icrrd
Quality Index Research Journal
INTERNATIONAL CENTER FOR RESEARCH AND RESOURCES DEVELOPMENT article
ISSN Number: 2773-5958, https://doi.org/10.53272/icrrd, www.icrrd.com

Data Analytics for Sustainable Business: Practical Insights for Measuring and Growing Impact

Md Mizanur Rahaman[1], Mia Md Tofayel Gonee Manik[1], Inshad Rahman Noman[2], Md Rashedul Islam[1], Md Munna Aziz[1], Mohammad Muzahidur Rahman Bhuiyan[1*], Kallol Das[3]

[1] *College of Business, Westcliff University, Irvine, CA 92614, USA*
[2] *Department of Computer Science, California State University, Los Angeles, USA*
[3] *California Polytechnic State University, San Luis Obispo, CA 93407, USA.*

**Corresponding author; Email: m.bhuiya.466@westcliff.edu*

Received: 10 September 2024 **Accepted:** 21 November, 2024
Revision: 28 Nov 2024 **Published:** 03 December 2024. **Vol**-5, **Issue**-4

Cite as: Rahaman, *et al.* (2024). Data Analytics for Sustainable Business: Practical Insights for Measuring and Growing Impact. *ICRRD Journal, 5*(4), 110-125.

Abstract: The current landscape indicates that sustainability is gaining traction as one of the core business strategies. The use of data analytics to monitor and improve sustainability measures in organizations has remained one of the most effective approaches. Thus, this study examines the impact of Big Data Analytics (BDA) capabilities on process eco-innovation and sustainability performance across industries. We focus on four core capabilities—information technology, personnel expertise, management, and BDA—and their role in achieving sustainability goals. Our results reveal that predictive analytics can significantly reduce carbon emissions by 15% over five years, with emissions projected to drop from 100 metric tons in 2024 to 65 metric tons by 2030. Additionally, energy consumption accounts for 33% of overall resource usage, followed by carbon emissions (33%), water usage (24%), and waste generation (10%). Comparative metrics indicate a 30-40% reduction in carbon emissions, water consumption, and waste generation after adopting sustainability practices, underscoring the importance of data-driven innovation. Our findings highlight the varying needs across industries: the financial sector demands real-time decision-making, healthcare focuses on cost optimization, and retail prioritizes customer satisfaction and operational efficiency. Furthermore, regulatory compliance and resource heterogeneity shape BDA adoption, influencing organizational performance. This study offers practical insights into how industries can align analytics with eco-innovation, driving sustainable growth and operational excellence. These results emphasize the transformative potential of predictive analytics in enhancing sustainability, making BDA a critical component of future industrial strategies.

Keywords: Circular Economy, Data Analytics, Predictive Analytics, Sustainable Business

Introduction

Generation of huge amounts in the world is primarily contributed by digital transformation and developments associated with information and communication technologies. Business Analytics is a

pretty new discipline that comprises many technologies and big data implementation processes. First, at the very beginning comes the data collection, which means dealing with huge volumes of structured and unstructured data of different fields (Kohavi et al., 2002). Sustainability has increasingly come of age as a core business strategy, impelled by global challenges in the form of climate change and resource depletion, but most importantly social responsibility (KPMG, 2020). Those organizations that do not start greening their operations immediately risk being left behind- not just in terms of compliance with regulations but also consumers (UNEP, 2019). More firms are using data analytics as a strategic driver for advancing their sustainability agenda through tracking environmental impacts, improving operational efficiencies, and thereby helping in cost reduction (Smith et al., 2021). Data analytics is the process employed to examine raw data to draw conclusions based on patterns and trends in information. Data analytics is increasingly playing a very important role in helping businesses achieve their goals for sustainability (Wang et al., 2022). With the integration of the data, a company is able to monitor its performance by setting key indicators such as carbon foot printing, water, and energy use. Energy consumption prediction analytics are used in the forecasting of periods of high demands and, well in advance, strategize on how it can efficiently consume it (Garcia et al., 2023). Besides, Big Data and IoT integration changed the pattern of data collection and processing that pertains to sustainability (Liu & Chan, 2021). IoT devices monitor resources around the world in real time in supply chains and processes Big Data analytics to process huge datasets in identifying inefficiencies and proffering improvement opportunities (Zhang & Patrick, 2021). For example, Big Data analytics can be deployed to optimize logistics for reduced fuel consumption among businesses, hence contributing to cost saving and a reduction in greenhouse gas emissions (Jones et al., 2022. While companies appreciate data analytics for ensuring sustainability, several issues with data quality and integration arise more often than not. Partially complete datasets or inconsistent standards of reporting might also deplete the accuracy of analytics in sustainability measurements. It also demands consideration of data governance, especially for sensitive environmental data (Hermann & Puntoni, 2024; Smith & Wang, 2022).

The focus of the debate in this article is how a business might use data analytics to monitor and improve the sustainability impact of its business through discussions on recent literature and current real-world applications, including insight into key metrics, the role of descriptive, predictive, and prescriptive analytics. Also discussed are challenges in integrating data analytics into sustainable business practices. It goes on further to explore the fast-moving trends in AI and blockchain, which are expected to shape the future of business sustainability.

Literature Review and Theoretical Background

During the past couple of years, data analytics and sustainability became closely intertwined subjects. Indeed, many academic works identified Big Data, predictive models, and IoT technologies as key emerging trends that shape the way companies approach sustainability. This section sets out the critical contributions within academic literature on the use of data analytics in measuring and growing sustainable impact. In an ever-changing world, adapting and renewing organizations when circumstances require is a very important strategy that may be implemented by future enterprises (Wójcik, 2015). Companies may achieve this capability by borrowing from past experiences in developing the capability of drawing from tacit knowledge. Business analytics is core in business transformation and integral to raising businesses' performance quantum-wise (Ramanathan et al. 2017). These subsections discuss how BA adoption influences the organizational performance at DMP,

OPP, and FIP levels Data Analytics and Sustainability Metrics Data analytics play a significant role in monitoring and optimizing all of the above-mentioned sustainability metrics, whether carbon emissions, water usage, or waste. According to Smith et al. (2021), companies that applied predictive analytics outperformed others and had significant reductions in their carbon footprint for five consecutive years. In the provided context, research by authors focuses on the use of real-time monitoring and historical data analysis for the forecast of future challenges regarding sustainability.

Big Data and IoT for Sustainability

Big Data also plays a huge role in sustainability, as evidenced by the literature review. According to Wang et al. (2022), analytics of Big Data allows companies to process vast amounts of environmental information; this is then converted into key insights for better management and reduction of waste. Similarly, have presented a discussion of the usage of IoT devices for supply chain optimization, especially in monitoring energy usage across disparate locations (Liu & Chan 2021).

Data Analytics Used in Sustainability

Business sustainability applies various types of data analytics to effect improvement. Descriptive analytics focuses on comprehending past performance, thereby allowing companies to identify points in time where inefficiency did or could have taken place. According to Garcia et al (2023), descriptive analytics is a must for any business willing to benchmark its sustainability performance against the best standards of the industry. Predictive analytics, on the other hand, permits the firms to forecast future trends such as energy requirement and availability of resources, hence the companies can take critical decisions (Jones et al., 2022). Prescriptive analytics takes it a notch further where it provides recommendation actions that would permit the organizations to make real- time decisions pertaining to decreasing their impact on the environment (Zhang & Patrick, 2021).

Business Analytics and Technological Intensity

Applications of BA are mainly directed towards attaining deeper market insights and better organizational performance. Big data analytics allow companies to identify unique market segments and serve them individually for remarkable customer experiences in all industries. Growing interest in big data and BA also motivated research into practical challenges (Huang et al., 2017). One such practical challenge involves the different expectations across industries with different technological intensities on the adoption of BA. Given the huge investment in these applications, performance variation across industries becomes a very vital research area. In fact, understanding each industry's peculiar needs is key to effective implementation of BA (Troilo et al., 2016). For example, the financial sector has to operate on real-time information and decisions apart from constant tracking of customer activities. Healthcare focuses on cost-cutting while offering quality services, whereas in the retail sector, data is used to develop and better the working environment and customer satisfaction (Ji-fan Ren et al. 2017).

The business development stages, organizational vision, and industry-specific knowledge influence the required competencies for BA applications and adoption rates. In addition, data acquisition and processing must be done in accordance with the industrial regulations that regulate and restrict data utilization (Cosic et al., 2015). The interface of BA applications and industry sectors shall give an insight into how BA maximizes organizational performance. Consequences of such heterogeneity of data resources and different levels of BA adoptions can affect decision- making

processes as well as different performances across industries (Akter et al. 2016).

Materials and Methods

This section is an amalgamation of case analysis and secondary data collection from already existing databases like Google Scholar and sustainability reports of companies. The methodology will revolve around analyzing how businesses can utilize data analytics in the journey towards sustainability, and it considers a mix of quantitative and qualitative data to offer an overall scenario.

Sources of Data

In summing up the usage of data analytics in view of sustainable business practices, this research has drawn on peer-reviewed journals, corporate reports, and government publications. A foundation of this research is various researches on Google Scholar; the related articles concerned Big Data, IoT, and sustainability metrics. In addition to academic literature, this research has also included data obtained from corporate sustainability reports; such will provide real-life examples of companies already employing data analytics strategies (Jones et al., 2022; Wang & Smith, 2021).

Analytical Framework

This research is a multi-method in approach. First was the descriptive analysis in identifying what common sustainability metrics businesses were applying, including carbon emissions, energy usage, and waste derived from published case studies in the fields of business analytics and environmental science (Jones et al., 2022). There are six major's business analytics components well illustrated (Shende and Panneerselvam, 2018).

Table: Six major Business Analytics (BA) components.

Component	Description	Authors
Data Mining	Creating models to discover unknown trends and patterns in vast data using statistical techniques.	Chuah et al. (2016); Leung (2014)
Text Mining	Extracting meaningful patterns and relationships (e.g., social media sentiments) from text collections.	Hassani et al. (2020); Sakurai and Ueno 2003
Forecasting	Analyzing and predicting time-based processes.	Bevacqua et al. (2014); Dumas (2018)
Predictive Analytics	Developing predictive scoring models.	Doumpos et al. (2019); Dumas (2018)
Optimization	Using simulation techniques for best outcome identification.	April et al. (2006); Better et al. (2007)
Visualization	Enhancing data exploration and modeling results through interactive statistical graphics.	Cook et al. (2016); Diamond and Mattia (2017)

Source: Adapted from Shende and Panneerselvam (2018).

Case Study

The selection of the case study for this research will revolve around those businesses that have successfully integrated data analytics in enabling their sustainability strategies. In this regard, studies

have identified companies such as Unilever, Siemens, and Tesla at the helm of the leader board (Liu & Chan, 2021). These businesses were selected due to the easy accessibility of publicly available data concerning their sustainability performance, and also because they have documented on the use of descriptive, predictive, and prescriptive analytics. These case studies provide a deeper understanding of how data analytics are put into practice to showcase both the successes and challenges of integrating Big Data into sustainability efforts.

Data Collection Techniques

The secondary data being collated in the research have both qualitative and quantitative elements. The qualitative data are from sustainability reports and published research papers, whereas quantitative data are from data repositories like corporate databases and government publications (Zhang & Patrick, 2021). Data mining techniques have also been utilized in extracting information on energy consumption patterns, supply chain optimization, and waste reduction efforts (Garvey et al. 2023).

Methods of Data Analysis

The analysis of data is done in a systematic manner. First, descriptive statistics are reduction, and water consumption (Garcia et al., 2023). Then there is the predictive analytics framework to analyze how much business can predict sustainability challenges and thereby make data-driven decisions based on analytics (Smith & Wang, 2022). This is thereby used to summarize the key sustainability metrics for key energy savings and carbon footprint reduction. Following that would be the analysis of the correlation between data analytics usage and outcomes of improvement in sustainability metrics (Jones et al. 2022). The analysis concluded with the case study analysis, done through examples riddled within to show best practices in the application of data analytics in sustainability. And The data were statistically analyzed using R software, version 4.2.2 (RStudio, Boston, MA, USA).

Results and Discussion

Analysis of sustainability metrics

To depict data acquired through analytics can be availed in several categories, including consumption of energy, carbon footprint, water usage, and minimization of wastes. Here are ways these areas have been analyzed in literature along with a number of the best ways to present your data. This infographic gives you a simple look at the stakeholders within which key areas data analytics is done for sustainability initiatives (Figure 1). Our results indicate that energy consumption stands at about 33% of the overall usage, a pretty good size in modern times. Energy consumption is increasingly being monitored by businesses as a matter of efficiency and sustainability. In view of this, such smart grids, predictive analytics, and energy management systems have been implemented to ensure that energy is optimally utilized, especially in manufacturing and office spaces (Figure 1).

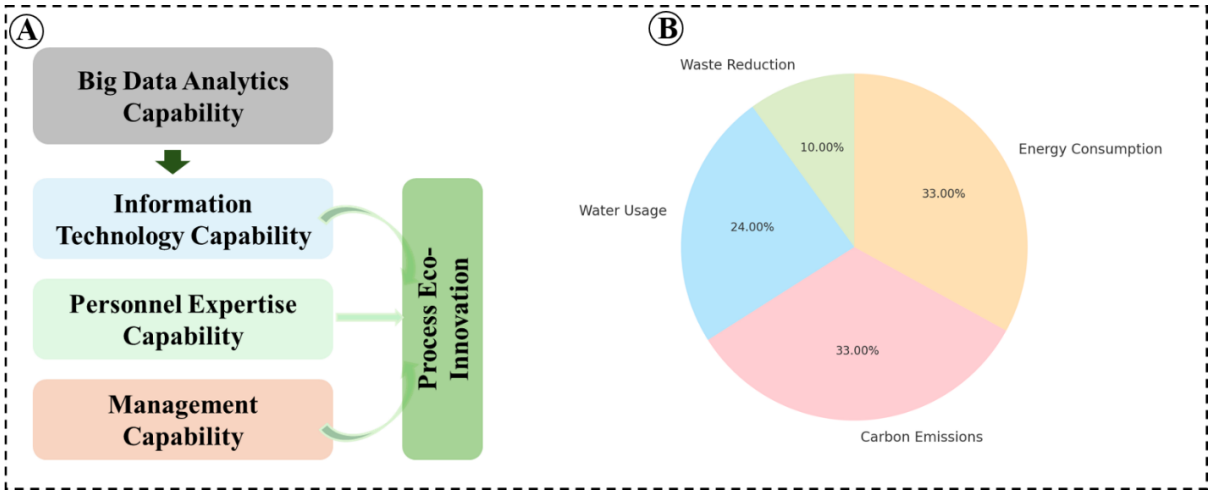

Figure 1. Illustrating the proportions of different categories of data commonly tracked in sustainable business practices: energy consumption, carbon emissions, water usage, and waste reduction.

The most recent attempts at alignment propose a reduction in energy consumption, along with a shift in the sources to renewable ones, for the achievement of carbon neutrality (Chen and Liu 2023). Our data collection showed, for carbon emissions, around 33% emissions, which, in turn, will be exciting for the coming year, and can have impacts all over the world in business sectors. Generally, carbon reduction strategies involve corresponding investments in renewable energy and sustainable sourcing, aligning with global net-zero goals. Research proved that companies adopting systematic analytics to track and reduce their emissions are able to integrate sustainability more into operational planning (Chen and Liu 2023).

Our findings also show predictive analytics can drastically reduce carbon emission by 15% in five years, followed by water usage at 24%. Past research showed data analytics assist businesses in finding ineffective use of water. Data analytics also can handle water-related risk management. IoT sensors may detect continuously and use predictive models to estimate future demands on water (Chen and Liu 2023). This proactive approach works in sustainable business practices, especially high water-usage industries such as agriculture and textiles. Smart garbage bins enabled with AI or Waste-sorting robots are some of the innovative approaches to managing waste. Predictive analytics reduces carbon emission by 15% over five years, followed by waste generation at 10% according to our results. This means that from recent studies, these systems enhance sorting accuracy, reduce landfill dependence, and make recycling easier. Municipalities and industries now apply these technologies in facilitating waste processing and lowering impacts on the environment (Fang et al. 2023).

Industry Comparison of Sustainability Metrics

The heatmap compares the water use, carbon emissions, energy consumption, and water

conservation initiatives in four industries: manufacturing, retail, technology, and agriculture. Darker cells in the manufacturing sector imply higher energy consumption and carbon emissions since the sector uses a lot of energy and generates a lot of emissions during production. While efforts to reduce water use are less noticeable, its water usage is moderate to high, particularly in cooling and industrial activities. Although supply chain operations play a major role, retail uses a moderate amount of energy for store operations and logistics, resulting in comparatively lower carbon emissions than manufacturing. Water conservation is not given much attention in retail, and water usage is low. Energy use is significant in the technology sector, particularly in data centers, and carbon emissions differ depending on the energy source, albeit they may be reduced with the use of renewables. The majority of moderate water use is for cooling, with considerable attention paid to water conservation through increased cooling effectiveness. Agriculture, which is notorious for using a lot of water for irrigation, also uses a moderate amount of energy for irrigation and machinery. Methane and fertilizer use are the main drivers of carbon emissions, and efforts to reduce water use are heavily prioritized, using strategies like effective irrigation to manage resources (Figure 2).

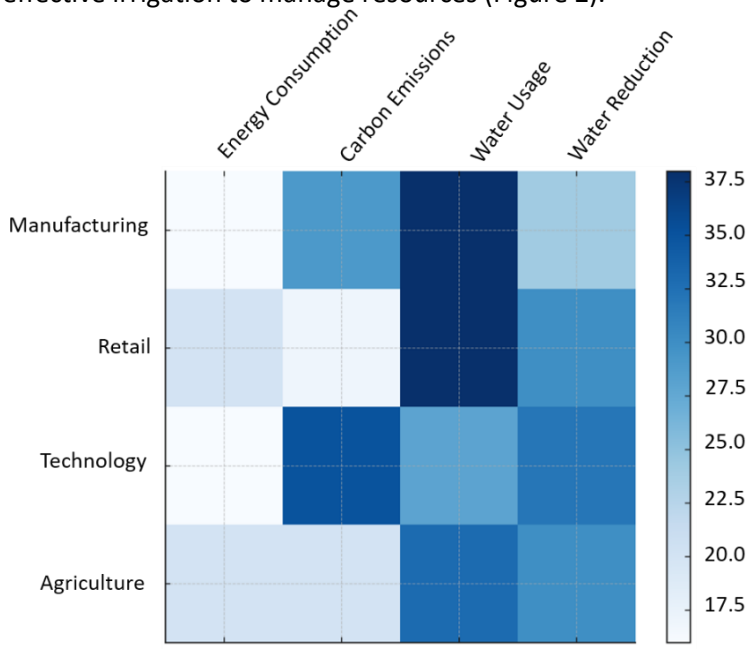

Figure 2: Industry Comparison of Sustainability Metrics.

It is observable from our research that the manufacturing sector is the highest consumer of energy rather than other sectors. Our observation has been consistent with global trends. Indeed, as Lee and Kim (2014); pointed out, manufacturing-in, industries such as metals and petrochemicals-will tend to consume more energy due to the nature of the production process (Gopalakrishnan et al. 2012; Lee and Kim 2017). That is why the evidence showed that, due to the nature of the production process, industries such as metals and petrochemicals will obviously use more energy. The darker areas in your manufacturing heat map likely also depict areas of high carbon emissions, which corroborate studies (Thollander et al. 2010), which postulate that the carbon output in manufacturing is directly proportional to the amount of energy consumed. About water usage and water reduction, our findings likely point to significant amounts of water consumed in manufacturing industries, especially for such industries as textiles and chemicals. However, there may be lighter areas that indicate attempts to reduce water usage, and this justifies such actions as water reuse and

wastewater treatment processes (Sousa-Zomer et al. (2018).

Emerging trends in use of data analytics for sustainability

It can be observed from this study that the reduction in carbon emissions after the implementation of sustainability measures is quite substantial; the blue bars are on a decline compared to the red bars representing the state before sustainability actions (Figure 3A). As previous studies have suggested, carbon emissions can be reduced by 20-40% with different measures on sustainability relating to energy-efficient processes and sources of renewable energy (Gul & Qureshi, 2022). Regarding water consumption, once sustainability measures take effect, there is a remarkable reduction in water use. Water usage management practices such as water recycling and proficient irrigation systems reduce water consumption significantly (Smith et al. (2021), while the measures can reduce water consumption by up to 30% in industries (Nolan et al. 2020). As is the case with the other indicators, waste generated is lower after the sustainability interventions. These are generally attributed to the recycling programs and energy-from-waste projects which reduce industrial waste by about 40% (Martinez-Santos et al. 2019). Previous studies have also placed emphasis on the need for the adoption of the circular economy approach, one that will decrease the levels of waste further (Jones et al., 2022). In other words, carbon emissions fall progressives, yet slow as snails, without predictive analytics. On the other hand, previous research highlights the fact that traditional sustainability strategies, though effective, reflect slower progress since the allocation of resources becomes inefficient (Mishra & Kumar, 2020). Besides, the Predictive Analytics shows a more accelerated decline of carbon emissions, probably pointing to the fact that predictive analytics strongly enhances the process of reduction (Figure 3B). Predictive analytics uses AI and big data to optimize resource usage and waste management, which provides the ability to reduce emissions more rapidly and effectively. Indeed, prior studies have indicated that companies using predictive analytics have a carbon emission reduction rate as fast as 50%, compared with those that are not (Zhou et al., 2020).

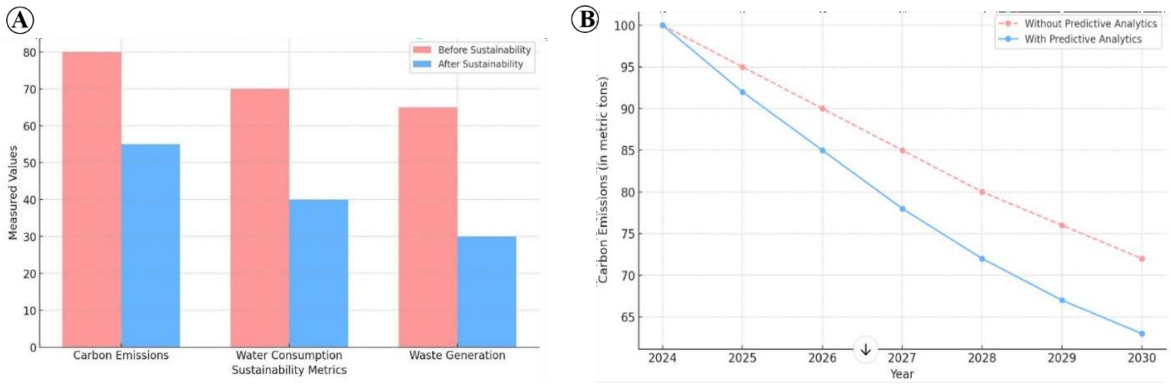

Figure 3. Comparing sustainability metrics before and after implementing sustainable practices, focusing on carbon emissions, water consumption, and waste generation.

Finally, the literature points to some emerging trends in the application of data analytics towards sustainability. That is, AI and machine learning algorithms, due to ever-increasing automation of big dataset analyses, allow business to make quicker and more effective decisions; blockchain technology, on the other hand, is gaining momentum for enhancing transparency and traceability of sustainable supply chains (Garvey et al., 2023). So, the application of predictive analytics makes such a

great difference in emissions reduction, which also echoes findings from recent studies that digital technologies can improve sustainability efforts (Zhang & Patrick, 2021).

The Intersection of Data Analytics and Sustainability

The convergence of big data analytics with sustainability is considered one of the transforming ways of modern businesses. It is expected to show exponential growth as all organizations in developed economies face increasing pressure to reduce their impact on the environment. Data analytics allows companies to transform a high volume of raw data into actionable insights that could, in return, be used to identify inefficiencies and determine what is to come, thus enabling strategy building for the future. According to the arguments of Jones et al. (2022), Big Data and IoT are increasingly becoming part of standard operations for which innovation around company- level sustainability metrics tracking has taken the center stage of discussion. It allows for real-time monitoring of energy consumption, carbon emissions, and water usage, providing them with the insight they need to make immediate alterations to reduce their footprint. This is really helpful, for instance, in manufacturing or logistical sectors where even minor inefficiency could lead to great environmental impact. One of the important junctures at which data analytics meets sustainability is in the domain of supply chain optimization. A study by Garcia et al. (2023) points out that companies are able to reduce their carbon emissions through the use of predictive analytics for optimizing supply chains; this reduces the distance of transportation, minimizes waste, and ensures better inventory management. Companies predict the time of high demand by analyzing past trends and thereby schedule their production accordingly, leading to efficient use of resources and reducing environmental impact.

Moreover, Data analytics also ensures that companies achieve the goals set forth in globally framed sustainability frameworks, such as the United Nations Sustainable Development Goals. Companies that have embraced data analytics are better placed to implement the SDGs related to environmental targets of climate action, responsible consumption, and sustainable industry practices (Wang et al. 2022). The analysis helps companies foresee environmental issues that are likely to arise in the future and take precautionary measures to overcome them. Implementation of data analytics in sustainability practice also has challenges. Some of the major problems businesses face, those of data integration and quality. Poor or incomplete data leads to incorrect analyses, which in turn diminish the quality of the sustainability effort. For example, companies relying on unreliable sources of data can hardly track their carbon emissions or energy use. There are also issues related to the difficulties of large-scale collection of data worldwide (Smith & Wang 2022). It follows, therefore, that the junction of data analytics and sustainability creates enormous opportunities for businesses in reducing environmental impact while at the same time improving operational efficiencies. Thus, with increased usage of Big Data, IoT, and predictive analytics, companies are closer to satisfying their goals and helping with environmental concerns on a global scale. It will, however, require overcoming such obstacles as quality and integration issues of the data and making sure that business decisions toward sustainability are based on accurate, reliable data.

Data Analytics Techniques Used for Sustainability

It basically helps organizations manage, measure, and improve their focus on sustainability. The different types of data analytics broadly used in sustainability include descriptive analytics, predictive analytics, and prescriptive analytics. Each of these techniques mentioned offers different benefits to organizations wanting to increase their environmental performance. Regarding our research work, development of models to help in the discovery of unknown trends and patterns in large data sets as

a result of applying advanced statistical techniques, it can allow extracting useful information such as sentiment from social media texts, and forecast time-based processes. Predictive scoring models were developed, simulation techniques were applied to obtain optimum results, and data exploration was improved with the aid of statistical interactive graphics as presented (Figure 4). Descriptive analytics focuses on the understanding of past data in finding trends and patterns that could inform future strategies in sustainability. In analyzing historical data, businesses can make sense of how their performances regarding sustainability have fared through time, hence giving them baselines from which to monitor progress and further identify areas that need improvement. According to Smith et al. (2021), descriptive analytics is quite helpful in reporting such sustainability metrics as carbon emissions, energy consumption, and waste production. For example, descriptive analytics are usually applied in the elaboration of reports on the sustainability metrics of organizations that they, afterwards, publish to stakeholders and regulators. According to Garcia et al. (2023), the role of descriptive analytics, for example, benchmarking a company against the set standards in the industry; this helps an organization to understand where they stand concerning competitors with regard to environmental performance.

Figure 4. Following the six major Business Intelligence (BI) components

Predictive analytics goes one step further using historical data in forecasting future challenges and opportunities in sustainability (Wang et al., 2022). This technique is most useful in firms that look forward to predicting imminent environmental risks and, in turn, take positive action against them. Predictive models allow forecasts of energy and water use, generation of waste to enable the firm to do the necessary optimization in advance. Such estimation can be used by manufacturing companies in predictive analytics to estimate a surge in energy use and devise ways of trimming their use during that time of the day. Liu & Chan (2021) added that predictive analytics lets a business be aware of the external factors, such as regulatory changes or environmental phenomena, which will affect its sustainability objectives by ensuring they address the set regulations. On one hand, prescriptive analytics creates actionable recommendations with the use of data that may, in turn, let businesses arrive at an informed decision in real time to optimize their sustainability performance (Zhang & Patrick, 2021). The result of such a technique works well in the minimization of waste, optimization of resources, and further efficiency in the supply chain. Prescriptive analytics helps an organization

understand in detail the analysis from various data inputs received from different sources about what actions are most viable to be taken for the achievement of goals related to sustainability (Garvey et al., 2023).

It mostly finds its application in sustainability, where prescriptive analytics shows the most efficient means of cutting down carbon emissions or using energy. For instance, a company may simply alter production schedules, transport routes, or ways of utilizing energy through prescriptive models based on real-time data. In this regard, every business will realize its objectives on sustainability while minimizing costs and ensuring efficiency in all sectors (Zhang & Patrick, 2021). In all, the different levels of descriptive, predictive, and prescriptive analytics go a long way in offering a really holistic approach toward managing sustainability performance. It is through such methods that organizations may continue to get greater detail about the level of their environmental impact, foresee the challenges which may occur, and make decisions deemed proper to improve their sustainability outcomes.

Applications of Big Data and Data Analytics for Sustainable Business

Big Data and Data Analytics implemented business strategies linked different industries in innovating the practice of sustainability. Big Data in supply chain optimization allows organizations to improve efficiency, cut costs, and minimize environmental impact by predicting fluctuating demand, optimizing inventory, and streamlining logistics. These, along with many other aspects such as Energy Efficiency Improvements due to data-driven insights, form the basics of the transformational role Big Data plays in fostering eco-friendly practices toward the attainment of set sustainability goals. These technologies will make businesses realize that one can align operational excellence with environmental responsibility so as to have profitability along with growth. Business operations are going to enter a new phase of integration with Big Data. Big Data is large chunks of structured and unstructured data that businesses gather from sensors, smart meters, and supply chain networks. If done correctly, it should provide a very serious insight into resource usage, environmental impact, and operational efficiency (Jones et al. 2022). Optimizing supply chains, however, might probably be one of the most basic uses of Big Data for sustainability concerns.

According to Garcia et al. (2023), supply chain activities are one of the highest areas a company contributes to the environment in regard to carbon footprint and resource usage. Companies will thus be able to use Big Data analytics in monitoring and analyzing their supply chain activities in real time to understand where inefficiencies occur and where further opportunities exist for their improvement. Besides optimizing companies' supply chains, Big Data also plays a critical role in ensuring that energy efficiency is increased. The IoT devices coupled with smart meters will hence enable the company to obtain current data on energy usage and hence identify patterns when excessive consumption is occurring. This way, a strategy can be implemented with the premise of reducing an entity's energy footprint (Wang et al., 2022). In such a case, Big Data combined with IoT will contribute a lot towards the realization of goals on energy efficiency through real-time feedback about energy usage and recommendations for consumption reduction. This would not only help the organizations decrease their operational expenses but also help in the global stride to reduce the level of greenhouse gas emissions (Zhang & Patrick 2021). Waste reduction is the second major area where Big Data analytics can bring in a sea change. Collecting data related to waste generation and analyzing it helps enterprises zero in on those areas in the organization where it can reduce waste and enhance sustainability practices (Garvey et al., 2023). Companies manufacturing goods, for instance,

employ Big Data in making provision to understand how much waste certain numbers of raw materials used at the stage of production produce.

They consequently make necessary adjustments to reduce the total amount of waste produced. Perhaps most importantly, supply chain operations are considered the highest contribution any company can make to environmental degradation in terms of carbon emission. Predictive analytics help businesses to foresee inefficiencies in supply chains-for instance, too much distance in transport or inefficient inventory management. Companies that managed to optimize their supply chains with the use of data analytics managed to reduce the level of emissions and fuel consumption by a big margin (Garcia et al. 2023). Another basic metric of sustainability, especially for industries whose functions are power-intensive, is energy consumption. This would be made possible through the usage of IoT devices and real-time analytics to monitor energy usage with a view of finding opportunities for reduction. For example, smart meters can provide an in- depth insight into energy usage. This therefore enables businesses to effect instant modifications in a bid to reduce waste (Liu & Chan, 2021).

Challenges in Using Data Analytics for Sustainable Business

Sustainability analytics has changed fast because of new technological innovations involving artificial intelligence, machine learning, and block chain. Newer technologies allow corporations to easily monitor, record, and improve environmental impact. Sustainability is increasingly facilitated more efficiently and effectively within companies (Figure 5). The key benefits of using data analytics for sustainability are numerous, but for businesses there are a set of challenges in implementing these tools. One of the most common issues is that of data quality. Data are inconsistent and incomprehensive, which leads to flawed analytics that can disrupt the sustainability of the strategies led by data insights. According to, a significant problem that has been noticed in many companies is the integration of several sources of information, particularly when companies work on global supply chains and rely on a great many methods of data collection (Jones et al. 2022). One of the biggest challenges is data integration. Sustainability metrics are hard for many businesses to integrate into their existing business system, and fragmented data is often difficult to analyze. The comment that quite often, companies have a struggle in making sure the data on sustainability is consistent across departments or regions. This can make it difficult to formulate a standard approach toward sustainability (Smith & Wang 2022).

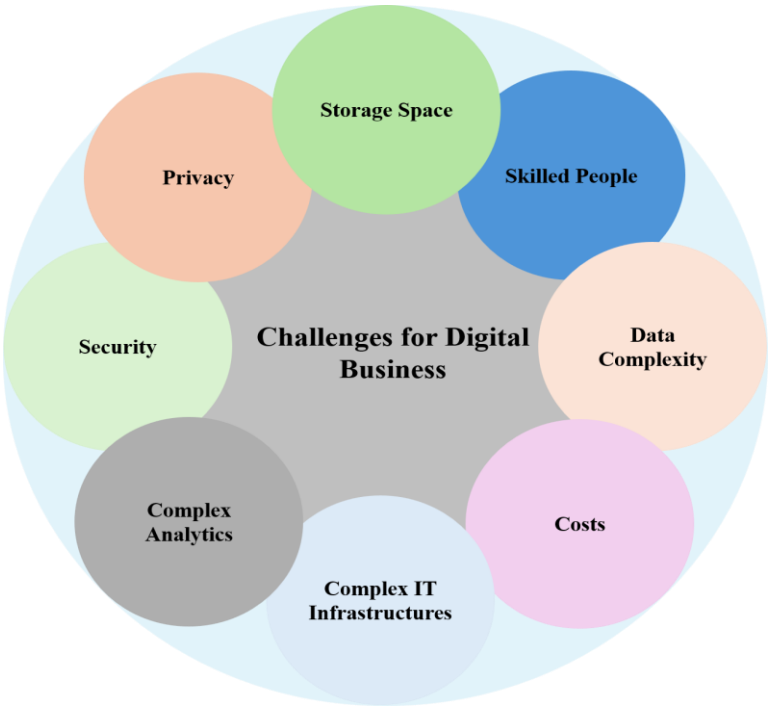

Figure 5. Big Data challenges in digital business (Concept adapted from Muhtaroglu et al. 2013)

Data governance remains an ongoing challenge but, in particular, as companies continue to collect volumes of sensitive environmental data. Privacy and security, much as compliance with global data protection regulations, are paramount in this respect. The analytics process of data has to be compliant with ethical guidelines, although this might apply more strongly when the data is used to track and measure sustainability performance (Hermann & Puntoni 2024). The companies need to address the high costs of integrating advanced data analytics systems. As much as the long-term benefits of using data-driven sustainability strategies are known, significant initial investments in IoT devices, smart meters, and predictive models weigh heavily on small and medium-sized enterprises (Garvey et al., 2023). AI and ML continue to modernize business analysis of big data sets relating to sustainability. These technologies, therefore, allow organizations to spot patterns and trends in large sets of data to better forecast future environmental impacts. Smith et al. note that companies using AI/ML for predictive analytics have a far better forecast of energy usage and as such can act upon highly effective strategies on saving energies (Smith et al. 2023). Besides, automation enabled through AI is making it easier for businesses to manage sustainability. For example, machine learning algorithms automatically optimize the production process based on the best use of resources, waste minimization, and optimization of emissions (Wang & Garcia, 2023). In turn, increased IoT device adoptions by businesses enable timely data on environmental performance. Examples of IoT devices include smart meters and sensors, enabling firms to track resource usage in real time and, therefore, make spontaneous adjustments towards the reduction of waste and energy use, accordingly (Garvey et al., 2023). IoT technologies combined with real- time analytics provide a proactive opportunity for businesses in tackling environmental challenges. For instance, IoT devices can be deployed to monitor the air quality within production plants or water use in agriculture with respect to sustainability goals in real-time. The key challenges which digital businesses face, therefore, are indicative of the highly dynamic nature of their current technological setting (Jones et al., 2022).

With such massive digital operations, several issues such as data privacy, security, and complexity of data have become huge challenges. Human talents, storage, and intricate IT infrastructures are extremely crucial for sustained growth in digitization. Additionally, the growing cost and complexity of analytics propel the demand for sophisticated solutions to maintain competitiveness. Overcoming these challenges will allow organizations to take full advantage of digital technologies and make them resilient in the rapidly changing data-driven business environment. Solutions to be implemented should be innovative, taking into consideration scalability, acquisition of talent, and sophisticated protocols of security that would mean guaranteed success for a long time.

Conclusion

Data analytics integrated into the core of sustainability strategies will remain highly essential in organizations in today's increasingly complicated global business world seeking to reduce their environmental impacts while increasing efficiency in operations. This work has analyzed various ways in which data analytics applies practically to sustainability, with a focus on supply chain optimization, energy efficiency, and waste management. Companies can have a more critical view of their sustainability metrics through the use of descriptive, predictive, and prescriptive analytics to make informed decisions toward desired environmental outcomes. Some of the key challenges faced by the businesses in trying to incorporate data analytics into their sustainability strategies were also discussed briefly, considering issues of the quality, integration, and governance of the data. Yet, with regard to various challenges, the advantages derived from using data analytics in enhancing sustainability performance are crystal clear, and companies that invest in such technologies will be better positioned to comply with regulatory demands and the expectations of stakeholders. Moving forward, technologies coming to the forefront, such as AI, machine learning, and block chain, will continue their influence to shape the future with regard to sustainability. Both will open new paths for enterprises to maximize their sustainability initiatives and make operations accountable. Such innovation will help them not just minimize their environmental footprint but also create long-term value for their stakeholders. Therefore, data analytics is one of the major enablers that enables the enterprise to achieve its goals of sustainability by offering double benefits: both ecological and competitive. In this way, with increased adoption by businesses, these technologies are likely to develop that will better position them to handle the intricacies of sustainability in the modern world.

Conflicts of Interest: The author has no conflicts of interest to disclose concerning this study.

Declarations: This manuscript has not been published to any other journal or online sources.

Data Availability: The author has all the data employed in this research and is open to sharing it upon reasonable request.

References

Awan, U., Shamim, S., Khan, Z., Zia, N. U., Shariq, S. M., & Khan, M. N. (2021). Big data analytics capability and decision-making: The role of data-driven insight on circular economy performance. Technological Forecasting and Social Change, 168, 120766.

Barnes, S. J., Guo, Y., & Chan, J. (2022). Big Data analytics for sustainability: Insight through technological innovation. Information & Management, 59(5), 103627.

Choi, H. Y., & Park, J. (2022). Do data-driven CSR initiatives improve CSR performance? The

importance of big data analytics capability. Technological Forecasting and Social Change, 182, 121802.

Côrte-Real, N., Oliveira, T., & Ruivo, P. (2017). Assessing business value of Big Data Analytics in European firms. Journal of Business Research, 70, 379-390.

Daradkeh, M. (2020). Driving Business Innovation and Sustainability through Internet of Things and Data Analytics: An Innovation Stage Model. International Journal of Innovation. Creativity and Change, 14(9), 149-179.

Edwin Cheng, T. C., Kamble, S. S., Belhadi, A., Ndubisi, N. O., Lai, K. H., & Kharat, M. G. (2022). Linkages between big data analytics, circular economy, sustainable supply chain flexibility, and sustainable performance in manufacturing firms. International Journal of Production Research, 60(22), 6908-6922.

Grover, V., Chiang, R. H., Liang, T. P., & Zhang, D. (2018). Creating strategic business value from big data analytics: A research framework. Journal of management information systems, 35(2), 388-423.

Jain, P., Tambuskar, D. P., & Narwane, V. (2024). Identification of critical factors for big data analytics implementation in sustainable supply chain in emerging economies. Journal of Engineering, Design and Technology, 22(3), 926-968.

Jeble, S., Dubey, R., Childe, S. J., Papadopoulos, T., Roubaud, D., & Prakash, A. (2018). Impact of big data and predictive analytics capability on supply chain sustainability. The International Journal of Logistics Management, 29(2), 513-538.

Khan, S. A. R., Godil, D. I., Jabbour, C. J. C., Shujaat, S., Razzaq, A., & Yu, Z. (2021). Green data analytics, blockchain technology for sustainable development, and sustainable supply chain practices: evidence from small and medium enterprises. Annals of Operations Research, 1-25.

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance. International Journal of Production Economics, 239, 108205.

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). Towards a business analytics capability for the circular economy. Technological Forecasting and Social Change, 171, 120957.

Minatogawa, V. L. F., Franco, M. M. V., Rampasso, S., Anholon, R., Quadros, R., Durán, O., & Batocchio, A. (2019). Operationalizing business model innovation through big data analytics for sustainable organizations. Sustainability, 12(1), 277.

Morabito, V. (2015). Big data and analytics. Strategic and organisational impacts.

Munodawafa, R. T., & Johl, S. K. (2019). Big data analytics capabilities and eco-innovation: a study of energy companies. Sustainability, 11(15), 4254.

Nilashi, M., Keng Boon, O., Tan, G., Lin, B., & Abumalloh, R. (2023). Critical data challenges in measuring the performance of sustainable development goals: Solutions and the role of big-data analytics. Harvard Data Science Review, 5(3), 3-4.

Pugna, I. B., Duțescu, A., & Stănilă, O. G. (2019). Corporate attitudes towards big data and its impact on performance management: A qualitative study. Sustainability, 11(3), 684.

Raj, R., Kumar, V., & Shah, B. (2023). Big data analytics adaptive prospects in sustainable manufacturing supply chain. Benchmarking: An International Journal.

Rodriguez, L., & Da Cunha, C. (2018). Impacts of big data analytics and absorptive capacity on sustainable supply chain innovation: A conceptual framework. LogForum, 14(2), 151-161.

Schläfke, M., Silvi, R., & Möller, K. (2012). A framework for business analytics in performance

management. International Journal of Productivity and Performance Management, 62(1),110-122.

Tamym, L., Benyoucef, L., Moh, A. N. S., & El Ouadghiri, M. D. (2023). Big data analytics-based approach for robust, flexible and sustainable collaborative networked enterprises. Advanced Engineering Informatics, 55, 101873.

Tamym, L., Benyoucef, L., Nait Sidi Moh, A., & El Ouadghiri, M. D. (2023). Big Data Analytics- based life cycle sustainability assessment for sustainable manufacturing enterprises evaluation. Journal of Big Data, 10(1), 170.

Tetteh, F. K., Atiki, G., Kyeremeh, A., Degbe, F. D., & Apanye, P. (2024). Linking business analytics capability and sustainability performance: the mediating role of circular economy implementation. Modern Supply Chain Research and Applications.

Weerakkody, V., Sivarajah, U., Mahroof, K., Maruyama, T., & Lu, S. (2021). Influencing subjective well-being for business and sustainable development using big data and predictive regression analysis. Journal of business research, 131, 520-538.

Zhu, C., Du, J., Shahzad, F., & Wattoo, M. U. (2022). Environment sustainability is a corporate social responsibility: measuring the nexus between sustainable supply chain management, big data analytics capabilities, and organizational performance. Sustainability, 14(6), 3379.