Article

Competitive Sustainability of Saudi Companies through Digitalization and the Circular Carbon Economy Model: A Bold Contribution to the Vision 2030 Agenda in Saudi Arabia

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Abstract: This study examines the challenges and opportunities of implementing the circular carbon economy model and digitalization in Saudi Arabia with a focus on CO_2 emissions. The research finds that, prior to the pandemic outbreak in 2020, Saudi Arabia had succeeded in stabilizing production-based CO_2 emissions due to a combination of policies outlined in the scope of Saudi Arabia's Vision 2030. However, the economic downturn caused by the pandemic has led to a short-term reduction in CO_2 emissions trends, highlighting the need for preparation for a rebound. Driven by the use of analytical methods including the Kaya Identity, this study suggests that the newly proposed circular carbon economy model could be an effective way for the country to mitigate greenhouse gas emissions by coordinating all significant stakeholders, including businesses and government actors. The research analyzes Saudi Arabia's CO_2 emissions trends over the past two decades and presents several steps necessary to achieve social, environmental, and economic outcomes for sustainable businesses operating in a fossil-rich country. We also highlight the need for organizational changes, new policy-making tools, as well as government, consumer, and stakeholder support to drive the changes required for integration of the circular carbon economy model and the adoption of smart technologies. Overall, the results can be used to emphasize the importance of sustainability as a competitive feature that allows businesses and countries to benefit from the distribution of risks and shared accountability.

Keywords: sustainability; digitalization; circular carbon economy; circular economy; CO_2; Saudi Arabia

1. Introduction

Apart from substantial losses to the economy, the recent upheavals associated with the global pandemic brought up a significant opportunity to counteract climate change. As manufacturing and transportation halted, the international community experienced an unprecedented decrease in GHG emissions. Major corporations and small businesses both recognized it as a cue to embrace the circular economy approach on the path toward sustainability [1]. Traditionally existing within the domain of large companies, corporate social responsibility appears on the agenda of small- and medium-scale enterprises [2]. In this context, it is necessary to dispel concerns regarding the financial feasibility of the circular economy approach while highlighting its competitive benefits when combined with digital solutions.

Since a circular economy is typically associated with commercial entities, the King Abdullah Petroleum Studies and Research Centre (KAPSARC) helped to introduce a more comprehensive platform for economic diversification, i.e., the circular carbon economy model [3]. For entrepreneurs and business leaders, the circular economy approach becomes

a transformational instrument that helps to prepare businesses for the anticipated uncertainties and challenges [4,5]. However, all efforts to preserve non-renewable resources and reduce waste fall short without a comprehensive strategy connecting new trends with sustainability goals [6]. In the context of societal, environmental, and economic frameworks, sustainability can be achieved by utilizing corporate resources to create long-lasting bonds with all stakeholders, including policymakers [7,8]. Consequently, a company is expected to realign its modes of operation while implementing business strategies that preserve its competitive advantage. Previously considered detrimental to competitiveness, the introduction of sustainable practices is being reimagined with the help of a circular economy approach and digitalization.

1.1. Sustainability Challenges in Saudi Arabia

Implementation of transformational instruments for sustainability outcomes will be a logical next step for the ever increasing number of executive leaders and managers. Although scholars and activists have advocated against unsustainable business practices for decades, the eventual shift occurs due to technological developments and external forces such as the global pandemic [1,9]. Furthermore, corporate-wide transformations would not be possible without the growing emphasis on circular thinking in scholarly circles. The concerted effort of all involved parties could become instrumental in introducing new business practices in Saudi Arabia that would be informed by KAPSARC's circular carbon economy model and Saudi Arabia's Vision 2030 [10]. An ever expanding body of knowledge covers different approaches to comparing circular economy initiatives as well as harnessing their potential to foster new innovations [11]. In addition, innovation efficiency driven by strict environmental policies has been shown to have major impacts on economic outcomes in several European and Asian countries [12,13]. The overall concept of sustainable competitiveness should be explored in the context of businesses and also from the broader perspective of individual countries and their associated policymaking efforts.

In addition to economic and environmental sustainability, the social dimension of sustainability is also crucial for achieving sustainable outcomes for Saudi companies. The existing research suggest that the recent introduction of the circular carbon economy framework had no tangible impacts on stakeholders' social sustainability efforts beyond statements and long-term pledges [14]. Therefore, in this study, we also examine the potential of digitalization and the circular carbon economy model to improve social sustainability in Saudi companies. This includes analyzing the impact on workers and communities, as well as assessing the potential for creating social value through sustainable business practices. An illustrative example is the government's incentive program that targets the production chain companies as well as the commercial and private consumers of air conditioning units [15]. By providing substantial monetary incentives, the policymakers seek to address the problem of the unsustainable air conditioning use [16].

Despite the progress made in recent years in terms of stabilizing CO_2 emissions in Saudi Arabia, there is still a significant gap in understanding the most effective strategies for improving all aspects of sustainability in Saudi companies [14,15,17–19]. This study aims to address this gap by examining the potential of digitalization and the circular carbon economy model to improve sustainability in Saudi companies, specifically in the context of Saudi Arabia's Vision 2030. This study provides a comprehensive overview of the current state of sustainability in Saudi companies, as well as an in-depth analysis of the potential benefits and challenges of implementing digitalization and the circular carbon economy model. Through this research, we hope to contribute to a better understanding of how to improve sustainability in Saudi companies and to provide valuable insights for policymakers and business leaders.

1.2. The Role of Digitalization in Sustainable Competitiveness

Although studies of the impacts of digitalization and a circular economy on a state's economic sustainability have flourished in the past decade, there is a considerable lack of evidence in regard to Saudi Arabia. For example, economic sustainability has been shown to be closely interconnected to both policymaking efforts as well as the implementation of digital solutions [20,21]. The circular economy approach has already been linked to digitalization in several studies that have suggested that circularity benefits could be attained with the help of artificial intelligence and the Internet of Things as facilitators of the transitory stage from the linear economic model [22,23]. In turn, business leaders have begun to recognize competitive advantages stemming from organizational changes that prioritize sustainability-oriented digital solutions as well as the circular economy approach [24,25]. Nevertheless, most of these studies have approached the topic from narrow industry-specific perspectives and have failed to capture the broader significance of digitalization for Saudi Arabia's work on entrenching circular a carbon economy at all levels.

For these reasons, the current study provides an overview of the most pertinent sustainability trends, and analyzes total CO_2 emissions trends in Saudi Arabia with the help of the Kaya Identity, GDP per capita, and other methods. The literature review enables an analysis informed by industry-specific perspectives on the studied concept and its practical implementations. Coupled with the 4R principles for implementing the circular carbon economy model, the obtained data can be used to inform both organizational and country-wide efforts to mitigate climate change. The novelty of this research lies in its focus on the specific context of Saudi Arabia, and its examination of the combined potential of digitalization and the circular carbon economy model to improve sustainability in Saudi companies. This research contributes to the existing knowledge by providing valuable insights for policymakers and business leaders on how to attain sustainability at a regional scale, such as defined by the Vision 2030 agenda, as well as on the global scale. Overall, this research provides a better understanding of the potential benefits and challenges of implementing digitalization and the circular carbon economy model in developing countries, and more specifically in Saudi Arabia.

2. Comprehensive Literature Review

2.1. Sustainability Trends

By the 2020s, the critical necessity to pursue sustainability goals became apparent not only for environmental researchers but the global community as a whole. This common objective binds all stakeholders to alleviate climate change [26]. Consumers are acutely aware of the detrimental consequences associated with the irresponsible exploitation of natural resources, waste pollution, and greenhouse gas emission. While people are less inclined to buy services and products from socially irresponsible providers, governments pressure corporate players to optimize their business operations [27]. In response, most companies will be unable to preserve their competitive advantage without embracing sustainability trends to counteract climate change.

From this standpoint, the demand for environmentally friendly products and services can be satisfied by engaging in economically justified processes that respond to the current trends. The circular economy appraoch and digitalization are examples of such transformative trends. In contrast to linear production models, the former approaches manufacturing processes from a systemic perspective [28]. Due to the need to overhaul entire life cycles, sustainability-driven cooperation pushes businesses towards adopting renewable energy sources and relying on recyclable materials. Refurbishing and reusing products provides an opportunity to considerably reduce waste while preserving corporate resources [29]. Additionally, digitalization serves a supplementary purpose by not only optimizing the circular economy approach but also providing competitive advantages.

2.2. Circular Carbon Economy Model

According to the precepts of the circular economy approach, efforts to reduce waste by introducing circular approaches are instrumental for significantly reducing the reliance on natural resources. Consequently, the value added with the help of circular strategies results from optimization of corporate processes instead of uncontrolled exploitation of the environment [7]. As a sustainable alternative to the linear economy appraoch, the circular economy approach is invaluable for the following reasons: minimizing all forms of emissions, reducing manufacturing inefficiency, and reducing waste and pollution [5,28]. In this context, the described framework saves natural resources from overexploitation while ensuring that operational processes remain sustainable and effective.

The circular carbon economy model is an economic model that aims to reduce greenhouse gas emissions and create economic value by keeping resources in use for as long as possible. In contrast, the conventional linear economy approach is based on the traditional model of extracting resources, using them, and disposing of them [1]. The circular carbon economy model has several advantages over the conventional linear economy mode, such as reducing waste and pollution, creating new business opportunities, and increasing resource efficiency [30]. However, there are also some challenges to implementing the circular carbon economy mode, such as the need for significant investment in new technologies and the need for collaboration between different sectors [3,19]. From this perspective, digitalization initiatives can also play a significant role in contributing to sustainability by enabling more efficient use of resources, reducing waste and pollution, and creating new business opportunities [31]. For example, digitalization can enable the use of smart technologies such as IoT and AI to optimize resource use, and digital platforms can facilitate the sharing of resources in a circular economy.

It is important to note that the social aspect of sustainability has not been well documented in the literature. In addition to environmental and economic sustainability, social sustainability is crucial for achieving sustainable outcomes. When approached through the social lens, sustainability includes aspects such as the well-being of workers and communities, sustainable business practices that create social value through, and efforts to address issues such as inequality, poverty, and social exclusion [32,33]. Furthermore, there are several blockages and barriers to sustainable development that must be addressed in order to achieve sustainable outcomes. Social cultural issues, such as traditional attitudes towards resource use and waste, can make it difficult to implement sustainable practices [34]. A capitalistic mindset that prioritizes short-term profits over long-term sustainability can also be a barrier to sustainable development. Inequality can also be a significant barrier to sustainable development, as marginalized communities may not have access to the resources and opportunities needed to implement sustainable practices [35]. Political and policy issues, such as a lack of government support for sustainable development or a lack of regulations to enforce sustainable practices, can also be barriers [34]. A decline in transparency and freedom of expression can also be a barrier to sustainable development, as it can make it difficult for stakeholders to hold decision-makers accountable for their actions.

To successfully implement a circular economy as it has been originally defined, companies are required to make necessary adjustments along the cradle-to-cradle cycle [36,37]. Throughout different life cycle stages, transformations may include adopting renewable energy sources and implementing recycling and remanufacturing solutions to reduce the resulting waste [15,38]. Since this approach pertains to a near complete overhaul of traditional business operations, many businesses are hesitant to undergo the transformation. Nevertheless, the ever increasing push towards sustainability has helped to change the status quo by allowing such businesses to gain a competitive edge.

Whether driven by environmental laws or the desire to overcome competitors, businesses are gradually embracing the circular economy approach as the new norm. However, a lack of experience may prove challenging when overturning the existing business strategies and processes. Since the implementation of the circular economy approach encom-

passes all spheres of a firm's operations, there can be multiple approaches to this process [5]. In all cases, the shift towards sustainable solutions necessitates a re-evaluation of business partnerships and relationships with stakeholders [8]. Based on the ideas described above, a group of researchers led by McDonough defined the concept of the circular carbon economy model [39].

In contrast to eliminating fossil fuels from the equation, the novel circular carbon economy model relies on transforming fugitive carbon into durable carbon and other solutions to reduce, recycle, remove, and reuse CO_2. While KAPSARC has streamlined the idea on a country-wide scale, the lack of business cooperation is likely to impede progress due to the latter being one of the key stakeholders in the entire process [10]. The novelty of the circular carbon economy model explains the absence of a widely accepted definition of the concept, but digitalization is likely to form the foundation of all conceptualizations [40]. Whether aimed to minimize fugitive carbon via mitigation and energy efficiency or reuse and store CO_2 in the "durable" form, policies cannot be feasibly implemented without digital solutions.

2.3. Digitalization

Digital technologies are an integral element of business operations in all industries. Smart solutions are widely used for streamlining traditional manufacturing and production processes yet to be adapted for the circular economy approach. Under these circumstances, businesses seek to invest in research and development as one of the key ways to optimize sustainable business models. In this framework, digitalization pertains to developing and integrating the following technologies: big data, the IoT; artificial intelligence; and others [38,41]. If adjusted in alignment with operational processes, they can considerably impact sustainability.

Digitalization is a transformational instrument that helps to achieve social, economic, and environmental outcomes by translating sustainable business strategies into daily operations. Moreover, new technologies are critical for promoting sustainable values at the organizational level while enhancing a firm's competitiveness [8]. Capable of enabling new business models and geared towards opening opportunities to add value, smart technologies are expected to form the bedrock of future digital businesses [42]. The ability to monitor and adjust the production process on the go is transformational for most businesses seeking to embrace the circular economy approach.

Despite the highlighted strengths of digital solutions, digitalization is associated with risks that necessitate additional expenses and considerations. With cyberattacks emerging as a leading threat of the twenty-first century, organizations are required to implement industry-wide standards for cybersecurity and data protection [43]. Other considerations should be focused on privacy and handling sensitive data, as previous incidents have demonstrated the potential consequences of cyberattacks.

Among the most promising digital technologies for businesses is the Internet of Things, a solution allowing reimaging asset management, logistics, and manufacturing. With the help of IoT, firms are able to substantially increase production capacity by optimizing efficiency and performance [41]. Monitoring corporate assets throughout all life cycle stages is an invaluable addition to the circular economy approach [29]. Materials and products can both be monitored to reduce downtimes and, ultimately, to enable the circular flow of resources. Additionally, reports have revealed that corporations that have relied on big data and cloud solutions have enjoyed a 36-percent edge over competitors [44]. One of the crucial functions of data analytics pertains to the assessment of input–output flows and the estimation of energy consumption and production downtime.

2.4. Circular Economy Approach and Digitalization for Sustainable Economic Development

With the linear economic framework serving as a baseline, adoption of the circular economy approach is a gradual process that individual countries have embraced to varying extents. In contrast to the former which operates according to the unsustainable assumption

that access to natural resources will remain unrestricted and easy, the latter incorporates solutions to minimize waste and optimize resource consumption. Specifically, multiple countries across the globe have already started entrenching waste recycling and the consequent reuse to utilize the value of resources involved in production cycles [37,45]. In contrast, only select Saudi cities have adopted municipal solid waste management programs as pilot initiatives [46]. Otherwise, the country currently lacks the capacity to capture and reduce CO_2 and waste products, with the only facility being the plant in Jubail's industrial city [15]. Governments emerge as principal economic and legal agents for promoting sustainable efforts, but the CE approach should be embraced by all entities involved in economic development, from the industrial sector to small entrepreneurship [47]. Without the government's support, the transitory process can become an insurmountable obstacle for many organizations due to the associated restructuring costs, logistical challenges, and production cycle adjustments [24,48]. Nevertheless, a solid literature base exists regarding the importance of sustainable development as well as the tangible benefits of the circular economy approach and digitalization. In the context of economic growth and development, all three concepts are usually studied in isolation which is evidenced by the lack of complex research on the topic.

Seeking to provide a broad outlook on the benefits of the circular economy approach, one study focused on the USA and concluded that consistently sustainable economic growth could only be attained by investing in new technologies that would facilitate waste reduction, recycling, and resource management [49]. In the case of Saudi Arabia, the government appears to be disproportionally prioritizing the reduction component of the framework [50]. Several articles have highlighted another significant aspect of the circular economy approach—the prioritization of renewable energy technologies is a key step for preventing natural resource depletion and reducing CO_2 emissions [18,51]. Importantly, the full advantage of the circular economy approach can only be accessed by successfully transitioning from a conventional linear economy which involves both educational and policy-making efforts. When taking into consideration a more novel concept such as the CCE model, an additional focus should be placed on perspectives shared by the involved stakeholders regarding sustainability, economy, and society [52].

Apart from scholars based in North America and Europe, these topics have been extensively studied by Chinese economists who are seeking to resolve the unmitigated exploitation of China's natural resources in the past decades. While sustainable policies incorporating the circular economy approach have been in place for several years, there are concerns pertaining to circular economy measurements at micro- and macroeconomic levels [53,54]. An already implemented sustainable solution can effectively counteract some of the problems posed by a linear economy. Notably, China's policies prioritize natural resource preservation and recycling, a stance reflected by measurement indicators that record industrial waste production, pollution from industrial activities, national GDP, and economic benefits [55]. From this standpoint, it is important to highlight that Saudi policymakers can follow the example of other countries, at least partially, when it comes to the successfully implementing the CCE model, a policy streamlined by the Middle Eastern country itself.

In the case of the Cooperation Council for the Arab States of the Gulf (GCC), the status quo radically changed following Saudi Arabia's proposal, during the course of its G20 Presidency, to implement the CCE model. Partially informed by the circular economy models developed within the framework of the EU's Circular Economy Action Plan, the CCE model accounts for sustainable competitiveness in a variety of key sectors such as electronics, energy, vehicles, packaging, water, and others [14,56]. According to the policymakers, the CCE model is expected to encompass all pre-existing circular economy initiatives in the GCC region while drawing from the experiences of other states and collaborating with the EU [57]. From this perspective, particular attention can be placed on Saudi Arabia and the UAE as both Middle Eastern states are characterized by fossil fuel dependency and the growing need for sustainable alternatives for economic

growth [58]. According to Shehri et al. [15], the existing policies in the region are lacking as compared with other states, and they require substantial operationalization with the help of accounting frameworks aligned with internationally recognized standards.

Despite the fact that the CCE model is still in its early stages, the key underpinnings align with already existing solutions and programs in the GCC region. As a driving force behind the initiative, Saudi Arabia has shown its dedication to sustainable economic development by laying down Saudi Arabia's Vision 2030 plan [59]. The latter emerges as a roadmap for developing high-level circular economy strategies and implementing technologies necessary to reduce natural resource depletion and optimize waste management. However, multiple authors have pointed out the need for a targeted approach that would identify problematic industries and address the associated value chains and waste management mechanisms [60–62]. In addition, the UAE has successfully implemented a robust policy base to ensure that organizations operate within regulatory frameworks optimized for sustainable competitiveness and waste management [63]. Previous studies have indicated that, although both GCC states engage in meaningful sustainability-oriented action, the existing CE policies have been largely limited to waste management and have failed to account for waste reduction [57,64]. Another challenge that should be addressed in the nearest future stems from the lack of waste markets, infrastructure, regulatory enforcement, incentives for businesses, and funding mechanisms [65]. Since the circular carbon economy model and digitalization can help foster sustainable economic development and support economic diversification in the GCC region, it is necessary to conduct a comprehensive overview of the current status quo.

3. Research Methodology

3.1. Theoretical Framework

An effective transition to sustainable economic development requires the availability of transparent and reliable metrics that are capable of measuring a country's progress. Apart from recording milestones on the path to full sustainability, such metrics can provide crucial insights regarding shortcomings and challenges encountered during the transformation stage. Traditionally applied for assessing national and industry-specific dynamics, different interpretations of GDP and CO_2 emissions data for a given country or sector are bound to have certain limitations when it comes to sustainable development [66]. Moreover, the introduction of the circular carbon economy model and digitalization practices have revealed additional insufficiencies in the established measurement techniques. For this reason, one of this study's objectives is to investigate the impact of social, environmental, and economic factors on sustainable businesses operating in Saudi Arabia.

A comprehensive country-wide assessment of emissions drivers with the help of the Kaya Identity opens the possibility to further analyze four main determinants, i.e., population, GDP per capita, carbon intensity, and energy intensity. In the studied case, the next logical objective is to examine the propensity of the CCE model and digitalization for streamlining informed action on climate change without sacrificing competitiveness. As one of the secondary objectives, in this study, we seek to establish a contextual basis for future-use cases for both the CCE model and smart technologies by Saudi companies. Our final goal is to fill knowledge gaps regarding competitive sustainability and its interrelation with the CCE model and digitalization in the context of Saudi Arabia. A flowchart is presented in Figure 1 which provides a visualization of this study's structure and arrangement which is discussed in detail below.

**Investigating the impact of social, environmental, and
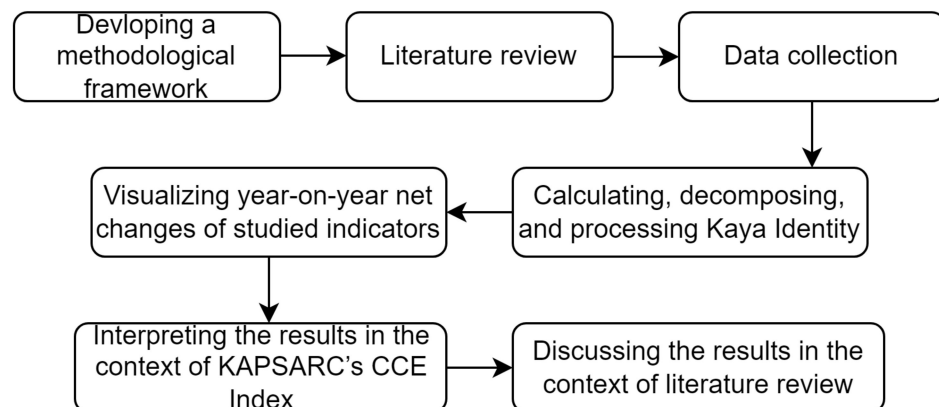economic factors on sustainable businesses operating in Saudi Arabia.**

Figure 1. Schematic representation of the methodological steps taken in the course of this study.

3.2. Data Collection

This emphasis in this paper is on the current state of organizational and statewide efforts aimed to mitigate climate change by focusing on CO_2 emissions, guided the choice of methodological approaches and methods that are described further. For the purposes of assessing Saudi Arabia's emissions of carbon dioxide in dynamics, we collated, reviewed, and analyzed data from the following internationally recognized sources: Emissions Database for Global Atmospheric Research by the European Commission, International Energy Agency's data libraries; Statistical Review of World Energy by BP, Climate Watch Data by CAIT, and Global Carbon Project's data libraries [67–71]. At the time of data collection in July 2022, all sources offered public or partially public access to raw datasets comprising pertinent estimates for Saudi Arabia from 1990 to 2020. The only exception was BP's Statistical Review of World Energy which covered specific metrics, such as CO_2 emissions, up to 2021. Considering that the latest Greenhouse Gas Emissions Inventory prepared as a part of KSA NC4 for UNFCCC covered only 2016 and earlier dates, the Saudi government's reports were not illustrative of the latest emissions dynamics. Despite the lack of regularly updated national datasets that focused on CO_2 emissions, a vital source referenced in the paper was the KAPSARC's Circular Carbon Economy Index, which incorporated policy-related and other metrics relevant to Saudi Arabia [3].

The decision to include multiple sources of data on CO_2 emissions in Saudi Arabia was precipitated by the fact that each dataset had specific strengths and weaknesses in the context of accuracy, availability, timeliness, level of detail, and other factors. Specifically, international providers had employed different methodologies when accounting for consumption-based and production-based CO_2 emissions, a characteristic that became especially evident in fuel-centered and sectoral datasets. Another consideration related to the frequency of updates and distinct operational approaches to estimations made during the outbreak of the COVID-19 pandemic in 2020 and later dates. Despite the existence of widely recognized approaches for estimating aggregate and sectoral CO_2 emissions, there were technicalities and alternative assumptions that often led to inconsistent attributions of emissions and fuel used by industrial sectors [15]. From this perspective, the incorporation of five significant sources was critical for accurately assessing and analyzing CO_2 emissions trends in Saudi Arabia.

3.3. Data Analysis

Due to this paper's scope encompassing the concept of the circular carbon economy model as well as data constraints regarding other GHGs, we primarily focused on CO_2 emissions with a reservation that methane and nitrous oxide emissions would be covered in future studies. In alignment with the circular carbon economy framework and the need

for a country-wide assessment of emissions drivers in Saudi Arabia, the Kaya Identity emerged as one of the critical analytical tools [72]. In combination with the total CO_2 emissions, the Kaya Identity equation provided an opportunity to investigate four main determinants or factors: population, GDP per capita, carbon intensity, and energy intensity. The corresponding equation can be presented as follows:

$$CO_2 \text{ Emissions} = CO_2/\text{Energy} \times \text{Energy}/\text{GDP} \times \text{GDP} \times \text{Population} \tag{1}$$

In the Kaya Identity Formula (1), CO_2 emissions is the total CO_2 emissions in a country or sector; CO_2/Energy is the carbon intensity, which is the amount of CO_2 emissions per unit of energy consumption; Energy/GDP is the energy intensity, which is the amount of energy consumption per unit of GDP; GDP is the Gross Domestic Product; Population is the total population of a country or sector. This equation allows for the calculation of CO_2 emissions based on the factors that drive them, such as population, GDP per capita, carbon intensity, and energy intensity [72]. By analyzing these factors, in this study, we could identify opportunities for reducing emissions through improving energy and carbon efficiency.

To apply the Kaya Identity equation to various sectors, we used sector-specific data on emissions and energy consumption. Then, these data were used to calculate the carbon and energy intensities for each sector. The carbon intensity was calculated by dividing the sector's CO_2 emissions by its energy consumption; then, the energy intensity was calculated by dividing the sector's energy consumption by its GDP. Subsequently, the sector-specific carbon and energy intensities, along with data on population and GDP per capita, were used to calculate the CO_2 emissions for each sector using the Kaya Identity equation. This provided a detailed examination of the factors that were driving CO_2 emissions in each sector, and allowed us to identify opportunities for reducing emissions through improving energy and carbon efficiency.

In the research framework, the Kaya Identity could be further decomposed and processed to visualize year-on-year net changes of all indicators, starting from 1990. To this end, in this study, the calculations were based on the raw data from the following sources: annual CO_2 emissions from the Global Carbon Project, energy data from BP, GDP measures in PPP-adjusted 2011 USD from the Maddison Project Database, and population from the UN Population Division [73,74]. While the assessment of sectoral emissions was primarily based on CAIT Climate Watch Data, the consequent analysis involved further cross-checking and comparisons with sectoral allocations of emissions, as presented by IEA and EDGAR [68,70,71]. Notably, all sources reflected the outcomes of the COVID-19 pandemic, which were further triangulated by using government and industry reports. Since all the used materials demonstrated the economic decline caused by the pandemic and its impacts on emissions in 2020, we also used the KAPSARC's CCE Index [3] to triangulate and validate the results of the analysis, which enabled us to compare the current scenario with a benchmark and also identify gaps and recommend measures to fill those gaps.

4. Analysis and Results

As a brief background to this study results, it is essential to note that, although the collated data focused exclusively on CO_2 emissions and de-emphasizes other GHGs, the former emerged as a majorly unmitigated concern in the later twentieth century. In the 1980s, the efforts of stakeholders in Saudi Arabia's petrochemical industry enabled the successful implementation of policies that resulted in a sizable reduction of total CH_4 reduction by the end of the decade [75]. Thanks to efficient research-based policies as well as the infrastructure funding by the Saudi government, it became possible to capture and reduce the amount of fugitive methane by nearly 70%. In principle, the process of capturing fugitive gases, such as methane, that result from crude oil extraction is not dissimilar from the 4R principles introduced as a part of the circular carbon economy model [40]. For example, the same expertise and determination can be employed for entrenching CCUS, a different yet increasingly effective emissions reduction technology.

One of the research hotspots in the field of a circular carbon economy is examination of the economic benefits and challenges associated with implementing this approach. This includes analyzing the potential for cost savings through resource efficiency, as well as the potential for creating new business opportunities. Another research hotspot encompasses examination of the potential for digital technologies, such as IoT and AI, to enable the circular economy. Specifically, the assessment of potential digital platforms to facilitate resource sharing and the optimization of resource use. In addition to this, we focused on analyzing the potential of the circular carbon economy model in various sectors and industries such as manufacturing, construction, agriculture, and transportation. From this perspective, it is necessary to highlight the role of government, consumers, and other stakeholders in driving the adoption of sustainable practices. While future studies are recommended to analyze each of these relationships individually, a comparative visualization can be observed in Figure 2. Importantly, the government and businesses can influence all steps in the circular process, either via direct initiatives or indirect involvement.
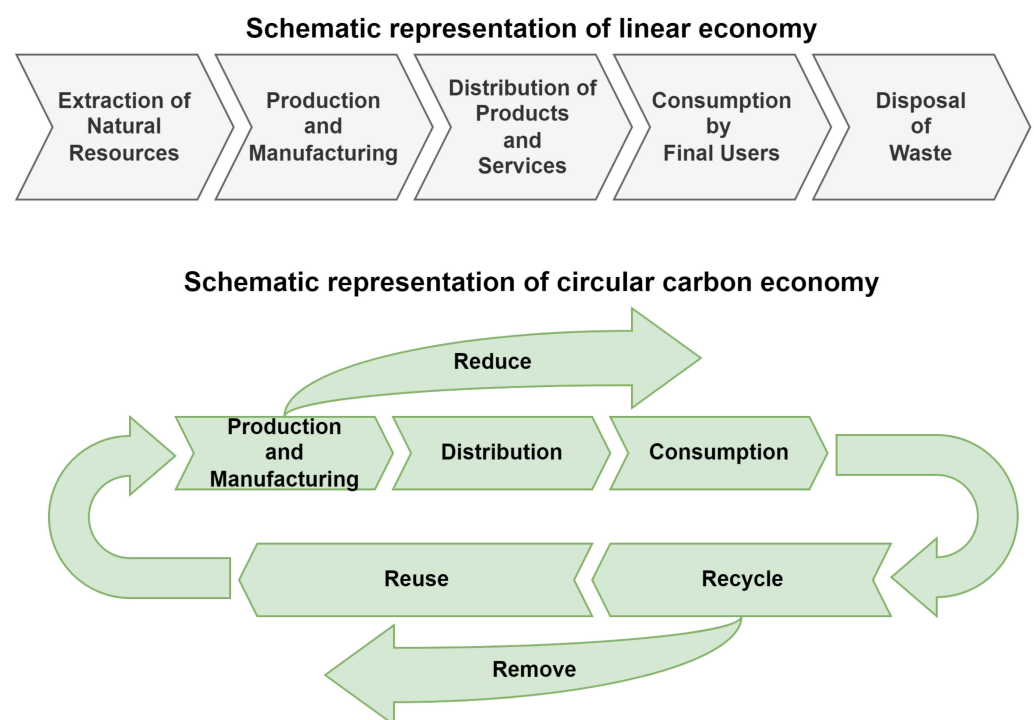
Schematic representation of linear economy

| Extraction of Natural Resources | Production and Manufacturing | Distribution of Products and Services | Consumption by Final Users | Disposal of Waste |

Schematic representation of circular carbon economy

Reduce

Production and Manufacturing → Distribution → Consumption

Reuse ← Recycle

Remove

Figure 2. A schematic comparison of the linear economy model versus the circular carbon economy model. Sources: authors, based on [76].

In a comprehensive outlook on Saudi Arabia's total CO_2 emissions for the last two decades, Figure 3 visualizes data accounting for the following main fuel use agents: the industrial sector, electricity and heat, the transportation sector, the construction and manufacturing sectors, buildings, and fugitive emissions. Historical trends pertaining to the sectoral decomposition of CO_2 emissions are critical for understanding current dynamics and identifying key areas of concern. While the power sector is one of the main contributors, with emissions peaking at 256 $MtCO_2$ in 2015, the second and third positions can be attributed to the transportation sector as well as the manufacturing and construction spheres, respectively. Following economic issues precipitated by the COVID-19 pandemic, a downturn in CO_2 emissions can be observed regarding the first two sectors but not manufacturing and construction, which continued to increase steadily throughout 2020. Coupled with a relatively low contribution from industries, these observations can inform the adoption of circular carbon economy policies at the organizational level.
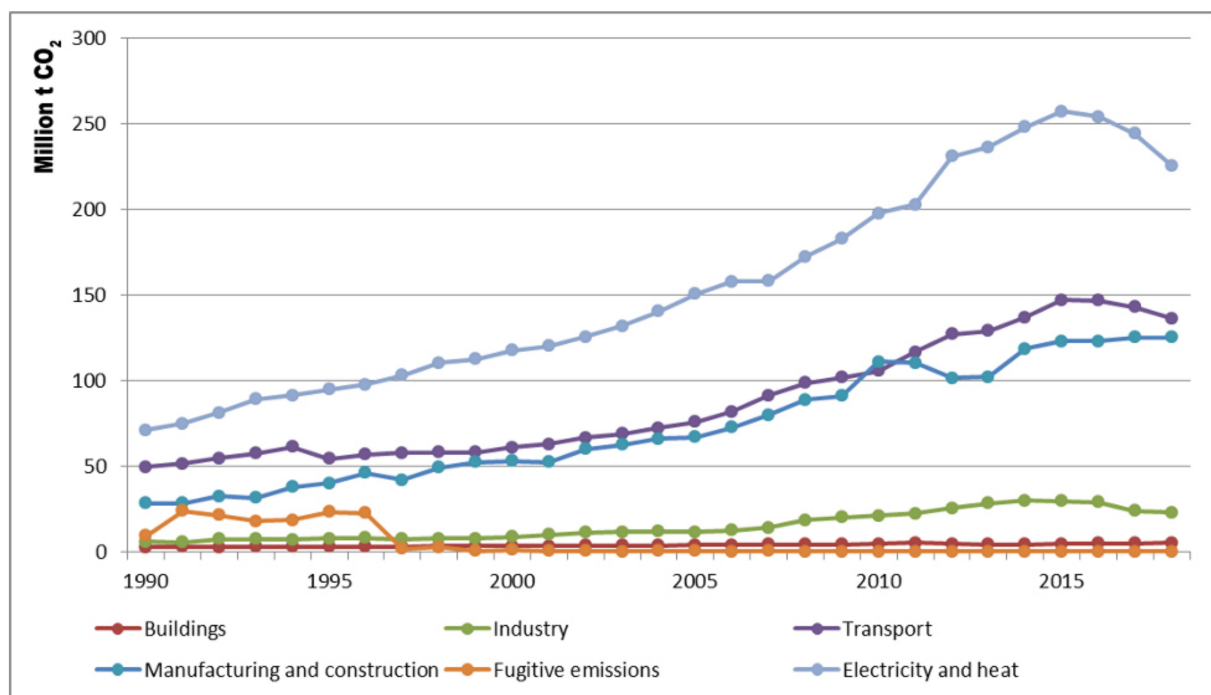
Figure 3. Saudi Arabia's historical timeline of CO_2 emissions by sector. Sources: authors, based on [71].

Figure 4 showcases country-wide estimations of total production-based CO_2 emissions in Saudi Arabia between 1990 and 2020. The raw data provided by BP and EDGAR closely mirror each other, but the former suggest a steeper reduction in 2020. In contrast, the Global Carbon Project's estimates are comparatively higher and do not reflect any noticeable downturns in response to the COVID-19 pandemic. Despite not being updated beyond 2019, the annual CO_2 metrics by IEA exhibit similar magnitude and directional characteristics as compared with the other three. In this context, the 2019 estimates from the four used sources are as follows: 495.2 $MtCO_2$ from IEA, 622.4 $MtCO_2$ from the Global Carbon Project, 582.17 $MtCO_2$ from BP, and 593.3 $MtCO_2$ from EDGAR. As compared with 2018, the dynamics were insignificant except for BP, which showed a 3.69% decline in total CO_2 emissions. While differences between the four data providers appear significant, they mainly result from different estimation techniques and attributions among end-use sectors [15]. Nevertheless, the overview provides a holistic perspective on total CO_2 emissions trends in Saudi Arabia as observed by internationally recognized agencies.

Drawing from the CO_2 emissions data provided by BP, Figure 5 demonstrates year-on-year deltas for Saudi Arabia as one of the most significant contributors by volume in the Middle East. As compared with consistent yearly increases in total CO_2 emissions in the region until 2019, Saudi Arabia exhibited several periods of downward trends in 1992, 1995, and 2017. Another critical observation pertains to the rebound of total CO_2 emissions in 2021, as Middle Eastern states, including Saudi Arabia, gradually recovered from the economic outcomes of the COVID-19 pandemic.

From the macroeconomic perspective, the Kaya Identity provides an opportunity to decompose total CO_2 emissions by identifying the contributions of the four main drivers, i.e., population, energy intensity, carbon intensity per unit of energy and GDP, and GDP per capita [72]. As evident in Figure 6, steady population growth has decoupled from the total CO_2 emissions, but the latter remains closely tied to other indicators. For example, a fall and the consequent stabilization in 2015 and, to a lesser extent in 2017, are reflected by similar changes to GDP per capita and carbon intensity. On the whole scale from 1990 to 2021, there have been no consequential shifts to the carbon intensity per unit energy index, which has remained at −5.08%. However, the steady decline in energy intensity (56.27% in

2018) and carbon intensity per GDP (59.05% in 2018) reveals that Saudi Arabia has partially managed to offset the rapid increase in GDP and population. While GDP per capita growth has primarily slowed down after peaking in 2015, the graph shows a limited rebound by 2018. The consequent sharp decrease in response to the COVID-19 economic outcomes is not reflected in raw data. Another Kaya Identity decomposition would be necessary as soon as the data becomes available [77].
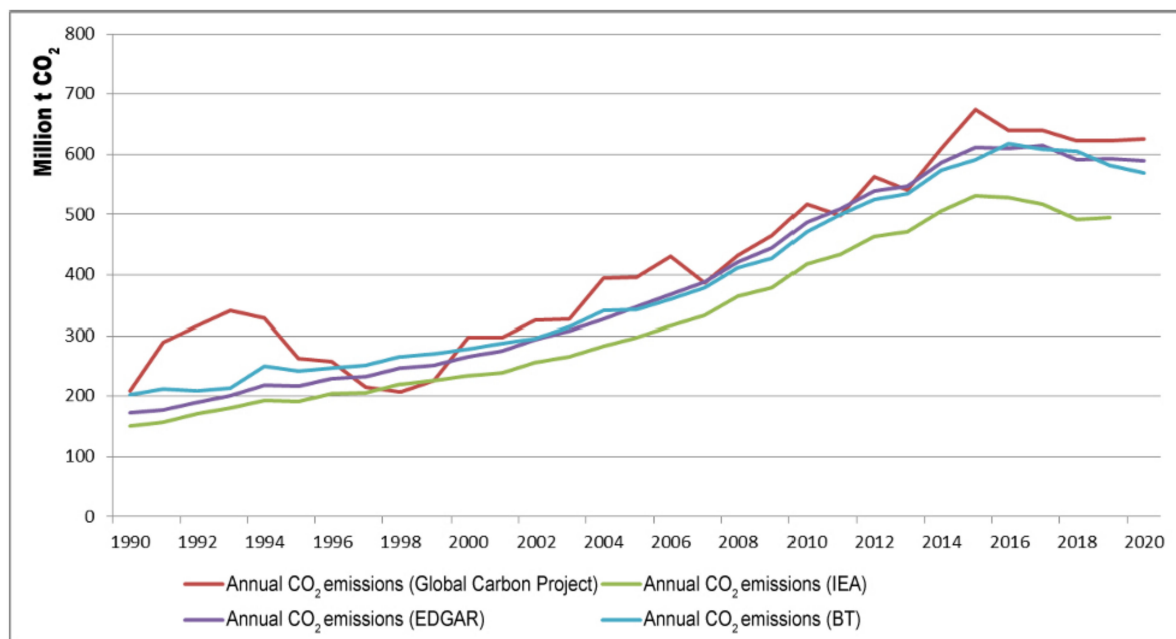

Figure 4. Saudi Arabia's annual CO_2 emissions trends from 1990 to 2020. Sources: authors, based on [67–70].
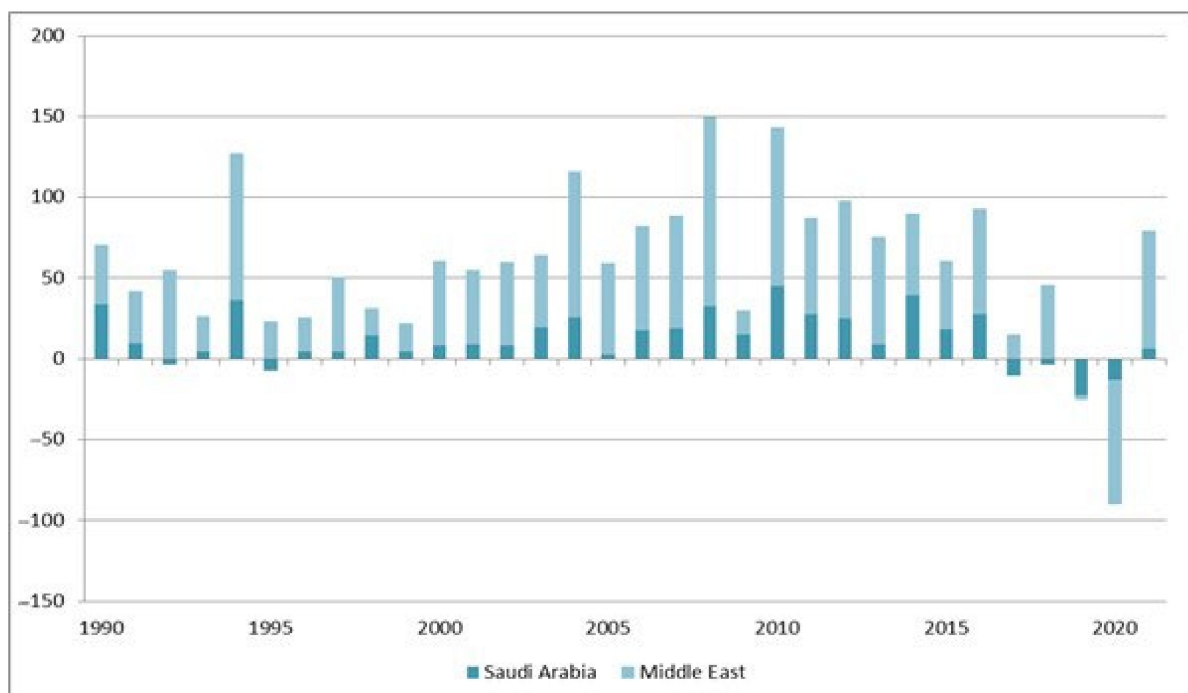
Figure 5. Year-on-year deltas of total CO_2 emissions (in a million tons) for the Middle East (including Saudi Arabia). Sources: authors, based on [67].
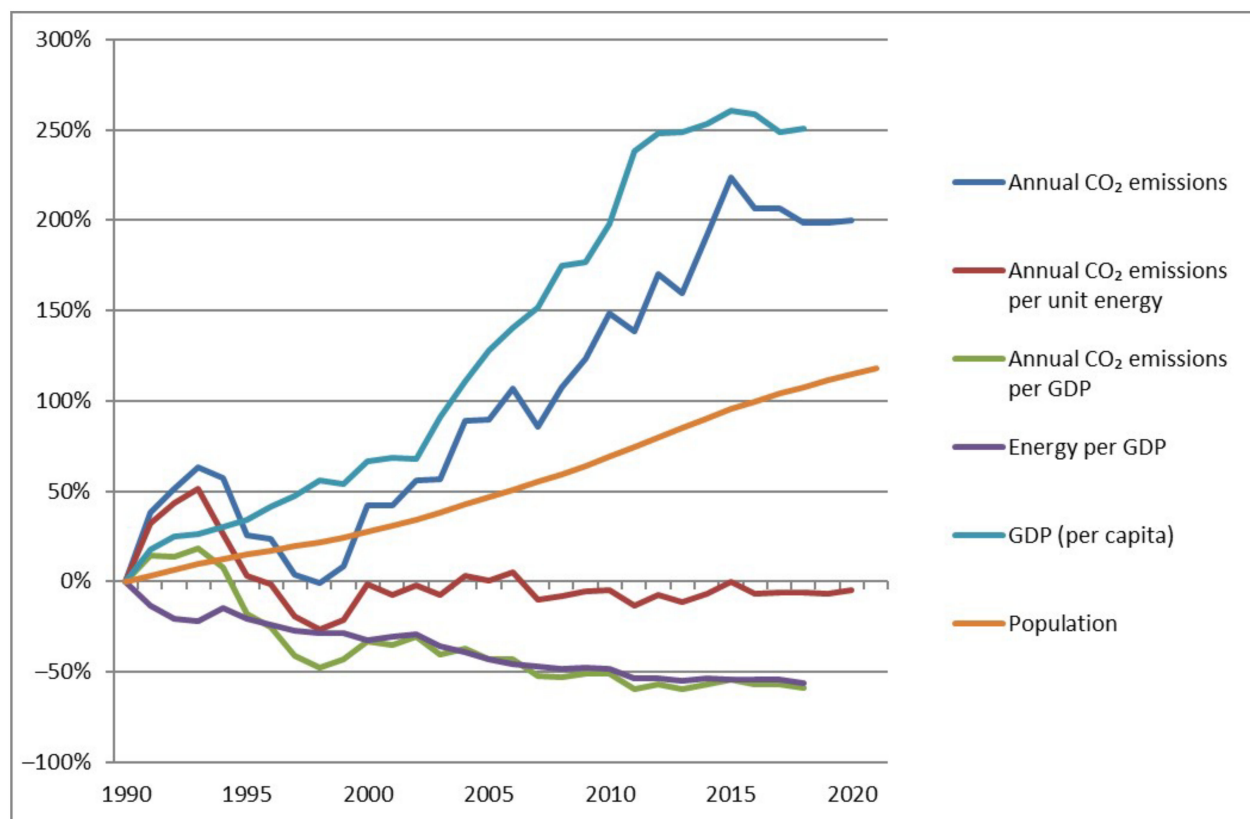
Figure 6. Year-on-year percentage change for Saudi Arabia's CO_2 emissions drivers comprising the Kaya Identity. Sources: authors, based on [30,67,69].

Overall, the year-on-year percentage change for Saudi Arabia's CO_2 emissions drivers shows that sluggish GDP and population growth and also policy-related indicators, such as carbon intensity and energy intensity, have contributed to the observed changes in total CO_2 emissions. The latter has partially stabilized in response to policies that the Saudi government introduced as a part of Saudi Arabia's Vision 2030. Industry-specific sources further indicate that the country has succeeded in gradually phasing out diesel consumption for the purposes of power generation and transportation [15]. Although not reflected by the Kaya Identity, the recent decline in CO_2 and GDP in response to the pandemic is likely to result in a symmetrical rebound throughout the consequent years. Consequently, Saudi policymakers and researchers can rely on the successes of previous stabilization efforts to inform steps necessary to prevent potential rebounds in CO_2 emissions. In the scope of the circular carbon economy framework proposed by KAPSARC, several vital steps would involve the development of economic diversification plans, energy-efficient practices, and technological solutions [10]. The observed data resemble statistics reported for the UAE which warrants a brief comment due to the latter's similarly high dependence on fossil fuels. Specifically, the situation in the neighboring state is largely characterized by a considerably smaller population and more proactive sustainability-oriented reforms [5]. Particular attention can be placed on the effort to mitigate CO_2 emissions with the help of CO_2-enhanced oil recovery as well as carbon recapture and storage [78]. These techniques can be combined with waste management and digitalization solutions discussed below.

5. Discussion

5.1. Interpretation of Key Findings

As evidenced from the Kaya Identity, the data analysis reveals the current state of Saudi Arabia's CO_2 emissions trends in the context of main emissions drivers. While observers comment that the unexpected economic downturn due to the pandemic helped

reduce total emissions temporarily, the underlying patterns have remain unchanged [15]. Despite slow reductions in carbon and energy intensity, CO_2 emissions are intrinsically tied to the country's population and GDP growth. The introduction of new climate-oriented policies as a part of Saudi Arabia's Vision 2030 has helped to partially alleviate the situation. However, KAPSARC's circular carbon economy index emerges as an additional tool for policy-making efforts [3]. At the time of writing, Saudi Arabia showed the highest performance indicator of 40.63 among Middle Eastern states as well as the fourth highest enablers score [10]. By implementing the 4R principles of the circular carbon economy model at the country-wide and organizational levels, it would be possible to stabilize the CO_2 emissions increase further and prevent anticipated rebounds.

Due to the relative incompatibility with traditional business strategies, a circular carbon economy model and other sustainable practices serve as a push toward organizational change and transformation. Apart from attaining sustainable goals, it is imperative to not only preserve stable operations but also gain a competitive edge. Hence, businesses can rely on smart technologies and the 4R circular carbon economy principles to enhance production capacity and generate profit [8,40]. The emerging business models should account for opportunities and risks associated with new frameworks. For example, the demand for sustainable products can be met with the help of new products, improved operations, and life-cycle responsibility [9]. As a result, the chosen business model should reflect transformation to a circular economy.

Depending on a business's reliance on data, the organizational change could involve new strategies aimed at developing and integrating digital and physical resources together with the government. All data-driven processes predicate the implementation of appropriate data governance, regulations, and corporate culture [38]. From another standpoint, responsible employees should be trained to handle data and manage newly established circular processes and indicators proposed by KAPSARC and other agencies [10]. By ensuring their compliance with government regulations, companies secure themselves from the potential downsides of both the circular carbon economy model and digitalization.

Furthermore, the use of digitalization and circular carbon economy solutions and policies precipitates the development of internal assets and resources to address new challenges. The growing demand for sustainable products drives firms to reassess the skills and knowledge necessary to maintain sustainable organizational processes [27]. The following capabilities are among the essential functions that facilitate organizational change: strategic, operational, dynamic, and other capabilities [7,15]. As a result, businesses should focus on pertinent capabilities to ensure their alignment with a sustainable business strategy. Unfortunately, the scope of strategic and operational changes becomes a major obstacle to firms seeking to adopt smart technologies or re-orient towards the circular economy approach.

5.2. Propositions

As previously explored in the Comprehensive Literature Review section, the growing emphasis on the circular economy among North American and European policymakers contrasts with the current situation in the GCC region. While it becomes increasingly evident that the linear economic model is unsustainable from the long-term perspective, the Saudi government and businesses are only starting to acknowledge the value of sustainable economic development [63,75]. The findings presented above form the foundation for the first proposition to accelerate economic diversification by ensuring that both policymakers and businesses adhere to the optimal regulatory frameworks.

However, the recent economic upheavals complicate objective assessments of the short-term effects of Saudi Arabia's Vision 2030 and other associated initiatives such as the CCE model [79,80]. Despite ambitious plans to restructure hydrocarbon dependent sectors with the help of sustainability-driven regulatory frameworks, there are no discernible effects of circular economy policies on the country's shift to sustainable economic development. This situation can be partially explained by the policymakers' focus on high-level strategies and the lack of a targeted approach guiding specific sectors, a situation similar to that

observed in the UAE [62]. As compared with other GCC states, Saudi Arabia's move to launch the CCE model is further supplemented by various economic diversification strategies highlighted in Saudi Arabia's Vision 2030 [65]. Particularly, previous studies have pointed to the evidence suggesting that businesses are encouraged to adopt advanced recycling processes and embrace sustainable production chains [75]. In this context, the second proposition is that policymakers and researchers shift their focus on more narrow industry-specific strategies that account for conditions faced by the involved stakeholders.

This study further highlights the unprecedented growth of CO_2 emissions which, together with rapid resource depletion, is likely to result in dire consequences for Saudi Arabia as well as other GCC nations. Albeit temporarily alleviated by the COVID-related decline, the current situation calls for a transition from the conventional linear economic model [77,80]. The literature review highlighted evidence suggesting that circular economy initiatives are being implemented not only in the GCC region but also in China, North America, and Europe. Unfortunately, the practical implementation and the consequent effectiveness of such efforts vary from country to country. For example, the UAE's Circular Economic Policy is a framework that closely resembles the CCE model proposed by Saudi Arabia [62]. While the UAE's authorities acted upon the aforementioned strategies and developed policies helping to reduce consumption and increase recycling, there are currently no tangible large-scale outcomes at the time of this research. Arguably, waste management and digitalization appear to have been prioritized over other aspects of a circular economy by both the UAE and Saudi Arabia. These observations are used to define the third proposition that tangible effects on CO_2 emissions from the CCE-driven initiatives can only be realized by incorporating experiences of other countries with an equal focus on the reduce, recycle, reuse, and remove stages.

5.3. Global Applications of the CCE Model

Since this study focusing on Saudi Arabia provides a regional context for the global issue, many of the findings remain applicable to other countries and regions, especially in the context of globalization. Considering that sustainability cannot be achieved without the concerted effort of all partners and stakeholders, industry-wide transformations are critical to the eventual success of a company and the country. In this case, partnering businesses are responsible for jointly taking steps toward digitalization and a circular economy by coordinating with government agencies and other organizations [81]. To achieve a competitive advantage as well as benefit from sustainable outcomes, a business should either redefine its relationships with partners and stakeholders or take initiatives offered by newly introduced concepts such as the circular carbon economy model. Domestic and international stakeholders both need to adopt new roles to ensure that a circular economy approach results in superior savings and profit for companies while negating waste and emissions for the country as a whole [29]. As equally involved in the circular economy approach, consumers should act responsibly and assist businesses in attaining sustainability goals [1]. Accordingly, industry-wide transformation is critical to establish prerequisites for value co-creation resulting in a competitive advantage on a global scale. The academic community involved with technological forecasting and social change can benefit from this study's contributions as both digitalization and the circular economy model emerge as the driving forces underlying the proposed steps toward a more sustainable future for all countries.

5.4. Current Challenges and Policy Recommendations

As can be inferred from the findings and literature review, the implementation of the CCE model is facing several challenges. One of the main challenges pertains to the difficulty in measuring and verifying circular economy activities, which makes it hard to track progress and evaluate the effectiveness of policies and initiatives. Another challenge is the lack of data on circular economy activities, which complicates the process of identifying opportunities for improvement and tracking progress. There is also a lack of understanding and awareness of the circular economy approach among stakeholders,

which makes it hard to engage them in the transition. In addition, the difficulty in scaling up circular economy activities, as many companies struggle to implement circular economy practices on a larger scale, emerges as a critical obstacle to plans outlined by the Saudi government [82]. Moreover, there is insufficient collaboration and coordination among stakeholders, which makes it difficult to achieve the systemic change required for a successful transition to a circular economy. To overcome these challenges, it is important to increase transparency and data collection, raise awareness, encourage collaboration and coordination, and provide the necessary policies and legal frameworks to help companies adopt circular economy practices.

Policies and legal aspects play a crucial role in promoting and implementing the circular carbon economy model, with one of the key examples being carbon pricing and emissions trading schemes, which provide a financial incentive for companies to reduce their carbon emissions by putting a price on carbon [15]. Government subsidies and incentives for resource-efficient and low-carbon technologies can also encourage companies to adopt circular economy principles. Regulations and standards for product design and end-of-life management can assist with ensuring that products are designed to be easily repaired, reused, or recycled [19]. Extended producer responsibility schemes shift responsibility for product end-of-life management from the government to the producers, encouraging the latter to design products that are more easily recycled. Resource efficiency and waste reduction policies can also encourage companies to adopt circular economy principles by reducing the amount of resources used and waste generated, as has been observed in other countries [11,50]. These policies and legal aspects, when implemented effectively, can promote the circular economy approach and can reduce greenhouse gas emissions.

6. Conclusions

6.1. Contribution to Theory

As evidenced by the lack of current research approaching the CCE model and digitalization in the context of sustainable competitiveness, the topic remains relatively understudied. Moreover, there is a limited theory body of knowledge pertaining to the high-level analysis of sustainable economic development in Saudi Arabia as well as the implications of the studied problem for the industry and the country's economy. As a result, the current study has focused on the Kaya Identity as well as CO_2 emissions trends in Saudi Arabia for the last two decades. Apart from providing a background for the perspectives of implementing circular carbon economy policies, the results of the data analysis showcase the need for resilient solutions that would be embraced and followed by all stakeholders. One of the key contributions pertains to the development of a foundation that can be potentially used by the government to develop policies that account for the needs of local businesses and to ensure that the 4R principles of a circular carbon economy model are compatible with the realities of Saudi Arabia. From a broader perspective, the research combines existing evidence with new data and propositions to be eventually scrutinized and applied in other contexts.

6.2. Contribution to Practice

Since the current study provides a high-level outlook on Saudi Arabia's sustainable economic development as well as the roles played by the circular carbon economy model and digitalization, the findings can be used as a foundation for crafting informed policies and strategies. Furthermore, the comparative analysis of competitive sustainability on multiple levels in Saudi Arabia in contrast to other states reveals pertinent challenges and opportunities for policymakers. Considering that circular economy implementations are largely limited to high-level policies, there is a need for focused initiatives that would encourage individual businesses to cooperate with the government's agenda. However, the practical contributions are not constrained to theory making as some of the proposed solutions can be immediately adopted by major stakeholders, such as government corporations and agencies.

6.3. Limitations

In this framework, one of the main limitations is the lack of industry-specific data that could help to create a more cohesive representation of the transitionary stage between linear and sustainable economic models. This limits the ability to provide a detailed analysis of the different sectors and their specific challenges and opportunities for implementing the circular carbon economy model and digitalization. Additionally, this study relies on data from different sources which may have different methodologies and assumptions, which could introduce some uncertainty in the analysis. Furthermore, this study is based on data that is mostly available up until 2021, which means that it does not consider any changes or developments that may have occurred after that date. Another limitation is that this study focuses primarily on CO_2 emissions and does not consider other greenhouse gases such as methane and nitrous oxide which are also significant contributors to climate change. Finally, this research is based on a single country, and therefore, the results may only partially be generalizable to other countries. Despite these limitations, this study provides valuable insights into the challenges and opportunities of implementing the circular economy approach and digitalization in Saudi Arabia and can serve as a basis for further research.

6.4. Future Research

The current study provides valuable insights into the challenges and opportunities of implementing the CCE model in Saudi Arabia with the help of digitalization efforts. However, there is still a considerable opportunity for further research that could be based upon the findings of this study. A key area for future research is to conduct a more detailed analysis of the different sectors and their specific challenges and opportunities for implementing the CCE model in Saudi Arabia. Scholars are recommended to involve collecting industry-specific data and conducting case studies to provide a more detailed understanding of the different sectors. Another opportunity for future research pertains to the investigation of other greenhouse gases such as methane and nitrous oxide as well as their roles in the circular economy approach and digitalization. Additionally, it would be increasingly relevant to conduct a similar study in countries with different economic backgrounds to compare the results and identify common challenges and opportunities. This work could help to determine optimal practices and policy recommendations that could be further applied globally. There is also a need for long-term research to evaluate the effectiveness of the policy recommendations and the progress made in implementing the circular carbon economy model and adopting smart technologies. Overall, the current research provides a valuable starting point for further academic inquiries in the field of the CCE model and digitalization while highlighting the importance of addressing pertinent issues in order to achieve sustainable outcomes.

7 October 2022); the International Energy Agency (https://www.iea.org/countries/saudi-arabia, accessed on 7 October 2022).

Conflicts of Interest: The authors declare no conflict of interest.

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