuable insights from the data. Volume, velocity, variety, and authenticity are characteristics of big data. The volume alludes to the enormous volumes of data that are produced, processed, and analyzed daily. Data generation speed is referred to as velocity. Variety refers to the different types of data, such as text, audio, video, and images. Data's authenticity is defined as its truth and dependability [38]. To handle Big Data, organizations need to use specialized tools and techniques that can process and analyze huge volume of data quickly and efficiently [39]. BDA which is the process of analyzing large and complex data sets to extract useful insights and knowledge. BDA involves a combination of data mining, machine learning, statistical analysis, and other techniques to identify patterns, correlations, and trends in the data. BDA is used in various industries, including healthcare, finance, retail, and manufacturing, to improve decision-making, optimize operations, and enhance customer experience [40]. The key components of BDA illustrated in figure 2:

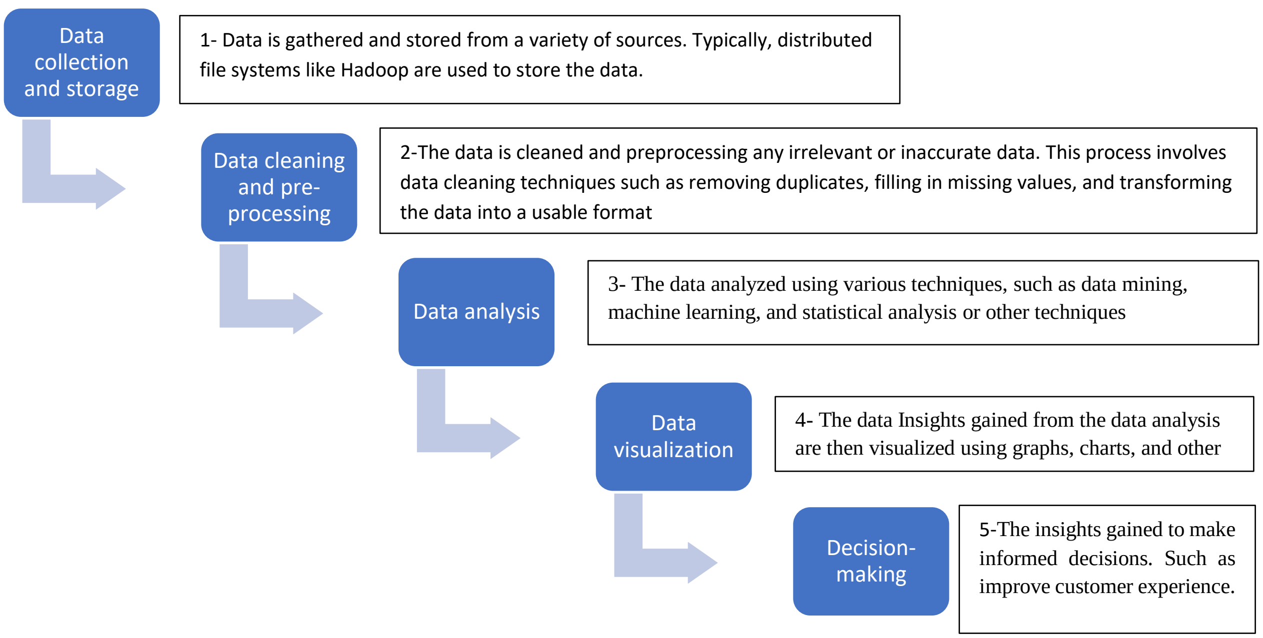

Figure 2: BDA key components

In summary, BDA is the process of dissecting vast and intricate data sets to get forth insightful information. Data collection, storage, pre-processing, analysis, visualization, and decision-making are all components of BDA. BDA can provide organizations with a range of benefits, like improved decision-making, enhanced customer experience, and gain a competitive advantage.

2.2.1 BDA techniques

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BDA employs a range of methods for analyzing massive and intricate data sets, from data mining and machine learning to NLP and sentiment analysis [41]–[44]. By leveraging these techniques, organizations can gain valuable insights and knowledge from their data to drive decision-making, optimize operations, and improve the customer experience[45], [46]. Table 1 list the BDA techniques

Table 1: BDA techniques

Technique	Description	Applications
Data Mining	the process of utilizing statistical methods and mathematical algorithms to find links and patterns in massive datasets	Fraud detection, market basket analysis, customer segmentation, anomaly detection, predictive maintenance.
Machine Learning	The development of algorithms that may get knowledge from data and then use that knowledge to create predictions or conclusions. Used in BDA to build predictive models and automate decision-making processes.	Predictive maintenance, recommendation engines, fraud detection, sentiment analysis, customer segmentation, churn prediction.
Natural Language Processing (NLP)	The processing and analysis of human language. Used in BDA to analyze and extract insights from unstructured data sources such as social media posts, emails, and customer reviews.	Sentiment analysis, topic modeling, text classification, language translation, chatbots, voice assistants.
Statistical Analysis	The application of statistical methods and techniques to data to recognize trends and relationships. Used in BDA to analyze data and make predictions based on that analysis.	Predictive modeling, hypothesis testing, A/B testing, time series analysis, regression analysis, data correlation analysis.
Data Visualization	The creation of visual representations of data to make it easier to understand and communicate. Used in BDA to display insights gained from data analysis in an intuitive and easy-to-understand way.	Interactive dashboards, real-time monitoring, data exploration, report generation.
Predictive Analytics	The technique uses historical data to forecast patterns and occurrences in the future. It involves the use of statistical models and making predictions based on data patterns and trends identified by machine learning algorithms.	Predictive maintenance, demand forecasting, sales forecasting, fraud detection, customer churn prediction, anomaly detection.
Text Analytics	The technique used in BDA to extract 8insights and knowledge from unstructured sources of data including emails, comments on social media, and client testimonials. It involves analyzing text data to find sentiment, themes, and patterns using NLP and machine learning algorithms.	Sentiment analysis, topic modeling, text classification, language translation, chatbots, voice assistants.
Sentiment Analysis	The subfield of text analytics that involves the identification and classification of the sentiment expressed in a piece of text. Used in BDA to analyze customer feedback and social media posts to gain insights into customer sentiment and preferences.	Customer feedback analysis, social media monitoring, brand reputation management, product reviews analysis.

2.2.3 BDA analytics tools

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There are many BDA analytics tools available today, each with its own set of features and capabilities [47]. Here are some of the most popular BDA analytics tools in table 2

Table 2: BDA analytics tools

Tool	Description	Features
Apache Hadoop	A large-scale data processing and storing open-source software framework.	Distributed file system, MapReduce processing, HDFS storage, supports various programming languages.
Apache Spark	a freely distributable data processing engine that can process huge volumes of data quickly and efficiently.	In-memory processing, data processing APIs, supports various programming languages, supports streaming and batch processing.
SAS Analytics	A suite of BDA analytics tools for data visualization, predictive modeling, and data mining.	Advanced analytics, data visualization, statistical analysis, text analytics, machine learning.
IBM Watson Analytics	A cloud-based platform for data analysis and visualization, which uses machine learning and natural language processing.	NLP, predictive analytics, data visualization, cognitive computing.
Tableau	A tool for visual analytics that makes it possible for users to produce interactive reports and dashboards.	Data visualization, drag-and-drop interface, supports various data sources, real-time analytics, and interactive dashboards.
Microsoft Power BI	A business analytics tool that allows users to create data visualizations and share insights across their organization.	Data visualization, business intelligence, machine learning, dashboard creation, supports various data sources, real-time analytics.
RapidMiner	An open-source platform for BDA analytics that offers data mining, predictive modeling, and text analytics.	Data preparation, data visualization, text analytics, predictive modelling, machine learning, and support for a variety of data sources.
Alteryx	A platform for data blending, analysis, and visualization that allows users to create workflows to automate data processing tasks.	Data preparation, data blending, data analytics, machine learning, predictive modeling, reporting and visualization.
Google Cloud Platform	A suite of BDA tools for storing and processing data, including BigQuery for data warehousing and analysis, and Cloud Dataflow for processing large real time data.	Big data processing, data warehousing, data analytics, machine learning, real-time data processing.
Amazon Web Services	A suite of BDA tools for storing and processing data, including Amazon Redshift for data warehousing and Amazon EMR for data processing.	Big data processing, data warehousing, data analytics, machine learning, real-time data processing.

3. IoT-enabled GSCM

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Green supply chain management (GSCM) is the process of integrating environmentally friendly and sustainable practices into supply chain(SC) operations [48]. This includes taking environmental impact in consideration of every step in the SC, from raw material extraction to product disposal, and implementing measures to reduce the impact on the environment. GSCM typically involves several key elements [49]–[52], including:

- Sustainable Procurement: This involves selecting and sourcing raw materials, products, and services that have a lower environmental impact. This includes evaluating suppliers based on their environmental performance and their ability to meet sustainability standards.
- Green Logistics: This refers to the transportation, storage, and distribution of goods in a way that minimizes their environmental impact. This can include reducing transportation distances, using more fuel-efficient vehicles, and optimizing delivery routes.
- Sustainable Manufacturing [53]: This involves adopting more eco-friendly practices in the production process, such as reducing waste, improving energy efficiency, and using renewable energy sources.
- Environmental Compliance [54]: This involves ensuring that the organization complies with all relevant environmental regulations and standards. This can include tracking and reporting on emissions, waste disposal, and other environmental factors.
- Stakeholder Engagement: This involves engaging with stakeholders, such as customers, suppliers, and employees, to promote sustainability and encourage participation in environmental initiatives.
- Life Cycle Assessment: This involves assessing a product or service's environmental impact over its entire life cycle, from raw materials through disposal or recycling.
- Eco-Design: This involves designing products with environmental considerations in mind, such as using sustainable materials, reducing waste, and improving energy efficiency.

By integrating these key elements into their operations, organizations can lessen their influence on the environment and increase their sustainability performance [49]–[52]. There are several applications of implementation GSCM in SC:

- Sustainable sourcing: This involves sourcing materials and products from suppliers that use sustainable practices, such as responsible forestry or organic farming.
- Energy efficiency [55], [56]: This involves reducing energy usage throughout the supply chain, for example by using more energy-efficient equipment or implementing renewable energy sources.
- Waste reduction [57]–[59]: This involves minimizing waste generated throughout the supply chain, for example by using reusable packaging or recycling materials.
- Transportation optimization [60]: This involves optimizing transportation routes and modes to reduce emissions and improve efficiency, for example by using electric vehicles or rail transport.
- Compliance with environmental regulations [52], [61]: This involves ensuring compliance with environmental regulations and standards to minimize environmental impact and reduce the risk of penalties and negative publicity.

Implementing GSCM practices can have several advantages for businesses, such as cost savings via increased effectiveness and decreased waste, greater brand perception, and increased customer loyalty, and compliance with environmental regulations. Additionally, GSCM can contribute to a more sustainable future by reducing the environmental impact of SC operations [52]. IoT-enabled (GSCM) refers to the use of IoT technology to optimize and enhance sustainable and environmentally friendly practices in supply chain operations. The integration of IoT devices and sensors with GSCM systems can enable real-time monitoring and analysis of environmental performance metrics, such as energy consumption, waste generation, and carbon emissions, throughout the supply chain[53], [62]. Some of the key benefits of IoT-enabled GSCM Improved environmental sustainability by identifying and addressing inefficiencies and reducing waste in the supply chain, increased visibility and transparency of environmental

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performance metrics, enabling more informed decision-making and targeted improvements, Cost savings through more efficient use of resources and reduced waste, Enhanced brand reputation and customer loyalty through demonstrating a commitment to environmental sustainability and Compliance with environmental regulations and standards, reducing the risk of penalties and negative publicity[49]. IoT technology can be used to track and monitor environmental performance metrics throughout the supply chain. For example, sensors can be used to monitor energy consumption and carbon emissions at manufacturing plants and distribution centers, while GPS tracking can provide data on transportation emissions and fuel usage [55]. This data can then be analyzed to identify inefficiencies and areas for improvement, such as reducing energy usage, optimizing transportation routes, or implementing more sustainable packaging practices. IoT technology can be used to enable more sustainable practices in the SC. For example, sensors can be used to monitor soil moisture levels in agricultural supply chains, enabling more efficient irrigation and reducing water usage. Similarly, IoT devices can be used to monitor air quality in warehouses, enabling more effective ventilation and reducing the risk of respiratory issues for workers. Overall, IoT-enabled green supply chain management can lead to significant benefits for businesses, including reduced costs, enhanced environmental sustainability, and improved brand reputation. By leveraging IoT technology to optimize and enhance sustainable practices throughout the supply chain, businesses cannot just increase their profits but also work towards a future that is more sustainable. [49] ,[64].

4. Role of BDA in IoT-enabled GSCM

BDA can play a critical role in enabling IoT-enabled GSCM by providing firms with the ability to collect, store, analyze, and act upon huge volumes of data generated from various sources in the supply chain.

4.1 BDA applications in IoT-enabled GSCM

The application of BDA in IoT-enabled GSCM has the potential to drive significant improvements in sustainability, efficiency, and profitability [63]. By leveraging the power of IoT devices and sensors, companies can capture and analyze data on supply chain processes, identifying areas of inefficiency and optimizing operations for sustainability. Here are some of the applications of BDA that can support IoT-enabled GSCM:

- Real-time monitoring and control [64]: IoT sensors can be used to collect real-time data on environmental factors such as temperature, humidity, and air quality, as well as on energy and water usage. This data can be analyzed in real-time using big data analytics tools to identify opportunities for optimization and to control environmental conditions in real-time.
- Predictive maintenance: IoT sensors can also be used to monitor the health of equipment and machinery in the SC. BDA tools can be used to analyze this data and predict when maintenance is required, reducing downtime and minimizing environmental impact.
- Supply chain optimization: BDA can be used to analyze data from across the supply chain, including data on procurement, transportation, and logistics. This can help organizations to identify opportunities for optimization, such as reducing transportation distances, improving delivery routes, and reducing waste.
- Environmental impact assessment: Big data analytics can be used to analyze data on environmental factors such as energy consumption, carbon emissions, and waste production, enabling organizations to assess their environmental impact and identify opportunities for improvement.
- Sustainability reporting: Big data analytics can be used to collect and analyze data on sustainability performance, which can be used to generate reports and communicate with stakeholders about the organization's sustainability efforts.
- Waste reduction: BDA can be used to analyze data on waste generation and disposal, identifying areas where waste can be reduced and recycled. This can help companies to reduce their environmental impact and improve overall sustainability.
- Analysis of customer behavior and preferences: BDA can be used to analyze customer behavior and preferences, providing insights that can be used to develop more sustainable products and services. For

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example, if customers are more likely to purchase products with sustainable packaging, companies can use this information to develop more sustainable packaging options

- Optimization of transportation routes[65]: BDA can be used to analyze data on transportation routes, including traffic patterns, road conditions, and fuel consumption. This can help companies to optimize their transportation routes, reducing fuel consumption and emissions, and improving overall sustainability.

- **4.2 BDA Benefits and Challenges in IoT-GSCM**

BDA can help organizations to make data-driven decisions that reduce environmental impact, optimize supply chain operations, and improve sustainability performance in IoT-enabled GSCM. Table 3 list the benefits and challenges of adopting BDA in IoT-GSCM

Table 3: BDA Benefits and Challenges in IoT-GSCM

No	Benefits	Challenges
1	Improved supply chain visibility and transparency	Need for significant investment in technology infrastructure and talent
2	Real-time monitoring and decision-making capabilities	Data quality and integrity issues
3	Enhanced demand forecasting and inventory management	Data privacy and security concerns
4	Improved supplier management and risk mitigation	Integration with legacy systems
5	Optimized transportation and logistics operations	Resistance to change and organizational culture
6	Reduced operational costs and waste	Complexity and difficulty in extracting insights from large datasets
7	Improved sustainability and environmental performance	Regulatory compliance and ethical considerations
8	Enhanced customer satisfaction and loyalty	Need for continuous updates and maintenance of technology infrastructure
9	Reduced environmental impact through optimized resource utilization and transportation planning	Legal and regulatory compliance related to data privacy and security
10	Increased agility and responsiveness to changing market conditions	Need for skilled data analytics professionals and IT staff
11	Improved decision-making through data-driven insights	Difficulty in identifying the most relevant data sources and variables for analysis

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12	Enhanced customer satisfaction	Need for specialized skills and expertise
13	Increased profitability and competitive edge	Managing and analyzing large volumes of data

4.3 The Architecture of BDA in IoT-enabled GSCM

The architecture of BDA in IoT-enabled GSCM typically involves several components that work together to collect, store, process, and analyze huge volumes of data from various sources in the SC, The components of the architecture:

- IoT sensors and devices [66]: These are the devices that are used to collect data from various sources in the SC, such as temperature sensors, humidity sensors, energy meters, and GPS trackers. These devices are typically connected to a network, such as a wireless network or a cellular network that enables them to transmit data to a central location like the cloud.
- Data collection and storage [18]: Usually, a data lake or a data warehouse is used to store the information gathered by IoT devices. Whereas a data warehouse is a centralized repository that stores data from numerous sources in a structured fashion, a data lake is a storage repository that maintains raw data in its original state. Large volumes of data can be stored and managed using either of these methods [25].
- Data processing and analysis [31]–[33]: Once the data has been gathered and saved, it needs to be processed and examined in order to glean insights and produce useful intelligence. Big data analytics tools like Hadoop, Spark, or NoSQL databases, which are made to manage massive volumes of data, are generally used for this and perform complex analytics.
- Visualization and reporting: The insights generated from the data analytics process are typically presented in a visual format, such as dashboards or reports that enable users to understand and act on the insights. This can be done using tools such as Tableau, Power BI, or other data visualization tools.
- Integration and action: Finally, the insights generated from the data analytics process need to be integrated into the supply chain operations and acted upon to achieve the desired outcomes. This can involve integrating with other systems, such as ERP systems or logistics management systems, and automating actions based on the insights generated.

Overall, the architecture of BDA in IoT-enabled GSCM is designed to enable organizations to collect, store, process, and analyze large volumes of data from various sources in the SC, and to generate insights that can be used to optimize operations, reduce environmental impact, and improve sustainability performance. Figure 2 represent the Architecture of BDA in IoT-enabled GSCM.

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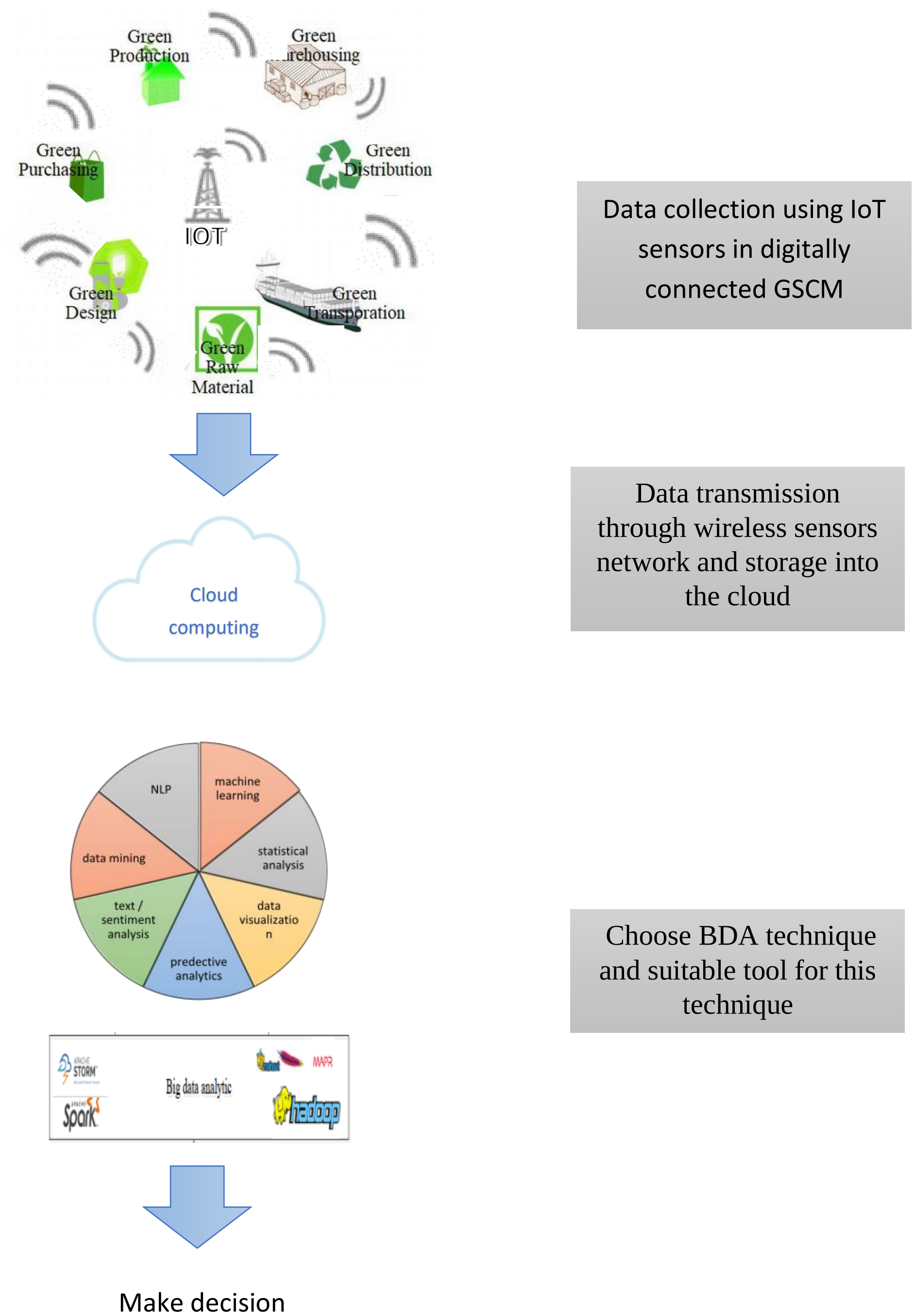

Figure 3: Architecture of BDA in IoT-enabled GSCM

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5. Future perspectives of research in this area

As the adoption of IoT and BDA in GSCM continues to grow, there are several areas that researchers can explore in the future. Some potential future research directions include:

- Integration of BDA and AI [17]: While BDA can provide valuable insights into GSCM, integrating BDA with AI can take it to the next level by enabling automated decision-making and optimization.
- Real-time analytics [13], [66]: Due to the proliferation of IoT devices, real-time data analytics can become a powerful tool for predicting and preventing disruptions in GSCM.
- Security and privacy [67]: As more data is collected and shared through IoT devices, ensuring the security and privacy of this data will become increasingly important. Future research can explore ways to secure IoT-enabled GSCM systems and protect the privacy of individuals and organizations involved.
- Sustainability and circular economy [61], [68]: BDA can be used to track and analyze the sustainability performance of GSCM systems, as well as to identify opportunities for circular economy initiatives such as closed-loop supply chains.
- Multi-objective optimization[69]: GSCM involves optimizing multiple objectives such as cost, environmental impact, and customer satisfaction. Future research can explore ways to use BDA and IoT to optimize these objectives simultaneously.
- Interoperability [66], [70]: As more organizations adopt IoT-enabled GSCM, ensuring interoperability between different systems and devices will become increasingly important. Future research can explore ways to standardize data formats and communication protocols to improve interoperability.

Overall, BDA and IoT have the potential to revolutionize GSCM by enabling real-time tracking, analysis, and optimization of supply chain operations. Future research can continue to explore and expand upon the many applications and benefits of these technologies in GSCM.

6. Conclusion

BDA has emerged as a powerful tool in the realm of IoT-enabled GSCM. With the growing adoption of IoT devices and sensors, there is an exponential rise in the quantity, variety, and speed of data produced by supply chain processes. BDA helps to process and analyze this data, providing valuable insights that can be used to optimize and improve supply chain operations, identify areas of inefficiency, monitor and reduce energy consumption, track emissions, and optimize transportation routes to reduce carbon footprint. It can also be used to analyze customer behavior and preferences, enabling companies to offer more sustainable products and services. Overall, the use of BDA in IoT-enabled GSCM has the potential to drive significant improvements in sustainability, efficiency, and profitability. However, it requires a well-defined strategy and a robust technology infrastructure to effectively capture, manage, and analyze the vast amounts of data generated by the supply chain.

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