

Big Data as Sustainable Educational Key to a Waste-Free Future

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How can we reconcile economic growth with environmental preservation? The answer largely lies in the education for application of innovative technologies such as Big Data. Big Data, understood as the vast volume of data that contains new forms of information with greater velocity, variety, volume, and veracity, offers immense potential to transform the way industries operate. By analyzing this massive data, companies can identify patterns, trends, and opportunities for improvement that were previously invisible. This ability to obtain valuable insights in real-time allows organizations to make more informed decisions and optimize their processes, from the supply chain to energy management. In this review, we will explore how Big Data is becoming a strategic ally in achieving Education in the Sustainable Development Goals. We will analyze the main applications of this technology in industry, the benefits it provides, and the challenges involved in its education and implementation. Additionally, we will present examples that illustrate how companies from various sectors are using Big Data to reduce their carbon footprint, improve energy efficiency, and promote more sustainable practices.

Key Words: Sustainable Education, Big Data, Waste Management, Sustainable Supply Chain, SDG 4, SDG 7 and SDG 12

Introduction

In an increasingly interconnected world with limited resources, the pursuit of sustainable solutions has become a global priority. Industry, as one of the primary drivers of the economy, plays a crucial role in this challenge. According to the UN, sustainability is "everything that contributes to sustainable development, such as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" [1] (UN, n.d.).

When discussing sustainability, it is inherent to mention the concept of sustainability. Sustainability refers to an integrated approach that considers various pillars. The three main pillars are economic, social, and environmental. For this reason, various sources have agreed to focus on certain principles and objectives to have a more planned strategy for addressing sustainability issues. Among these sources, we can mention the 1987 Brundtland Report [2], the 1992 United Nations Conference on Environment and Development [3], the UN Sustainable Development Goals [4], and the United Nations Global Compact [5], among others. Each of them has its particularities, but if we were to encompass the most important aspects, we could highlight the following. Sustainability involves managing the resources at our disposal in an efficient manner to meet the needs of the present without compromising future generations. Additionally, it is necessary to identify opportunities that can be leveraged by emerging technologies and development systems. [6] Understanding this context, it is essential to seek opportunities to impact the world from various perspectives. Throughout this essay, we will delve into how Big Data can be an important factor in the sustainable development of the world.

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The Problem of Waste in Industry and the Application of Big Data

Inefficiency in resource management within the manufacturing industry has been a persistent problem that affects both corporate profitability and the environment. In Mexico alone, it is estimated that approximately 8 million tons of hazardous industrial waste are generated annually. Of this, only 26% receive adequate treatment [7]. One of the contributing factors to this is practices such as overproduction and inefficient inventory management. This not only generates additional costs but also contributes to the accumulation of waste and the emission of greenhouse gases, fueling the global environmental crisis. The United Nations Industrial Development Organization (UNIDO) pointed out in a report how sustainable and inclusive industrial development contributes positively to the achievement of the 17 SDGs [8]. In the same report, it can be observed how changing the way production systems, innovation, and industries operate presents significant opportunities that, in some cases, are already being exploited.

In this context, Big Data emerges as a key tool to transform the way industries manage their resources. This technology allows for the collection, storage, and analysis of large volumes of data in real time, providing a clear and detailed view of production processes. According to a report by the McKinsey Global Institute [9], companies that implement Big Data solutions can improve their operational efficiency by optimizing resource use and reducing waste. "In the private sector, for example, we estimate that a retailer who makes maximum use of big data has the potential to increase its operating margin by more than 60 percent" as it may be observed in Figure 1

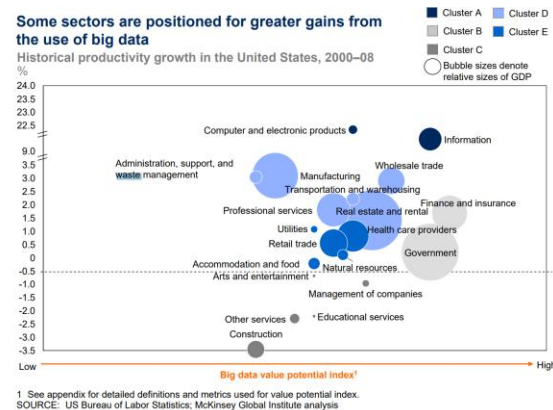


Figure 1. McKinsey Global Institute, Report May 2011

Big Data offers multiple applications to address industrial inefficiency. For example, by analyzing historical and real-time data, companies can identify consumption and production patterns, allowing them to adjust their production to real demand. This not only reduces overproduction but also minimizes the use of materials and energy. UNDERPIN, a company co-founded by the European Union, emphasizes the advantages of using predictive maintenance with the help of this technology. These new emerging systems maintain a sustainable focus by being integral in their impact; they reduce costs and time, which can be redirected towards the continuous sustainable improvement of systems, help to increase the useful life of equipment used in industrial processes, and can identify safety risks, promoting a safe and dignified work environment for workers [10]

In summary, the implementation of Big Data in the manufacturing industry represents an innovative and effective solution to combat resource inefficiency. By providing accurate and real-time data, Big Data enables companies to make informed decisions that not only optimize their economic performance but also contribute to more sustainable development, aligning with global sustainability goals and reducing the environmental footprint.

Developing Big Data Projects for Energy Optimization in Industrial Settings

To implement this opportunity in the operation of current systems and industries, it is necessary to address challenges in the implementation process, consider the operation of the largest current industries globally, review alternative proposals and solutions, as well as consider associated disadvantages and conflicts.

Examples of Opportunities in Industry

The food industry is often at the forefront of discussions surrounding resource waste, as it represents a critical sector where this issue is particularly significant. According to the UN, in 2022, 1.05 billion tons of food waste (including inedible parts) were generated, which amounts to 132 kilograms per person and approximately one-fifth of all food available for human consumption [11]. Companies in this industry can implement Big Data to optimize inventory management, forecast demand, and improve distribution logistics. For example, Walmart uses Big Data analytics to monitor real-time purchasing patterns, allowing them to adjust their inventory levels and reduce food waste in their stores. In the energy industry, Big Data plays a crucial role in managing energy production and distribution, particularly during the transition to renewable energy sources. Companies like GE Vernova implement data analytics to predict wind energy production and optimize turbine operation. This approach not only maximizes operational efficiency but also contributes to reducing the carbon footprint by increasing the utilization of clean energy sources. "The key to success for this wind farm lies in the ability to collect and deliver the right data, at the right velocity, and in the right quantities to a wide set of well-orchestrated analytics..." [12]. The textile sector faces numerous sustainability challenges, including excessive water consumption and waste generation. By implementing Big Data, companies improve their product production processes, optimize the use of materials, and reduce the waste of basic resources such as water. For example, "Through intelligent demand planning and a supply chain oriented towards the preferences of millions of customers, consumers worldwide can find the product they want. Levi Strauss & Co. can make data-driven decisions, leading to greater growth and a true competitive advantage" [13]. Lastly, in the mobility and health industries, Big Data, combined with technologies like Artificial Intelligence, can improve ventilation systems and help control virus infections. This type of technology has already been implemented in the Barcelona metro [14]. It also helps optimize the use of electricity consumption and ventilation in these public facilities. "...are centrally correlated to establish the optimal ventilation strategy thanks to a dynamic algorithm.

Implementation Process in large Industries

The rapid adoption of Big Data systems in large industries is essential for maintaining competitiveness, optimizing operations, and leveraging advanced analytics for better decision-making. With cloud infrastructure revenue growing significantly—driven by AI investments and digital transformation—companies must integrate scalable data solutions to remain agile. As competition among major cloud providers intensifies, businesses have more options to enhance efficiency, reduce costs, and drive innovation through data-driven strategies. We can observe this behavior in *Figure 2.1* and *Figure 2.2* [15].

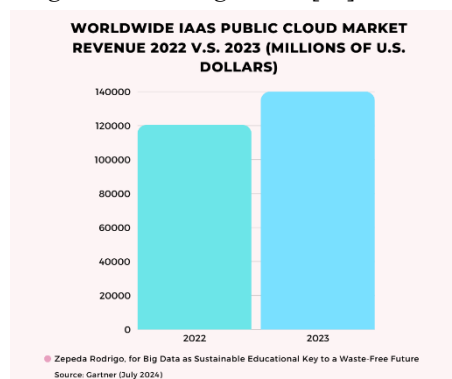


Figure 2.1 source: Gartner, July 2024

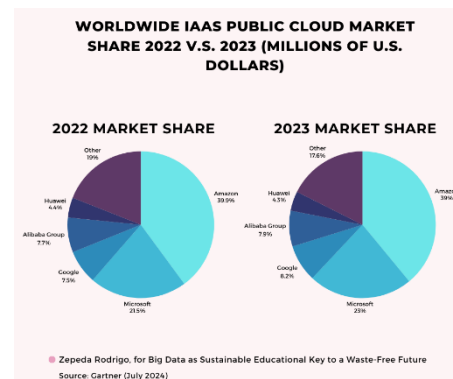


Figure 2.2 source: Gartner, July 2024

Implementing Big Data in large industries requires a strategic, multi-phase approach to ensure efficiency, scalability, and long-term success. The process begins with a comprehensive needs and opportunities assessment to identify key areas where Big Data can drive positive change, such as operational optimization, predictive maintenance, and supply chain efficiency. Once objectives are clearly defined, companies must evaluate their current infrastructure, assess data storage, processing capabilities, and cybersecurity measures to identify gaps that may hinder implementation. Developing the appropriate technological infrastructure is a critical next step, involving the selection of cloud storage solutions and advanced analytics platforms, with widely used services such as Amazon Web Services (AWS) and Google Cloud [16]. Additionally, selecting the right tools—such as Hadoop and Spark for distributed computing, Apache Kafka for real-time data streaming, and SQL/NoSQL databases for structured and unstructured data—is essential for effective data management. However, technology alone is not enough; employee training plays a crucial role, ensuring that staff are equipped to handle large datasets, interpret analytics, and make data-driven decisions.

Integration of data from both internal and external sources, including IoT sensors, ERP systems, and supply chain databases, provides a holistic view of operations and enhances decision-making accuracy. Once these foundational steps are in place, industries can leverage advanced analytics, including descriptive, predictive, and prescriptive models, to gain actionable insights and drive efficiency. Pilot testing and performance evaluation are essential before full-scale deployment, allowing companies to measure key performance indicators such as data processing speed, cost savings, and operational improvements. The process is further reinforced by continuous monitoring, optimization, and security updates to ensure system resilience and adaptability to emerging technologies. Finally, fostering a data-driven culture is vital, promoting cross-departmental collaboration, making data visualization tools accessible to non-technical users, and implementing data literacy programs for employees. The cycle is completed with continuous evaluation and improvement, monitoring key sustainability and efficiency indicators to refine strategies and adjust initiatives as needed, ultimately ensuring long-term business success.

Proposals and Solutions

Big Data offers transformative solutions to industrial challenges, enabling advancements in supply chain optimization through sophisticated predictive analytics that dynamically adjust production levels, reducing excess inventory and minimizing waste. For instance, by analyzing historical sales data, market trends, and real-time conditions, companies can enhance demand forecasting, ensuring that popular items are available while avoiding overstocking items unlikely to sell [17]. Furthermore, Big Data facilitates predictive maintenance by anticipating equipment failures, which not only minimizes downtime but also extends the operational lifespan of critical assets. In the energy sector, Big Data plays a pivotal role in enhancing energy efficiency by streamlining processes to lower costs and reduce consumption, particularly in energy-intensive industries. Data-driven insights can help optimize energy performance, more accurately predict demand, and locate the best sites for new projects. According to McKinsey, using data analytics could reduce energy costs by up to 25% [18]. In parallel, Big Data aligns with sustainability goals by optimizing operations to decrease carbon emissions, contributing meaningfully to global climate action efforts. For example, AI applications in various industries have demonstrated environmental benefits, such as reducing food waste in kitchens and providing farmers with crucial crop management insights, thereby promoting sustainable practices [19].

Disadvantages and Challenges

Implementing Big Data technologies offers numerous advantages; however, organizations must navigate several significant challenges to ensure successful adoption. One primary concern is the substantial financial investment required for infrastructure development, software acquisition, and workforce training, which can be prohibitive for some organizations. Additionally, the effectiveness of Big Data initiatives is heavily dependent on data quality; inaccurate or incomplete data can lead to flawed decision-making with potentially severe consequences. Data security and privacy concerns are paramount, necessitating robust systems to safeguard sensitive information against breaches and misuse. Furthermore, organizational resistance to change presents a notable obstacle, as adopting new technologies often requires a cultural shift and extensive buy-in from all levels of the workforce. Addressing these challenges is crucial for organizations aiming to leverage Big Data effectively [10].

Steps Towards a Globalized Future with a Sustainable Industrial Focus

To pave the way for a sustainable and globally interconnected future, industries must prioritize collaboration by fostering the sharing of data, expertise, and best practices. The United Nations emphasizes the importance of data sharing and collaboration in achieving sustainable development goals, highlighting that the Open SDG Data Hub enables data providers, managers, and users to discover, understand, and communicate patterns and interrelationships [21]. In other hand, the establishment of comprehensive sustainability policies that seamlessly integrate Big Data into core business strategies is crucial for driving measurable progress. According to Quantexa, integrating Big Data into business strategies allows organizations to better manage, track, and achieve sustainability targets, ensuring that eco-friendly goals are met effectively [22]. Equally important, is the promotion of education and continuous training programs to equip employees with the skills needed to maximize the potential of this technology. The Journal of Big Data discusses how manufacturing enterprises benefit from life cycle sustainability assessment thinking to incorporate environmental considerations, underscoring the need for ongoing education and training in sustainable practices [23]. Moreover, companies should implement rigorous monitoring and evaluation systems to assess the tangible impacts of Big Data initiatives. A study published in Corporate Social Responsibility and Environmental Management evaluates the impact of Big Data Analytics on firm sustainable performance, highlighting the necessity of robust monitoring and evaluation frameworks to ensure effective implementation. [24]. Finally, adopting a consumer-centric approach

ensures that the solutions developed are both practical and highly valued by the market, reinforcing the link between innovation and customer satisfaction. The Times reports on various AI applications that demonstrate environmental benefits, such as reducing food waste and providing farmers with crucial crop management insights, illustrating how consumer-focused solutions can drive sustainability while meeting market demands [25].

Conclusion

Through the implementation of Big Data, has immense potential to drive sustainability and sustainable development in various industries. The analysis of massive datasets allows for the optimization of critical processes such as the supply chain and predictive maintenance, generating a positive impact on operational efficiency, reduced resource consumption, and decreased carbon footprint. However, the adoption process of Big Data faces significant challenges, including high implementation costs, data quality and security, and organizational resistance to change. Despite these barriers, the path towards a more sustainable industrial future is marked by technological innovation, continuous employee training, and inter-company collaboration to maximize data utilization.

For larger global industries to fully adopt this technology, it is crucial that they continue developing robust infrastructures, sustainability-focused policies, and consumer-centric solutions. By overcoming current obstacles and seizing the opportunities offered by Big Data, industries will be better positioned to actively contribute to environmental preservation and the achievement of the Sustainable Development Goals (SDGs), striking a balance between economic progress and the conservation of resources for future generations.

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