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Exploring the Role of Information Technology in Supporting Sustainability Efforts in Saudi Arabia

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Abstract: This study examines how information technology (IT) contributes to sustainability endeavours in Saudi Arabia. The process of equipping companies to effectively leverage information technology for sustainability initiatives has remained a challenge, particularly in Saudi Arabia. Through an analysis of four case studies, we examine how technology has been implemented by Saudi Arabian companies to advance sustainability goals. The findings demonstrate a notable shift towards green initiatives in the country, with the adoption of technologies such as the Internet of Things (IoT), blockchain, and artificial intelligence (AI). These technologies have been instrumental in enhancing energy efficiency and waste reduction. The study highlights the significance of policy interventions and public–private partnerships in achieving both environmental sustainability and economic growth. To ensure the widespread adoption of sustainable practices, it is crucial for the government to focus on building digital capacity in companies and removing technological barriers. The case studies of four companies serve as illustrative examples of sustainable practices and the corresponding technological support in Saudi Arabia. The research underscores the importance of leveraging IT and collaboration to accelerate progress toward the nation's sustainability goals.

Keywords: accounting; environment; information technology; innovation; sustainability

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1. Introduction

Sustainability is a critical issue facing the world today, and information technology (IT) is playing an increasingly important role in promoting sustainability in developing countries [1]. The rapid pace of technological innovation presents new opportunities to address a wide range of environmental and social challenges, and developing nations are embracing these technologies to improve sustainability and create a more sustainable future. In recent years, the concept of sustainability has specifically gained significant attention across multiple sectors, including finance and accounting [2]. The role of IT in supporting sustainability initiatives has become increasingly prominent, offering companies new opportunities to enhance their sustainability performance. The aim of this study is to examine how IT is supporting sustainability efforts within Saudi Arabian companies. The research seeks to provide actionable insights and recommendations for leveraging IT effectively to enhance sustainability performance, including the implementation of technologies like IoT, blockchain, and artificial intelligence (AI). The study also highlights the importance of policy interventions, public–private partnerships, and building digital capacity in companies to achieve both environmental sustainability and economic growth. Sustainability entails integrating sustainability principles into financial reporting, risk management, decision-making processes, and overall business strategies [3]. It involves tracking and assessing various sustainability indicators, such as greenhouse gas emissions, energy consumption, waste management, social impact, employee well-being, and community engagement. In the IT sector, with global network expansion and increasing demands

on data centre networks, dynamically adapting to customer needs, such as zero packet loss, high-performance computing, and low latency, presents a significant challenge for network operators [4]. Scaling data centres on demand, especially when networks consist of heterogeneous devices from different vendors with varying configuration commands, poses difficulties. Integrating the concept of a digital twin network platform with sustainability can lead to significant advancements in data centre network management, aligning with sustainability principles [4]. Efficiently managing data centre networks and dynamically adapting to customer needs through a digital twin network platform can contribute to several sustainability-related aspects such as energy efficiency, resource conservation, and e-waste reduction.

The motivation behind this research stems from the growing global concern about sustainability and the escalating role of IT in addressing sustainability challenges. It becomes crucial to explore how IT can effectively support sustainability practices within businesses, especially in the context of Saudi Arabian companies. The utilisation of case studies is essential in this paper as it enables an in-depth exploration and contextual understanding of how IT contributes to sustainability in Saudi Arabian companies. The rich data collection from real-world scenarios provides practical insights and identifies best practices, offering relevant and actionable recommendations for enhancing sustainability efforts through the use of IT.

The significance of this research lies in the growing importance of sustainability for businesses worldwide. Saudi Arabia (SA), as the largest economy in the Middle East, plays a crucial role in regional and global markets [5]. As SA continues its efforts to diversify its economy beyond oil, companies must adopt sustainable practices that align with global standards and contribute to the achievement of national and international sustainability goals. The purpose of this study is to investigate how IT can facilitate the integration of sustainability practices within Saudi Arabian companies. By examining the use of IT, this research aims to shed light on the best practices for leveraging IT in sustainability initiatives.

The current state of research in this field indicates a growing interest in exploring the intersection of IT and sustainability. Several studies have delved into the adoption and impact of IT on sustainability practices across various industries and countries. For instance, De Villiers, Kuruppu, and Dissanayake proposed a conceptual framework that explores how businesses can leverage the Internet of Things (IoT) and blockchain IT to promote the United Nations' Sustainable Development Goals (SDGs) [6]. They highlighted that IoT enables real-time and accurate data measurement, while blockchain ensures transparent and trustworthy data recording and reporting. By utilising these technologies, businesses can develop innovative solutions for measuring and managing their activities in line with the SDGs, driving sustainability and creating new business opportunities. Another study by Tiwari and Khan investigated the relationship between Industry 4.0 and sustainability accounting and reporting [7]. They identified three levels of maturity for Industry 4.0, aligned with relevant sustainability topics. Tiwari and Khan noted that AI-based analytics and automation require more time to mature, and ongoing technical and training programs are required [7]. The role of IoT, blockchain, and Industry 4.0 in driving innovative and sustainable practices was emphasised through accurate data measurement, transparency, and the cautious adoption of IT, which can effectively support sustainability accounting and reporting [6,7]. However, the specific context of Saudi Arabian companies and the role of IT in their sustainability efforts remain relatively underexplored. Therefore, this study seeks to contribute to the existing body of knowledge by focusing on the unique opportunities available to Saudi Arabian companies and examining the extent to which IT can support their sustainability goals.

While some argue that IT can significantly enhance the efficiency and effectiveness of sustainability reporting and performance measurement [8,9], others express concerns about the potential limitations and unintended consequences associated with technological advancements in accounting for sustainability [10,11]. By considering these diverging perspectives,

this research aims to provide a comprehensive understanding of the potential impacts and trade-offs of IT adoption in the sustainability practices of Saudi Arabian companies.

The main aim of this work is to provide actionable insights and recommendations for Saudi Arabian companies, policymakers, and other stakeholders on how to leverage IT effectively to support their sustainability goals. In summary, the paper makes the following contributions.

- It offers an understanding of the role of IT in supporting sustainability efforts in SA. It provides insights into how IT solutions, such as the Internet of Things (IoT), blockchain, and AI, have been implemented by companies to enhance energy efficiency and waste reduction, leading to a notable shift towards green initiatives in the country.
- It highlights the significance of policy interventions and public–private partnerships in achieving both environmental sustainability and economic growth.
- It underscores the importance of building digital capacity in companies and removing technological barriers to ensure widespread adoption of sustainable practices. By highlighting the need to address digital disparities, the paper offers practical recommendations for policymakers and organisations to enhance digital literacy and encourage the integration of IT solutions in sustainability efforts.
- The absence of IT-related roles is raised particularly in areas such as community relations, communication, collaboration within the company, employee satisfaction and wellbeing, and education support. The paper encourages exploring the integration of IT solutions into these social dimensions of sustainability and promotes a more holistic approach to sustainable development.

The following sections will present an analysis of the current literature, research methodology, findings, discussions, and conclusions, with the ultimate goal of advancing sustainable practices in SA.

2. Literature Review

According to recent studies, 84% of globally recognised companies are focusing their priorities on environmental conservation efforts to ensure that they alleviate poverty, and also contribute to operational efficiency [12]. According to the 2021 Morning Star, the United States Sustainability Report reveals that companies with better environmental, social, and governance (ESG) scores reported 33% higher returns on their income statements [13]. These results show that corporate sustainability efforts are becoming a key metric in assessing the financial performance of institutions.

Organisations today are looking towards transformative change to improve quality of life and ensure sustainability in the future, as noted by various studies [14,15]. Digital technologies, such as IoT and blockchain, provide new avenues for achieving these goals [6]. However, digitalisation also brings challenges to the business world, requiring a deeper engagement with these technologies and transformations across many areas [16,17].

The COVID-19 pandemic and other unexpected crises have accelerated the adoption of digital technologies in society, presenting a challenge for managers, professionals, and management scholars. As a result, organisations are increasingly seeking to understand their place in society and how it may be shifting [18]. The response to the COVID-19 pandemic has spurred the use of IT and brought more attention to the SDGs, even as it has reduced human interaction and mobility worldwide [19]. In today's environment, sustainability is recognised as a crucial aspect of business that impacts value creation. As a managerial aspect, it drives social change and helps organisations navigate the important shift to digitalisation [20]. As a result, many organisations must incorporate sustainability into their business model, including aspects such as operations, risk management, product creation, and more, which will impact their sustainability performance [21]. This involves balancing financial, environmental, and social objectives in the delivery of core activities to maximise organisational value.

The United Nations Global Partnership for Sustainable Development Data (GPSDD) has made a clear call for a "data revolution for sustainable development" [22] (p. 10). The

utilisation of IT has the potential to drive sustainable development. The digital transformation highlights that the future of organisations is closely tied to sustainability, which requires the development of organisational, technological, and social capabilities within various ecosystems where different actors play a crucial role in the creation of value. For instance, the Saudi Arabian government and companies believe that sustainability is important in the promotion of socio-economic development. SA has also partnered with other corporations, such as the Gulf Corporation Council, nations under the Red Sea Project, and large companies as well as small and medium enterprises in the country, to promote sustainable development [23]. The country, in coordination with companies such as the Saudi Telecommunication Company, is focusing on green transformation, where environmentally conscious projects and technologies are prioritised. It is expected that these green initiatives will help in the management of toxic wastes, improve conservation efforts, replenish depleted resources, help in reclaiming previous wastelands, and improve mass awareness of conservation. IT is an important part of the promotion of sustainability, reporting, and making conservation efforts visible and relevant [23]. Therefore, this paper focuses on how IT such as the IoT, blockchain, AI, and machine learning can be used to promote the sustainability reporting of major Saudi Companies.

Firms are including their concerns for the environment as a key strength that forms a competitive advantage [24]. In a study that involved data collection from 53 apparel sector firms in Bangladesh, Alam and Islam discovered that environmental corporate social responsibility positively improves the ability of the company to survive, sustainably produce, and maintain efficiency and profitability in operational activities [24]. The authors found a direct relationship between a company's green image and its green competitive advantage. They also found that customer well-being is positively associated with a green image. The main enablers identified in this context were green innovation, people's capacity, consumer well-being, and the company's philanthropic activities. These findings align with the results of another study [25], which indicated that an increase in community involvement and engagement in sustainability efforts enhances the quality of available sustainable infrastructure and the sustainability of resources [24]. While it is acknowledged that the outcomes of community engagement may not always be desirable, in most instances, the reciprocity between government, private sectors, and communities can help resolve some of the conflict-related challenges. According to Hes, IT and innovation can be important resources for promoting a company's efforts for sustainability [25]. In a Loreto Bay Case Study in Mexico, Hes demonstrated how improvement in community engagement and collaboration became essential for the survival of a project even when initial funding sources were pulling away from the project [25].

Leveraging Digital Technologies for Sustainable Business Practices

Digital technologies offer promising solutions to the challenges companies face in adopting environmentally sustainable measures. Some of these sustainability problems are of a managerial and institutional nature [26]. Institutional hindrances to organisations attempting to improve sustainability focus include corruption, weak legal systems, a lack of institutional willingness, conglomerate companies that take advantage of consumers, and a lack of stakeholder agreements that can value and increase the strength of corporate sustainability efforts [26]. George, Merrill, and Schillebeeckx proposed a wide range of technologies and digital toolkits that can aid in company sustainability efforts [26]. However, they caution that the cost of scaling up these resources should be kept low to ensure a positive impact. The technologies should be adopted in a collaborative, coordinated, and sustainable manner that will improve communication and information-sharing capabilities. Technologies such as blockchain, the IoT, and machine learning can be extensively used in corporate social sustainability efforts if they promote the public good, and companies controlling them avoid exclusivity problems.

According to Salam, the IoT holds potential as an intervention in the management of vast forest systems, such as the Amazon Forest in South America [27]. However, the

adoption of IoT may be limited due to the need to cover extensive geographical areas, the lack of capacity of conservation agents, and challenges in improving human capital instrumental in resource management [27]. Nonetheless, the important strengths of the IoT, including prediction, data analysis, big data, and actuation, can help overcome these limitations. These features enable accurate deployment in predicting instances and areas susceptible to forest fires. Companies can leverage the IoT to predict real-time changes in temperature, analyse variance from normal forest temperature, forecast moisture level changes, and transmit real-time images depicting areas affected by pests [27]. AI has also played a significant role in helping companies like Huawei predict the future energy efficiency of their data centres. This proactive approach allows companies to take the necessary steps to improve efficiency before problems arise. As a result of these efforts, Huawei has been able to reduce the energy consumption of its data centres by an average of 15%. This has saved the company millions of dollars in energy costs and helped reduce its environmental impact. AlGhamdi and Sharma also examined the use of IT to promote quality, conservation, and sustainability [28]. AlGhamdi and Sharma noted the use of IT pioneered in SA for Mobile Communications (GSM) modules, the cloud, and water sensors to conserve water that flows into residential buildings [28].

Investigations show that certain institutions and corporations have an important role in promoting continuity during socioeconomic disruptions and climate change situations. Financial accounting can play a significant role in supporting these efforts [29]. Tettamanzi, Venturini, and Murgolo contend that the International Accounting Standards Board (IASB) and the Financial Accounting Standards Board (FASB) collaborate with international environmental boards to incorporate sustainable accounting standards into the Generally Accepted Accounting Standards (GAAPs) and the International Financial Reporting Standards (IFRS) that companies are supposed to adhere to [29]. Tettamanzi, Venturini, and Murgolo suggested that, to increase the prominence of conservation efforts, environmental sustainability information may receive higher materiality in auditing compared to previously focused financial information [29]. This elevation in materiality can aid stakeholders in making investment-related decisions. There is also a recommendation that pollution taxes and other incentives for companies actively involved in environmental conservation be taken into account in the calculation of Earnings Before Interest and Taxes (EBIT). Such measures aim to encourage and reward companies that go the extra mile to preserve the environment. On the topic of sustainability reporting and its inclusion in financial statements, Hoogervorst emphasises that the IFRS website notes that sustainability reporting may sometimes be done for public relations purposes [30]. This highlights the importance of ensuring that sustainability reporting is conducted in a meaningful and authentic manner to genuinely contribute to environmental efforts and not merely serve as a public relations tool [30].

Some also contend that not all digital technologies have been adopted in sustainability as research is still in its nascent stages [27]. However, some systems adopted in health have a direct bearing on environmental sustainability, which can be helpful in other contexts. For example, an application called the Healthcare Data Gateway (HDG) uses blockchain systems to automate patient medical records, reducing a hospital's usage of paper, and helping patients own, share, and control their information—an effort in digitisation and environmental conservation [24].

Dao, Langella, and Carbo, as well as Rivera and Kurnia, proposed four roles of IT in sustainable supply chain management:Automate, Informate, Transform and,: and Infrastructure (see Table 1). These roles encompass various functions that IT can fulfill within organisations [31]. The role of Automate corresponds to integration and operational aspects, whereas the role of Informate encompasses communication, coordination, and decision-making. The role of Infrastructure relates to integration and knowledge codification and management, while the Transform role empowers organisations to re-engineer their business processes. These four IT roles enable organisations to achieve information transparency, performance monitoring and evaluation, flexibility and responsiveness,

resource optimisation, value creation, and competitive advantage through the effective utilisation of information and knowledge [32].

Table 1. Roles of technology in supporting various sustainability practices.

Dimension	Key Practice	Information Technology Role			
		Automate,	**I Informate,**	**Transform**	**Infrastructure**
Economic	Reducing costs	Y	Y		Y
	Achieving stakeholders' satisfaction		Y		Y
	Enhancing sales	Y	Y	Y	Y
	Creating new business models	Y	Y	Y	Y
	Quality initiatives		Y	Y	Y
	Creating competitive advantage		Y	Y	Y
Environmental	Clean/lean production	Y	Y	Y	Y
	Green distribution/logistics		Y	Y	Y
	Efficient resource consumption		Y	Y	Y
Social	Community relations and communication		Y	Y	Y
	Collaboration within company		Y	Y	Y
	Employee satisfaction and wellbeing		Y	Y	Y
	Education support		Y		Y

Adapted from Dao, Langella, and Carbo [31] and Rivera and Kurnia [32].

The economic dimension focuses on practices that promote economic sustainability [31]. This includes ensuring a healthy cash flow, good profit margins, and a proper return on investment. It involves various practices such as business performance improvement, internal and external management practices, and creating competitive advantage through factors like cost, quality, speed, and flexibility that contribute to bottom-line performance. On the other hand, the environmental dimension of sustainability involves integrating environmental concerns [32]. This includes addressing issues related to energy use, hazardous material disposal, after-sales service practices, and promoting green purchasing. The fusion of economic and environmental sustainability adds complexity, requiring greater cooperation, collaboration, and an interdisciplinary focus. Measuring outcomes and balancing economic and environmental imperatives pose challenges, and the impact of green initiatives on firm performance remains ambiguous [32]. Lastly, the social dimension encompasses various considerations, such as community issues, corporate governance, diversity considerations, employee relations, human rights, safety, education, and ethical considerations. Emphasising the social dimension along with economic and environmental aspects is essential for creating a well-rounded approach to sustainability.

3. Methodology

This study examines how four organisations successfully implemented technologies to promote sustainability. We utilise a suitable exploratory method, the case study, to investigate how these organisations introduced IT. To identify the case studies to answer the question of exploring the role of IT in supporting sustainability efforts in Saudi Arabia, the following steps were taken: (i) We clearly outlined the purpose of the study, which was to investigate how IT can facilitate the integration of sustainability practices within SA companies. This helped to narrow down our focus and guide the selection of case studies. (ii) We reviewed existing literature by thoroughly analysing relevant academic papers, reports, and articles related to IT and sustainability in Saudi Arabia. This assisted

in identifying existing case studies. (iii) We identified potential sources for our case studies by exploring academic databases (Saudi Digital Library (SDL)), research institutes (Prince Sultan Research Center for Environment, Water, and Desert (PSRCEWD)), and internet searches. The focus was on looking for organisations, projects, or initiatives that showcase the use of IT to support sustainability in Saudi Arabia. (iv) From a list of 28 potential organisations/projects, we evaluated case study candidates based on the extent of their IT integration and the impact of their sustainability efforts. Major considerations included the sector (one sector per project/organisation), the size of the sustainability projects (multimillion-dollar projects/organisations), and the extent of IT and innovation within the projects/organisations. (v) Four case studies that best represent a diverse range of IT applications in supporting sustainability efforts in SA were chosen. While there are other cases in SA available for examining sustainability practices in different organisations, none of them provided such comprehensive details and a focus on IT usage as the selected cases. Due to the limited existing studies with in-depth descriptions of IT's role in supporting sustainability practices, the chosen organisations serve as indicative cases of sustainability practices and the corresponding technological support. Throughout this paper, the organisations are referred to as Company A, Company B, Company C, and Company D to maintain anonymity.

The comprehensive nature of the published data on Company A, Company B, Company C, and Company D facilitated a detailed analysis to address the research questions. Content analysis was employed to systematically examine and interpret the available data, aiming to identify patterns, themes, biases, and meanings [33]. Relevant organisational practices related to sustainability were identified, and patterns associated with the roles of IT were analysed.

Overview of the Case Studies

Company A project is a major land and property development project in SA developed as part of the Saudi Vision 2030 program. Initially announced in July 2017, the project focuses on attracting visitors to the Red Sea coast through ecotourism. Work began in 2019, and the project is projected to contribute USD 5.86 billion annually to the Saudi Arabian GDP. The phases include the construction of hotels with more than 3000 rooms, an airport, a yachting marina, historical sites, and recreational facilities. By 2030, Company A project aims to feature more than 50 hotels with 8000 rooms, along with over 1000 residential properties spread across 22 islands and six inland sites.

Company B is a publicly traded petroleum and natural gas company headquartered in SA. Company B came into being through a partnership between two countries, which include Saudi Arabia. The purpose of the partnership was to transform billions of barrels of oil and trillions of cubic feet of gas into various streams of value for Saudi communities. Company B intends to position itself as a top oil-producing company in the world. It holds a prominent position in the global corporate landscape, consistently generating substantial revenue and achieving record-breaking annual profits. Company B boasts the world's second-largest proven crude oil reserves, exceeding 270 billion barrels, and maintains the highest daily oil production among all oil companies. However, it has also been recognised as the leading contributor to global carbon emissions since 1965. Company B operates the largest hydrocarbon network worldwide, with numerous oil and gas fields. The company's shares are traded on the Tadawul stock exchange in SA and have been listed among the five largest public companies globally.

Company C is a sovereign wealth fund in SA, established with the aim of investing funds on behalf of the Saudi Arabian government. With an estimated total asset value of more than USD 600 billion, Company C ranks among the largest sovereign wealth funds globally. The fund's operations primarily focus on investments within Saudi Arabia, accounting for over 60% of its activities. Company C also directs its investments into foreign assets.

Finally, Company D is a major telecommunications operator in SA and the Middle East, offering a wide range of services such as landline, mobile, data, broadband, and cloud computing. Company D operates next-generation networks (NGNs) with a packet-based architecture for efficient communication. It has expanded its services, including obtaining approval for its conversion into a digital bank. Currently, Company D operates as a conglomerate, overseeing various assets, subsidiaries, and joint ventures within SA.

To perform content analysis and identify the IT dimension of the economic, environmental, and social aspects of the selected case studies, the following steps were taken: (i) The research team consisted of two researchers (one senior and one junior) to reduce research bias. The systematic procedure followed aimed to promote the rigour of the content analysis application. (ii) Data were collected from all relevant documents, reports, articles, and any other available materials related to the selected case studies. This included sustainability reports, project proposals, and IT implementation plans. (iii) A coding framework was developed that captured the key dimensions of IT in relation to the economic, environmental, and social aspects of sustainability, with EC representing the economy, EN representing the environment, and SO representing the social aspects of sustainability. (iv) Coded data were systematically analysed, involving the highlighting of specific passages, sentences, or paragraphs that reflect the IT dimension in each aspect of sustainability. (v) Upon completion of the coding process, a compilation and summary of the data for each case study were presented in tabular form. This enabled the identification of similar patterns and connections between the IT applications and the economic, environmental, and social aspects of sustainability.

4. Results

In this section, we show how the implementation of IT by companies A to D assumes diverse roles in supporting various sustainability initiatives. We also emphasise the significant practices of organisations that are influenced by the adoption of IT. Each company has implemented various IT-driven solutions to enhance its environmental performance and contribute to a more sustainable future. These IT-driven initiatives encompass areas such as risk and control integration, cybersecurity compliance, smart technology adoption, energy efficiency, water management, sustainable agriculture practices, and green finance frameworks.

4.1. Company A and Company B

Table 2 provides an overview of the key sustainability practices that are enhanced through the implementation of IT. Company A is actively embracing IT to drive sustainability throughout its operations. In terms of renewable energy, the company is employing solar and wind power as alternative energy sources to power its activities, significantly reducing its carbon footprint. IT plays a vital role in enhancing the efficiency and cost-effectiveness of these renewable energy sources [34,35].

Company A has implemented a large-scale enterprise GRC solution to integrate and automate risk and control functions, enhancing monitoring, reporting, and alignment across various divisions. This technology-driven approach fosters greater trust in their processes and extends to cover Health and Safety, Business Continuity Management, Environment and Sustainability, and Internal Audit.

To ensure cybersecurity, Company A complies with the National Cybersecurity Authority's Essential Cybersecurity Controls, incorporating technology implementation, policy development, and education for senior management and employees. It has also adopted the ISO 27001 standard for Information Security Management Systems.

Company A envisions its project as a smart destination, harnessing technology's power to offer 52 smart services across 12 domains, including smart mobility, utilities, administration, healthcare, and buildings. Under the umbrella of the smart destination project, Company A has curated an extensive portfolio of investments that seamlessly integrate various elements, aiming to deliver an unparalleled tourism experience while

minimising environmental harm. This holistic approach encompasses diverse sectors such as infrastructure development, security installations, retail, logistics, and even education. Augmented reality IT is leveraged to showcase tourism without endangering marine life or terrestrial habitats, allowing users to virtually experience the offerings in an eco-friendly manner.

Table 2. Key sustainability practices and the role of IT for companies A and B.

Dimension	Key Practice	IT Role	Description
Company A			
Economic	Reducing costs	Infrastructure	Using renewable energy sources for cost-cutting.
	Integration and Automation of Risk	Automation and Transformation	Large-scale Enterprise GRC Solution integrates and automates risk and control functions for enhanced monitoring and reporting.
	Cybersecurity Compliance and Information Security	Informating and Transformation	Complies with cybersecurity controls and adopts ISO 27001 standard for secure operations [36]
	Smart Destination and Innovative Services	Automation and Informating	Envisions The Red Sea Project as a smart destination, offering 52 smart services using technology.
	Sustainable Performance Management	Automation and Transformation	A developed structured model with IT-enabled processes and data for sustainability.
Environmental	Renewable energy	Automation, Transformation, Informating, and Infrastructure	Using renewable energy sources such as solar and wind power for its operations reduces carbon footprint.
	Water Management	Automation, Informating and Infrastructure	Reducing wastage of water while improving the efficiency of water treatment and distribution by using advanced water treatment technologies
	Energy efficiency	Automation, Transformation, Informating and Infrastructure	Sustainable building design efficiently utilising resources by optimising the design of buildings for energy efficiency.
	Renewable energy	Automation, Transformation, Informating, and Infrastructure	Reduction in the emission of poisonous gas into the atmosphere through investments in hydrogen.
	Clean tourism	Automation, Transformation, Informating, and Infrastructure	Augmented reality technology with users experiencing what is on offer without harming marine and other terrestrial habitat.
	Development of Zero-Emission Flights and Hydrogen-Electric Powertrains	Informating and Automation	Prioritizes zero-emission flights and hydrogen-electric powertrains using IT informating and automation.
Social	-	-	-

Table 2. *Cont.*

Dimension	Key Practice	IT Role	Description
Company B			
Economic	Reducing costs	Automation, Transformation, Informating and Infrastructure	Investing in renewable energy sources such as solar and wind power, leveraging technology to improve the efficiency and cost-effectiveness
	Carbon Capture and Storage	Automation	By incorporating advanced IT, Company B implements carbon capture and storage solutions to reduce greenhouse gas emissions and mitigate environmental impact.
	Energy Efficiency Optimisation	Informating and Automation	Leveraging digital technologies, Company B optimises energy usage in real-time, identifying and addressing inefficiencies to reduce environmental impact.
	IoT Technology for Process Control	Automation	Company B implements IoT technology in oil fields, deploying sensors to swiftly detect leaks in pipelines, enhancing process control and resource utilisation.
	Machine Learning for Oil Production Optimisation	Automation	Utilizing artificial intelligence algorithms, Company B stabilises oil production, increasing efficiency in the manufacturing process and reducing carbon emissions.
Environmental	Efficient resource consumption	Transformation, Informating, and Infrastructure	Using IoT to enhance process control mechanisms.
	Efficient resource consumption	Transformation, Informating, and Infrastructure	Using artificial intelligence algorithms to stabilise oil production to promote efficiency in the manufacturing process.
	Clean production	Automation, Transformation, Informating, and Infrastructure	Carbon capture and storage (CCS) technology to reduce greenhouse gas emissions and mitigate the impact of its operations on the environment.
	Water management	Automation, Transformation, Informating, and Infrastructure	Using technology to reduce waste while improving the efficiency of water treatment and distribution.
	Carbon Footprint Reduction	Transformation	Company B is pioneering CO_2 curing technology in the concrete industry to recycle approximately 63 million tons of CO_2 annually and reduce the carbon footprint significantly.
	Non-metallic Materials Innovation	Informating and Automation	Company B collaborates with partners at the Non-Metallic Innovation Centre to expand non-metallic materials' operational capabilities and ensure cost-effective operation and maintenance.
Social	-	-	-

Water management is another area of focus for Company A's sustainability initiatives. By utilising cutting-edge IT, the company is optimising its water management practices

to minimise water waste and enhance the effectiveness of water treatment and distribution. Advanced water treatment technologies are being implemented to reduce water consumption in operations while improving the quality of the water produced [37].

Efficient waste management is another aspect where Company A leverages IT to make a positive environmental impact. By utilising advanced IT, the company is streamlining waste collection processes, reducing waste and emissions, and transforming waste into clean energy. This approach enables Company A to contribute to a circular economy while minimising its environmental footprint [38,39]. Company A is also employing IT to drive sustainable building design. By utilising innovative tools like building information modelling (BIM) and energy simulation, the company optimises the architectural design of its buildings for improved energy efficiency, enhanced comfort, and overall sustainability [40,41].

Through strategic partnerships, Company A has successfully pursued the development of zero-emission flights, recognising the aviation industry's significant contribution to harmful gas emissions. By engaging in these collaborations, the company fosters sustainable tourism practices that prioritise environmental preservation. Company A is also pursuing hydrogen-electric powertrains, which have emerged as the most viable, cost-effective, and impactful solution to mitigate aviation's adverse effects on climate change and air quality.

For sustainable performance management, Company A has developed a structured operating model incorporating pre-defined processes, targets, and KPIs enabled by technology and supported by data contributors from various divisions. It initiated the establishment of its baseline data in 2021, with plans to report on it in future sustainability reports.

The sustainability report of company A shows that 45% of the company is currently in the construction phase and that 75% of the project's assets are on track to be certified by LEED or Mostadam. Company A is a leading example of a sustainable development project. The project is committed to building sustainable infrastructure and creating a sustainable tourism destination. Company A's sustainability performance is improving year-on-year, and the project is setting an example for other projects around the world (see Table 3).

Table 3. Company A sustainability performance: 2020 vs. 2021.

Metric	2020	2021
GRESB Score	84	91
Other Awards	Green Star	Green Star
Sector Leader	No	Yes

Source: Company A sustainability report 2021.

Company B is utilising digital energy to drive sustainability in mining operations (see Table 4). In one of SA's largest oil fields, the company has implemented IoT technology to enhance process control mechanisms. By deploying sensors in the pipeline management system, the company can swiftly detect any potential leaks, ensuring the integrity of the operations. With over 40,000 sensors deployed across more than 500 oil fields, the company actively promotes energy efficiency in boiler consumption, optimising resource utilisation [42]. Company B has also embraced machine learning in IT by employing artificial intelligence algorithms to stabilise oil production, leading to increased efficiency in the manufacturing process. This intelligent approach not only enhances operational performance but also contributes to a significant reduction in carbon emissions. By implementing these advanced technologies, Company B has developed effective digital transformation strategies, positioning itself as a market leader in sustainable practices.

Table 4. Company B sustainability performance: 2019 vs. 2020.

Metric	2019	2020
Carbon footprint (tons of CO_2e)	83,000,000	74,700,000
Reduction in carbon footprint (%)	10%	
Energy consumption (MWh)	150,000,000	142,500,000
Reduction in energy consumption (%)	5%	

Source: Company B sustainability report 2020.

Company B is actively leveraging IT to drive sustainability initiatives within the automotive sector. Company B collaborates with stakeholders to influence the design of new vehicles, focusing on developing innovative carbon fibre technology as a sustainable alternative to steel and aluminium. Additionally, it is striving for increased efficiency throughout the design and assembly processes.

The adoption of IoT sensor technology is driven by the investment data showcased in Figure 1. Company B has allocated substantial resources to the development of data centres, emphasising the importance of data management in its sustainability initiatives.

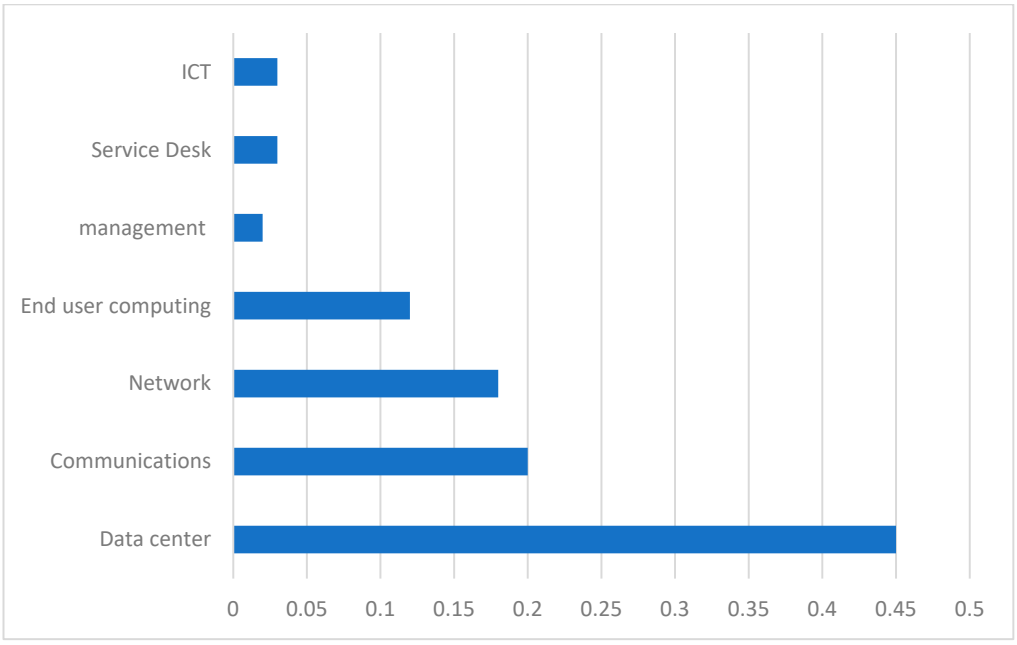

Figure 1. Company B's IT data spend. Source: Company B website.

Company B has established the Non-Metallic Innovation Centre in partnership with TWI Ltd. and Abu Dhabi National Oil Company, located in Cambridge, UK. This centre serves as a collaborative hub, bringing together academics, technology organisations, material suppliers, pipe manufacturers, and leading Oil and Gas companies to expand the operational capabilities of non-metallic materials, ensuring cost-effective operation and maintenance in the industry. This strategic investment demonstrates the company's commitment to leveraging digital solutions for optimal operational performance and environmental stewardship.

In its commitment to sustainability, Company B incorporates advanced IT to drive positive environmental impact through the implementation of carbon capture and storage solutions. This strategic investment allows the company to reduce its greenhouse gas emissions and mitigate the environmental footprint of its operations. Leveraging digital technologies, Company B optimises energy usage in real-time, identifying and addressing inefficiencies and reducing environmental impact. Company B has also recognised the significance of renewable energy sources and has invested in solar and wind power. This

approach not only reduces reliance on traditional energy systems but also contributes to a more sustainable energy landscape. Company B also harnesses IT to manage its water usage, improving the efficiency of water treatment and distribution.

Company B acknowledges the vital role of technology in achieving emissions reductions at the required scale. With its substantial business size, even incremental advancements can have significant global impacts. It highlights the potential impact of CO_2 curing technology in the concrete industry. By implementing CO_2 curing in the global precast concrete sector, an estimated 63 million tons of CO_2 could be recycled annually, equivalent to removing approximately 14 million cars from the roads each year. In collaboration with the Korea Advanced Institute of Science and Technology, Company B is working on developing CO_2 curing technology for precast concrete materials, capable of storing up to 20% of CO_2 in the concrete while delivering enhanced mechanical strength and significantly reducing curing time. This innovation results in a carbon footprint that is only one-third of that produced by conventional concrete. Field tests of this technology are being conducted in partnership with a local cement company.

As shown in Table 4, Company B is not only making significant strides in reducing its carbon footprint but is also actively working to reduce energy consumption. These efforts underscore Company B's dedication to promoting sustainability and minimising its environmental impact across various aspects of its operations.

4.2. Company C and Company D

Company C plays a crucial role in SA's commitment to achieving "net zero" greenhouse gas emissions by 2060. To advance sustainability, Company C has established the Green Finance Framework, which serves as a platform to match its diverse sustainable projects with appropriate resources.

Table 5 illustrates how Company C utilises IT to drive sustainability within its investment portfolio. The company embraces technological advancements to integrate sustainable investing principles into its decision-making process. By leveraging advanced data analytics and incorporating ESG metrics, the company identifies investment opportunities that align with its sustainability objectives [43,44]. Company C recognises the importance of energy efficiency technologies in promoting sustainability and reducing reliance on fossil fuels. Consequently, the company actively invests in such technologies, contributing to the development and expansion of renewable energy sources. Energy efficiency is also achieved through the installation of energy-efficient technologies and products, such as LED lighting, resulting in at least a 30% increase in operational energy efficiency. The company also deploys wireless technologies to enable real-time responses to energy demand, implementing smart city systems, smart building management systems, telecommuting systems, and smart grids.

In pursuit of sustainable management of natural resources and land use, Company C invests in agricultural technologies that promote water rationalisation, improved production efficiency, and environmental preservation. This includes activities for measuring, monitoring, reporting, and verifying emissions reductions. The company also conducts research and development in ruminant feed to reduce methane emissions and explore alternative meat and dairy products. Capacity building and education services on low-carbon agricultural practices further enhance their sustainability efforts.

In addition to investing in agricultural technologies, Company C focuses on sustainable infrastructure projects that foster both economic development and environmental sustainability. By utilising IT, the company identifies and evaluates investment opportunities in the infrastructure sector. Company C emphasises sustainable water management by investing in projects and infrastructure that enhance water-use efficiency, including water recycling and reuse projects, water-saving systems and technologies, and water metering. Their commitment extends to desalination plants with a carbon intensity below 100 gCO_2e/kWh over the residual asset life, operating on reverse osmosis technology powered entirely by renewables.

Table 5. Key sustainability practices and the role of IT for companies C and D.

Dimension	Key Practice	IT Role	Description
Company C			
Economic	Achieving stakeholders' satisfaction	Informating and Infrastructure	Integrates sustainable investing principles into its investment decision-making process.
	Sustainable Infrastructure Projects	Informating and Infrastructure	Leveraging technology to identify and evaluate investment opportunities in the infrastructure sector.
	Sustainable Investing	Informating	Using advanced data analytics and ESG metrics for sustainable investment decisions.
Environmental	Renewable energy	Automation, Transformation, Informating, and Infrastructure	Reduction of emissions and dependence on fossil fuels.
	Water Management	Informating and Transformation	Implementing water recycling, desalination with renewables, and efficient water use technologies.
	Agricultural Technologies	Informating and Automation	Utilising technology for water rationalisation, methane reduction, and low-carbon agricultural practices.
Social	-	-	-
Company D			
Economic	Reducing costs	Automation, Transformation, Informating, and Infrastructure	Using digital platforms to track the sustainability performance of its suppliers and to identify areas for improvement.
Environmental	Energy efficiency	Automation, Transformation, Informating, and Infrastructure	Implementing digital technologies to optimise energy usage in real-time, addressing inefficiencies.
	Efficient resource consumption	Transformation, Informating, and Infrastructure	Leveraging technologies such as virtualisation, cloud computing, and artificial intelligence to optimise data centre performance and reduce waste.
Social	-	-	-

IT enables the company to monitor the sustainability performance of its infrastructure portfolio, ensuring ongoing alignment with its sustainability goals.

In Company D's 2021 Sustainability Report, it was reported that the company successfully reduced its carbon footprint by 8% in 2021 compared to the previous year. This achievement was a result of the company's commitment to sustainability, reflected in seven key areas of focus: Expanding Access to Technology and Connectivity, Enhancing Economic Impacts, Advancing Digital Opportunities, Doing Business with Integrity, Enriching Lives and Experiences, Caring for the Environment, and Empowering People.

One of the significant strides in sustainability was made through championing technology for the greater good and forming partnerships across the GCC and beyond. This focused effort placed ESG considerations at the forefront of Company D's operations.

As shown in Table 6, Company D uses IT to drive sustainability in its operations. To enhance energy efficiency and minimise greenhouse gas emissions, the company employs digital technologies to optimise energy usage in real-time and address inefficiencies proactively. This approach not only reduces energy waste but also contributes to a significant

reduction in the company's carbon footprint. The sustainability of data centres is a priority for Company D due to its critical role in its operations. By leveraging innovative technologies such as virtualisation, cloud computing, and artificial intelligence, the company optimises data centre performance while concurrently reducing energy consumption and waste. Company D extends its commitment to sustainability to its network infrastructure and supply chain. To build a green network, the company adopts IT-driven solutions that diminish the environmental impact while enhancing network performance and reliability. This includes utilising energy-efficient network equipment, deploying low-emission vehicles, and implementing efficient cooling systems to minimise its overall carbon footprint. In its supply chain, Company D employs digital technologies to promote sustainability. By optimising supply chain processes and reducing waste, the company effectively minimises the environmental impact of its operations. For instance, the company utilises digital platforms to monitor the sustainability performance of its suppliers, enabling the identification of areas for improvement and fostering more sustainable practices throughout the supply chain.

Table 6. Company D's energy consumption by year.

		2020	2021	2022
Fuel consumption (litres)	Total petrol consumption	4,499,238.63	4,770,225.46	4,451,959
	Total diesel consumption	33,327.47	47,504.99	81,952.40
Electricity consumption from buildings		880,246	642,553	541,442
Energy consumption by telecom. infrastructure	Data centres (GJ)	455,163	479,746	570,583
	Base stations (GJ)	-	-	-
	Exchanges (GJ)	1,450,268	1,390,648	1,289,386
	Total energy consumption (GJ)	1,905,431	1,870,395	1,859,969

To reduce energy consumption, Company D implemented energy-optimising practices like Variable Refrigerant Flow (VRF) technology and Variable Frequency Drives (VFD) for efficient flow control in secondary chilled water pumps. Additionally, it embraced solar energy, steadily increasing its usage throughout its HQ premises. In 2022, two solar-powered sites were operational, and five were under construction, with plans for nine sites to be operational in 2023. These solar initiatives are projected to generate an average annual energy generation of 7 GWh, with a total installed capacity of over 4.3 MW.

The company initiated the "Go-Green" campaign in 2022, focusing on enhancing green technology practices, IT resource reclamation and re-use, energy consumption reduction, and obtaining the 14,001 Environmental Management System certification. As part of this initiative, Company D reduced paper consumption significantly through its "go paperless" program, achieving a 55% and 91% reduction in paper usage compared to 2021 and 2020, respectively.

Company D's digitisation efforts have also contributed to sustainability. By introducing eSIM technology to replace physical SIM cards, it saved on plastic, CO_2 emissions, and logistical complications. Over 1.2 million eSIM cards were newly issued through their application in 2022, demonstrating the success of this sustainable approach.

In line with its commitment to healthcare accessibility, Company D continued to provide e-health services, including virtual clinics, remote medical consultations, and healthcare connectivity. Its new Holo Doctor service utilised Holoportation technology, enabling lifelike patient-doctor interactions through 3D projections.

Company D improves its sustainability from year to year by using IT, as shown in Table 6. In 2022, Company D successfully reduced its total electricity consumption for all buildings by 16% due to the energy efficiency initiatives carried out in the previous year. Although there was a slight increase in diesel consumption, this was mainly due to the

higher demand for shuttle bus services in the HQ complex. However, Company D managed to achieve a 7% decrease in petrol consumption. To lower its carbon footprint, Company D actively explored energy-saving opportunities within its exchanges, leading to the implementation of innovative solutions that optimised energy consumption. Remarkably, all these improvements were achieved without any capital expenditure (CAPEX) and contributed to an 11% reduction in energy consumption at the exchanges compared to 2020.

5. Discussion

From the results, all four companies demonstrate a commitment to SA's Vision 2030, striving to achieve sustainable practices and reduce greenhouse gas emissions. They actively leverage IT to drive sustainability initiatives across their operations, investing in renewable energy sources like solar and wind power and emphasising energy efficiency with the deployment of smart grid systems and energy-efficient technologies.

Company B, for instance, is spending a significant amount of its ICT budget on data centres. This is due to the realisation that data centres often consume large amounts of energy as they require a lot of heat for their cooling systems. The company has employed a data centre infrastructure management tool to track each of its data centres in a bid to obtain additional information on the life cycle of the project. Once this information has been obtained, the company can then come up with a risk management approach and reduce the impact on the environment. Alternatively, Company B can considerably reduce the usage of oil as part of its energy to power data centres and replace this with solar energy. Similarly, Company D's IT-driven sustainability initiatives have garnered recognition, with the company receiving awards for its cloud infrastructure and data centre automation, showcasing its dedication to offering high-quality digital solutions to meet diverse needs. Company D actively supports SA's 2030 Vision through the development of information and communication technology products that empower carriers and operators.

Digital transformation emerges as a prominent theme, with all companies adopting IT-driven solutions to enhance sustainability practices. They utilise advanced data analytics, AI, and IoT technologies to optimise energy consumption, detect potential leaks, and stabilise oil production, resulting in energy and cost savings. IT plays a vital role in managing data centres for energy efficiency and supporting sustainability initiatives in various sectors.

Following the GRI Standards, Company A designed and put into operation its Sustainability Performance Management System (SPMS). The SPMS is a structured operating model incorporating pre-defined processes, targets, and KPIs enabled by technology and supported by data contributors from various divisions. Since June 2021, the SPMS team has actively collaborated with Taskforce members to gather and evaluate performance data on a monthly basis. Dashboards are accessible to Taskforce members and senior management, providing visibility into the company's performance. This data serves as the foundation for establishing baselines across key metrics, enabling the company to set targets and strive for ongoing improvement in the future. Company A's IT-driven sustainability efforts include implementing the Enterprise GRC Solution for risk and control integration, complying with cybersecurity controls, adopting smart technology for The Red Sea Project, and developing a structured operating model for sustainability performance management. These initiatives demonstrate the company's commitment to leveraging technology to enhance sustainability practices and drive positive impacts across its operations.

The use of machine learning by Company B reveals the importance of algorithms in the management of energy systems. For sustainable energy, companies should work towards updating their load requirements, checking the length of the battery, and making load predictions. Such a strategy has been adopted by Company B, and it is paying dividends as far as the management of energy consumption is concerned. The company has also expanded the usage of data analytics so that engineers can have real-time information and do quick repairs to the system in the event of a power failure or energy overload. Data

analytics promote economic sustainability, where cost savings are made in the event of massive failures in the system.

The results show that Company B has excelled in the usage of IoT-powered sensors to promote efficiency in the oil fields. There are some risks with the usage of this IT. The company should ensure that there is an adequate data protection policy in place. It is not just about ensuring that such a policy is in place but also about implementing it. Putting in place high-level security systems and then promoting the aspect of physical hardening is a step in the right direction because the company will have ensured that the sensors are in any region or area where they may be deployed [45].

Companies B and C actively pursue green finance projects and sustainable investments to attract funding for environmentally beneficial initiatives. They utilise IT solutions to integrate sustainable investing principles, considering ESG metrics in decision-making. Green finance initiatives aim to support SA's Vision 2030 and contribute to achieving "net zero" greenhouse gas emissions. Ultimately, Company C is looking forward to attracting investments as part of its efforts to put more money into green finance projects. Investors can only be attracted if there is the right proprietary framework that ensures that such company funds are not diverted to other projects. A key recommendation would be the inclusion of green finance projects and climate change as part of the high-level conversation in organisational decision-making.

Company C has limited implementation of blockchain IT to activate smart contracts and encourage increased adoption of environmentally friendly practices. Ecologically beneficial initiatives show that increased security systems around blockchain can encourage more people to participate in sustainability actions through trade in the bonds, and they do not have to wait for long before there is a full authorisation. Blockchain technologies may also be used in the promotion of digital asset exchanges that will facilitate the inclusion of digital assets on the stock market, thereby further expanding interest in the region.

The absence of any IT-related role in the social aspects, such as community relations, communication, collaboration within the company, employee satisfaction and wellbeing, and education support, as observed in the analysed documents, is an intriguing finding. It suggests that the focus of the documents and the companies examined may have been primarily on environmental sustainability rather than broader social sustainability. This could indicate a potential gap in the integration of IT solutions to address social aspects within the sustainability efforts of the companies studied. It raises questions about the extent to which technology-driven initiatives are being leveraged to enhance social engagement, employee well-being, and community development. Further research is warranted to explore the reasons behind this apparent neglect of IT's role in these critical social dimensions of sustainability and to identify opportunities for future integration and improvement.

This research has demonstrated potential applications of IT in assisting organisations in addressing sustainability. The evaluation of IT roles indicates that Informating and Infrastructure roles are widely applicable because data and information play crucial roles in business processes. Therefore, IT is necessary for analysing, processing, managing, and communicating information to achieve business objectives. The presence of infrastructure, whether virtual or physical, is essential for supporting the delivery of business objectives through information. This study demonstrates that the Infrastructure role is fulfilled by factors such as enhancing process control mechanisms throughout various operational environments. The Informating role is fulfilled by extracting meaningful insights from the infrastructure setup. In areas where automation is crucial, the role is realised through machine-to-machine communication facilitated by wireless sensor networks, reducing human intervention and automating business processes, particularly in support of environmental and economic aspects [32]. The Transformation role seems to significantly support environmental dimensions. This finding confirms that organisations aiming to address and support environmental aspects should re-engineer their business operations to align with environmental dimensions. The study highlights how IT can be leveraged to transform

specific organisational aspects across the three main operational areas, leading to more intelligent, efficient, and environmentally friendly operations.

Policy interventions, together with public–private partnerships where the government and the public sector combine efforts, can assist in making gains in environmental sustainability. Some of the technologies discussed in this paper, such as blockchain, can be used to show that sustainability is not only the effort of companies but also a platform where public investments count towards green projects that can accelerate achievements. The government has an important role to play in building the digital capacity of companies in the country. This capacity will ensure that benefits realised through the focus on sustainability can be spread throughout the entire country. The government will also need to raise awareness about digital transformation and sustainability.

6. Conclusions

This study sheds light on the pivotal role of IT in advancing sustainability efforts in SA. The findings underscore a notable transition towards green initiatives, driven by the adoption of transformative technologies like IoT, blockchain, and AI. These technologies have proven instrumental in bolstering energy efficiency, curbing waste generation, and fostering environmental sustainability, while bolstering economic growth. The exemplary practices of Company A, Company B, Company C, and Company D serve as beacons of sustainable strategies that align with SA's Vision 2030. The study emphasises the significance of policy interventions and public–private partnerships in achieving sustainability objectives. To realise sustainable practices across sectors, the government should focus on enhancing digital capabilities in businesses and eliminating technological barriers. Despite these valuable insights, the study acknowledges certain limitations that should be considered in interpreting the findings. Firstly, the focus on only four case studies may limit the representation of the entire Saudi Arabian business landscape. Secondly, relying solely on qualitative analysis might constrain the generalisability of the findings. Incorporating quantitative data and conducting larger-scale studies could offer more robust and comprehensive results. Lastly, the study did not explore the potential negative impacts of IT on sustainability, which warrants further investigation to ensure that technology adoption aligns with broader sustainability goals. Notwithstanding these limitations, the study's valuable findings regarding the role of IT in supporting sustainability efforts in SA imply that it can significantly contribute to promoting sustainable practices and fostering a more prosperous future for the nation and its people.

Future research endeavours could expand the scope to include a more diverse range of companies to provide a broader perspective, exploring the hurdles and challenges confronted by companies when integrating IT for sustainability aims. Additionally, investigations beyond IT's scope, encompassing cultural, social, and economic dimensions, will provide a comprehensive understanding of sustainable efforts. Examining IT's impact on sustainability across diverse sectors of the SA economy would further enrich our understanding of its role in promoting sustainable practices. By addressing these avenues of research, stakeholders, scholars, and policymakers can deepen their knowledge and contribute to the effective realisation of SA's sustainability goals. This, in turn, will pave the way for a prosperous and sustainable future for the nation and its citizens.

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