

THE IMPACT OF DIGITAL ECONOMY ON GREEN GROWTH IN THE KINGDOM OF SAUDI ARABIA

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ABSTRACT

In the background of the rapid development of the digital economy, Saudi Arabia is facing an imperative necessity to transition to green and sustainable growth from traditional growth patterns, as per its Vision 2030 ambitions. This study examines how the digital economy impacts green growth in Saudi Arabia during 1996–2022, addressing both environmental sustainability and inclusive development. The study uses reliable data from international sources such as the OECD, WDI, and Heritage.org, and applies cointegration tests along with Bayesian methods to estimate a vector autoregression model (BVAR) to investigate the relationships between digitalization (DESI), trade, corruption, and population growth in relation to green growth.

The empirical findings strongly support the hypothesis that digitalization significantly contributes to green growth in the long term, primarily by inducing structural transformation and greater sustainability. DESI emerges as a strong and growing determinant, explaining 14.24% of variation in green growth in the long run—just after trade. Historical decomposition also highlights that the positive impact of digitalization was most prominent between 2005 and 2015, matching a global digital shift. The analysis also gives interpretative proof of the role of the digital economy in inclusive green growth as better governance and less corruption appear to mediate this relationship.

The evidence confirms that while digitalization has giant potential to drive green growth, the success will lie in mainstreaming sustainability in digital policy, green investment in technology, and the alignment of trade and labour policies with green priorities. Policymakers should ensure that digital transformation is accompanied by proper institutional reforms and inclusive planning to realize an equitable and sustainable green transformation in Vision 2030.

Keywords: *Digital economy, green growth, sustainable development, cointegration approach, Saudi Arabia*

1. INTRODUCTION

The digital and green economy has been high on the environmental policy agenda in recent years. The revolution that the world witnessed in the field of information and communications during the nineties of the last century enabled the enhancement of the role of the digital economy in many aspects of life, as communications technology and information technology have

become the main role in various economic sectors by contributing to increasing the level of efficiency through two basic elements (reducing costs and shortening time). These two elements complete economic and financial transactions, improve labour productivity, and increase levels of competition between economic institutions. However, the development of the digital economy has also brought about negative effects, such as the weakening of environmental resources and a rise in carbon emissions. The green economy promotes the synergistic development of economic growth and environmental protection (Lin et Zhou, 2024; Nguyen et Hang, 2024).

The digital transformation in the economy is a necessity imposed by the current time in light of the need to diversify the economy to mitigate the negative effects of disasters and crises, especially in light of the Corona pandemic which has made the digital economy necessary. As the digital economy has emerged as a solution to many economic problems, it has been possible to benefit from the characteristics that distinguish the digital economy from. Benefiting from the traits that set the digital economy apart has been feasible since it has surfaced as a remedy to numerous economic issues. Rapid economic growth has been made possible for all nations with digital infrastructure (Al-Jomard et al., 2025), because the digital economy boosts flexibility by achieving a quick qualitative change in economic performance and has helped create a large number of jobs for the younger generations that are joining the workforce on a daily basis.

The research on green economy was one of the important researches of Al-Taai (2021) who consider that the green economy is very important for the development and growth of all sectors of society, as it is the basis for sustainable development and the main support of economic growth. Therefore, it attracted the attention of researchers and scientists. The green economy is considered a durable and perfect model for sustainable development, especially for economic growth. The green economy influences all areas of life, as it is key for reducing poverty and deprivation, upgrading living standards and ensuring people's well-being.

Before discussing how digitalization connects to green growth, we want to point out that technologies like Information and Communication Technology (ICT) and the Internet of Things (IoT), along with other digital innovations, have changed many parts of our lives and are closely linked to the digital economy and sustainable development (Liu et al., 2024; Nizetic et al., 2020, Li et al., 2022). Specifically, it is defined as the suite of technologies that enable the processing and communication of information, which forms the foundational infrastructure for digital transformation. Similarly, IoT is defined as the network of interconnected devices that collect and exchange data, enabling real-time monitoring, automation, and data-driven decision-making. However, both ICT and IoT serve as enablers of the digital economy by facilitating new forms of value creation, improving efficiency, and supporting innovation across sectors (OECD, 2023).

The Saudi government has worked to set up ways for the transition to the digital economy so that the economy can grow. This is because the digital economy is an important part of Saudi Arabia's Vision 2030. They have done this by preparing the legal environment and supporting the infrastructure to make it possible for the digital economy to work in all parts of the national economy, which will bring in a lot of investments and boost economic growth. The impact of technological development on our lives is increasing every day. We can observe this process in the rapid digitalization, which is the adoption of digital services by both public and private sectors (Mahaldar & Bhadra, 2015). This term refers to the penetration of ICT technologies in our daily lives, from basic online payments to more advanced applications of e-government. The determinants of growth have always been the major interest of economists. Solow and Swan indicated that the main factors of economic growth are capital, labor, and total factor productivity (TFP) growth (Solow and Swan, 1956). TFP growth, or Solow residual, which is the indicator of all exogenous factors affecting growth, has been widely discussed but never put into a clear framework. Luo et al. (2022) have discovered that the development of the digital economy has a

positive driving impact on firms, industries, and the macroeconomy. The main functions of the digital economy, according to Wang (2018) and Gubanov & Oborin (2019), are to strengthen the industrial structure, lower transaction costs, make economic organization and allocation more efficient, lower pollution emissions, and promote economic transformation. Recent academic research by Xie et al. (2022), Liu et al. (2022); and Khan et al. (2022); Elhassan (2025); Ludin et al. (2024) has shown that green and high-quality development is becoming more and more important. This is because green economic development aims to both grow the economy and make the environment better.

The majority of literature have studied the impact of the digital economy on traditional economic growth. Assessing the impact of the development of the digital economy on green growth is crucial for nations around the world, especially Kingdom of Saudi Arabia, to achieve Vision 2030's digital transformation agenda with broader sustainability objectives. This study empirically examines the impact of the digital economy on green growth. First, we establish a theoretical framework for the impact of the digital economy on green growth. Secondly, we apply econometric models to empirically analyse the relationship between the digital economy and green growth and examine the economic mechanisms. We find that the digital economy substantially promotes green growth. We also explore the potential economic channels through which the digital economy stimulates green growth. Our mediation analysis shows that institutional reforms are one plausible mechanism through which the digital economy enhances green growth.

The rest of paper is organised as follows: Section 2 presents a literature review on the contribution of digital economy to green growth. Section 3 investigates the data and measurement and outlines the appropriate research methodology for digital economy and green growth. Section 4 presents and discuss the findings. Finally, Section 5 provides a conclusion and policy implications.

2. LITERATURE REVIEW

The literature on digitalization has mainly focused on its definition and its effect on various macroeconomic measures such as GDP per capita, TFP growth, and productivity. The relevant literature has highlighted many positive effects of digitalization. For example, Sabbagh et al. (2012) conducted an analysis to measure the effect of digitalization on several indicators such as GDP growth, welfare, transparency. According to their findings, an increase in digitalization by 10% leads to a 0.5 to 0.62% increase in GDP per capita. Katz et al. (2014) looked at how different groups of countries were affected: for advanced adopters, a 10% rise in digitalization scores leads to a 3.1% rise in GDP; for transition adopters, it leads to a 3% rise in GDP; and for emerging and forced adopters, it leads to a 2.5% rise in GDP. Evangelista et al. (2014) showed a significant positive effect of ICT use on labor productivity growth and again a strong positive link between ICT empowerment and GDP growth. N'dri et al. (2021) showed that an increase in ICT exerts a positive influence on the environment in lower income developing economies while a discernible impact was found in high-income developing economies using a sample of 58 developing economies from 1990 to 2014. These studies highlighted the significant role of digitization in overall economic growth. They also laid the groundwork for us to question of how much digitization contributes to green growth (Idris & Razak, 2025).

Since Tapscott (1996) announced the term “digital economy” in 1996, the research has generally gone through three phases: information economy, internet economy, and new economy. According to Hang (2024) explore the key factors affecting the digital economy and their impacts on green growth. To reach their goal, the authors analysed the data using both qualitative and quantitative methods. They identify five determinants that influence the digital economy and its impact on green growth. Finally, the study's novelty helps policymakers and provincial managers apply research results to develop the digital economy and green growth. There are a lot of

ideas about how to make the digital economy and the green economy work together. These policy suggestions focus on things like investing in higher-quality human resources, new technologies, perfect digital policies, investing in digital infrastructure, and spreading information about the digital economy to everyone. [Dong & Ullah \(2023\)](#) argue that the Internet of Things and environmental regulations have the potential to support green growth. We want to find out if there is a real connection between the Internet of Things, environmental rules, and green growth in China. To do this, we will look at data from 1997 to 2021 using the autoregressive distributed lag (ARDL) and quantile autoregressive distributed lag (QARDL) methods. The baseline ARDL model shows that the Internet of Things, rules about the environment, using renewable energy, and research and development (R&D) all lead to long-term green growth. Likewise, the robust model also highlights that the internet, environmental policy stringency, renewable energy consumption, and R&D help encourage green growth. In the short run, environmental policy stringency and the internet are favourably linked to green growth in the robust model; however, environmental regulation is negatively linked to green growth. The findings from the QARDL analysis show that the impact of the Internet of Things on promoting green growth is significant across all quantiles. On the other hand, the effects of environmental regulation are more pronounced at higher levels of green growth. These findings imply that policymakers should try to increase the role of digitalization in society by promoting the Internet of Things and the internet to decouple economic growth and environmental pollution.

Using data from 2011 to 2019 at the provincial level of China, [Kong & Li. \(2022\)](#) used the fixed effect, mediation effect, and spatial Durbin models to look at how the growth of the digital economy has affected the efficiency of the green economy. The digital economy's development and green economic efficiency improved during the study period. After robustness and endogeneity tests, the growth of the digital economy has a catalytic effect on the efficiency of the green economy. A heterogeneity analysis proves that digital economy development encourages green economic efficiency in the eastern and central regions; the impact on the western region is non-significant. The growth of the digital economy makes the green economy work better in places where it is developing quickly and where big data is being tested. The growth of the digital economy encourages green economic efficiency by improving human capital, the structure of industries, and new technologies. Improving the structure of industries has a stronger mediating effect, reaching 40%. The growth of the digital economy helps the green economy work better in the region and spreads to neighbouring regions, making it even better overall.

According to [Zhang et al. \(2021\)](#), the digital economy can directly lead to high-quality green development. Restructuring industries and developing green technologies play a big role in this. [Dong et al. \(2022\)](#) proved that although the digital economy can significantly reduce the carbon emission intensity, it also promotes increases in carbon emissions per capita, and therefore, economic growth, financial development, and industrial structure upgrading can mediate the relationship between the digital economy and carbon emissions. [Li et al. \(2022\)](#) have also shown that the digital economy's development in China has increased carbon emissions because of improved energy efficiency. [Lin & Zhou \(2024\)](#) demonstrate the significant positive impact of applying the SURF algorithm to sustainable development research in the digital economy and green economy. [Han & Liu \(2022\)](#) used 30 Chinese provinces as research subjects and came up with a way to measure the level of development in both the digital economy and green development. The results show that the digital economy has a big positive effect on China's green development, and it can effectively promote green development at the provincial level.

[Qian et al. \(2020\)](#) investigated the digital economy and green economy policies in the post-COVID-19 economic recovery policies of various countries around the world and concluded that the digital economy and green economy could develop together to help economic recovery

as soon as possible. [Liu et al. \(2022\)](#) look at the digital economy and the greening of cities by examining how they affect production, life, and ecological space. They conducted an empirical test using cities in the Yangtze River's economic belt as an example and concluded that the digital economy could promote urban green transformation. The findings of [Zhang et al. \(2023\)](#) demonstrate that the development of the digital economy significantly contributes to the promotion of a green economy and there are regional differences in both the digital economy and the green economy in China, with the southern region experiencing better development than the northern region. [Nguyen et al. \(2020\)](#) show that the development of information and communication technology not only encourages economic growth but also increases the productivity of G20 countries with regard to carbon emissions.

[Ben Lahouel et al. \(2021\)](#) and [Kulyasova & Trifonov \(2020\)](#) found that the first effect of the digital economy on the green economy is the ease with which people can now share information. This has made regional economies run more smoothly, which leads to green urban development. [Li et al. \(2022\)](#) found that the digital economy has increased innovation and made it faster and cheaper for knowledge to spread and interact in the innovation network. This has led to faster technological progress and the green transformation of industries. Based on the statistical data of 30 provincial-level regions in China from 2014 to 2019, [Zhang & Yin \(2023\)](#) determined that there are five paths to achieve coordinated development of the digital economy and green economy, which are divided into two categories (technology–environment dual-drive type, and technology–organization–environment linkage drive type) and technological innovation capability and government financial support can substitute for one another under certain conditions to achieve the coordinated development of the digital economy and green economy. Using the fixed effects model, the instrumental variables method, the quantile regression model, and the mediating effects model with data from 2011 to 2019 in China, [Zhao et al. \(2023\)](#) indicate that the digital economy has a significant positive impact on green development, and that this impact grows as GTFP (Green Total Factor Productivity) increases. Taking the data for 30 provinces in China from 2006 to 2018, [Wang et al. \(2022\)](#) utilize the spatial dynamic Durbin model to investigate the impact of energy internet (EI) and digital economy (DE) on green economic growth (GEG). They confirm that energy internet and digital economy promote green economic growth.

[Ma et al. \(2024\)](#) mention a few of the key findings: (1) The advantages of digital economy agglomeration are higher compared to its drawbacks, leading to a net positive result with regional imbalances. (2) Digital economic clustering promotes inclusive green growth in the vicinity but has a spatially adverse spillover effect by repressing the same in the neighbourhood cities. (3) Among mediating variables, variables like industrial structure, technological progress, and resource allocation efficiency have beneficial roles in promoting inclusive green growth. By contrast, environmental control intensity is negatively affecting indirectly and represents a non-linear impact under threshold effects.

[Chen and Xing \(2025\)](#) investigate the effect of digitalization on high-quality development based on panel data covering 279 prefecture-level Chinese cities during 2010–2022. Their evidence verifies that the digital economy is positively associated with high-quality growth, both directly and indirectly via the encouragement of green innovation, by using instrumental variable estimation, propensity score matching, and the Heckman selection model. For their part, [Imansyah et al. \(2023\)](#) analyse the impact of the digital economy on output growth, CO₂ emissions, and income inequality in Indonesia. Using input-output analysis, they consider the output multipliers of ICT sectors and value added and their social and environmental impacts. Economic output is supplemented by ICT development, yet ICT development widens income disparity. Therefore, policy interventions need to stimulate the ICT sector with regard to social inclusion

to facilitate the transition to a green economy.

Myovella et al. (2020) examine the impact of digitalization to green growth of Sub Saharan Africa (SSA) in comparison with the OECD economies. They use a panel data set for 74 countries and GMM estimators. The results show that digitalization has a positive contribution to green growth in both groups of countries and internet and mobile telecommunications have different impacts for OECD and SSA countries. **Majeed and Sharif (2024)** analyze the green growth effects of digitalization using panel data from 164 countries spanning the period from 1990 to 2023. The empirical results remind that the increase of digitalization measures tends to raise Green Growth. The results, based on principal component analysis also reinforce the positive impact of digitalization, on Green Growth. **Majeed and Ayub (2018)** examined the impact of diverse Information and Communication technology on green growth at both global and regional levels. The analysis is based on a sample of 149 counties over the period 1980-2015. The results indicate that all indicators of ICT accelerate both global and regional green growth. However, some indicators such as online service, telecommunication infrastructure and e-government are comparatively more conducive in enhancing green growth. **Tawiah et al. (2021)** examined the Green Growth determinants employing a sample of 123 developed and developing countries. They showed that economic development applies a positive influence on Green Growth while trade exerts a negative influence on Green Growth. They analyzed green growth determinants at the global level, however, they did not consider the importance of digitalization in influencing global Green Growth. **Tawiah et al. (2021)** examined green growth determinants at the global level, however, they did not consider the importance of digitalization in influencing global Green Growth. On the contrary, **Hao et al. (2023)** focused on the role of digitalization on Green Growth in the case of China from 2013 to 2019. they support a positive association between digitalization and Green Growth in China.

This theoretical and empirical passage highlights a complex and generally positive relationship between digitalization and green growth. The existing literature highlights that digitalization, through innovations like ICT, the Internet of Things, and digital infrastructure, significantly enhances macroeconomic indicators like GDP, productivity, and technological progress. These can complement green growth through innovation stimulation, resource efficiency improvement, and sustainable industrial restructuring. However, the relationship is nuanced. While the majority of the literature proves that digital economy development promotes green economic efficiency, technological innovation, and urban green development [**Zhang and Liu (2015)** **Ozcan and Apergis (2018)** and **Sahoo et al. (2021)**], some literature also reaches the conclusion that digitalization can also exacerbate carbon emissions, especially when driven by economic growth and industrialization [**Salahuddin et al. (2016)**; **Avom et al. (2020)** and **Alataş (2021)**]. The impact is spatially heterogeneous and depends on environmental policies, technological change, and regional development levels.

Based on the subject of present interest, the review of the above-cited studies reveals several gaps. First, a minority of studies have examined the impact of the digital economy on green growth. This is particularly true given that the majority of studies have focused on the influence of the digital economy on economic growth. Additionally, fewer studies tend to observe the effect of institutional regulation on the relationship of the digital economy and the development of the green economy. To fill in the gaps in existing research, our study focuses on progressing current measurement approaches for both the digital economy and the green economy. We also observe that the literature covers limited time periods and uses traditional econometric approaches to explore the relationship between the assumed variables. Therefore, this study tried to fill this gap by using advanced and appropriate econometric approaches for achieving the evidence more comprehensively. The current study formulates the following hypotheses based

on the literature:

H_1 : There is a significant positive linear relationship shows between digitalization (as measured by DESI) and green growth.

H_2 : The digital economy has a positive effect on the improvement of green growth.

3. METHODOLOGIES, DATA SOURCES AND SPECIFICATION TESTS

To investigate the relationship between green growth (GG) and digital economy (DESI), we based our study on the work of Zhang et al. (2022). These two mean variables in our study need to be defined and explained, and how they are measured.

- **Green growth (GG)** is a composite indicator introduced by the OECD. This framework is a system that looks at multiple areas, focusing on four main aspects, to create a way to measure green growth that includes indicators about how well we use resources and the environment, the state of natural resources, the quality of the environment for living, and economic chances and government actions (OECD, 2011).
- **Digital economy (DESI)** or digitalization was measured by the Digital Economy and Society Index (DESI), based on the European Commission (2017) framework and tailored to Saudi Arabia's available data. This indicator is considered in many researches as a suitable variable that characterizes the development level of the digital economy (Neffati and Jbir, 2024). It includes four main dimensions, each weighted equally at 25%: human capital, connectivity, integration of digital technology, and digital public services. The compound indicators consist of ten dimensions, each assigned different weights. They present details in Table 1 in Neffati and Jbir (2024).

To accurately carry out the regression based on the case study's details, we included additional control variables such as institutional quality (IQCC), population growth (POPG), and the country's level of integration into world trade (Trade) in Saudi Arabia; our study provides the following multiple linear regression equation:

$$\text{Green Growth} = f(\text{DESI}, \text{IQCC}, \text{POP}, \text{Trade})$$

This relationship was expressed in a linear function as:

$$GG_t = \alpha_0 + \alpha_1 \text{DESI}_t + \alpha_2 \text{IQCC}_t + \alpha_3 \text{POP}_t + \alpha_4 \text{Trade}_t + \varepsilon_t \quad (1)$$

Where;

- GG; Economy Green Growth Index 2000,
- DESI; it is a digitalization index it measures The Digital Economy and Society Index, it is considered also as a proxy of digital transformation.
- IQCC; Institutional Quality presented by control corruption index
- POP; Population growth
- Trade; Integration of the country to World Trade, and;
- α_0 ; constant, and ; error term.

We employed the set of time series data collected from the World Development Indicator (WDI) in 2023 and OCDE in 2023. The series of data collection that cover 1996 to 2022. Table 1 bellow delineates the principal variables employed in this investigation, together with their definitions and sources. The variables encompass critical economic, environmental, and social issues, such as green growth, digitization, trade integration, corruption mitigation, and population expansion. The data sources include reputable institutes such as the OECD, WDI, and Heritage.org, which provide consistent and dependable analysis.

Table 1. Summary of Variables and data sources

Variables		Definition	Sources
GG	Economy Green growth	Economy Green Growth (Production-based CO2 emissions, index 2000)	OCED
DESI	Digitalization (the Digital Economy and Society Index)	It is a composite index which Includes the following components: 1. Human capital (25%) 2. Connectivity (25%), 3. Integration of digital technology (25%) 4. Digital public services (25%)	World Bonk Database; WDI
Trade	Integration of the country to World Trade	The same of export (E) plus import (M) divided by gross domestic product (GDP)	Calculation from WDI database.
IQCC	Institutional Quality: control corruption	Control corruption is one of the important measures of Institutional Quality.	Heritage.org
POP	Population growth	Population growth rate (annual %)	World Bonk Database; WDI

Source: Authors Preparations

As shown in Table 1, the study uses several important variables, such as population growth (POP), trade openness, institutional quality (IQ), and green growth (GG), all of which are taken from reliable international databases. As used by [Neffati and Khemiri \(2025\)](#), green growth was calculated by combining economic and environmental indicators to assess sustainable development. It includes carbon productivity (GDP per unit of CO₂ emitted), energy intensity (energy use per GDP unit), and the share of renewable energy. Resource productivity and eco-innovation indexes also contribute to evaluating green growth. As for the second compounded variable, the Digital Economy and Society Index (DESI), [Neffati and Jbir \(2024, pp. 17-18\)](#) specifically computed and explained the digitalization variable (DESI) for Saudi Arabia. The Digital Economy and Society Index (DESI) is a suitable choice for this study because Neffati and Jbir consider it a reliable proxy for measuring the development of the digital economy.

Table 2. Descriptive statistic of variables

	<i>GG</i>	<i>DESI</i>	<i>IQCC</i>	<i>TRADE</i>	<i>POP</i>
Mean	153.6563	22.93970	-0.004259	71.48967	2.430519
Median	161.7300	30.82771	-0.021000	68.16645	2.404000
Maximum	226.4900	35.07799	0.357000	96.10263	3.959000
Minimum	80.00000	4.768912	-0.313000	49.71348	-0.130000
Std. Dev.	58.53799	11.27503	0.210687	12.71342	0.923409
Observations	27	27	27	27	27

Source: Author's calculation

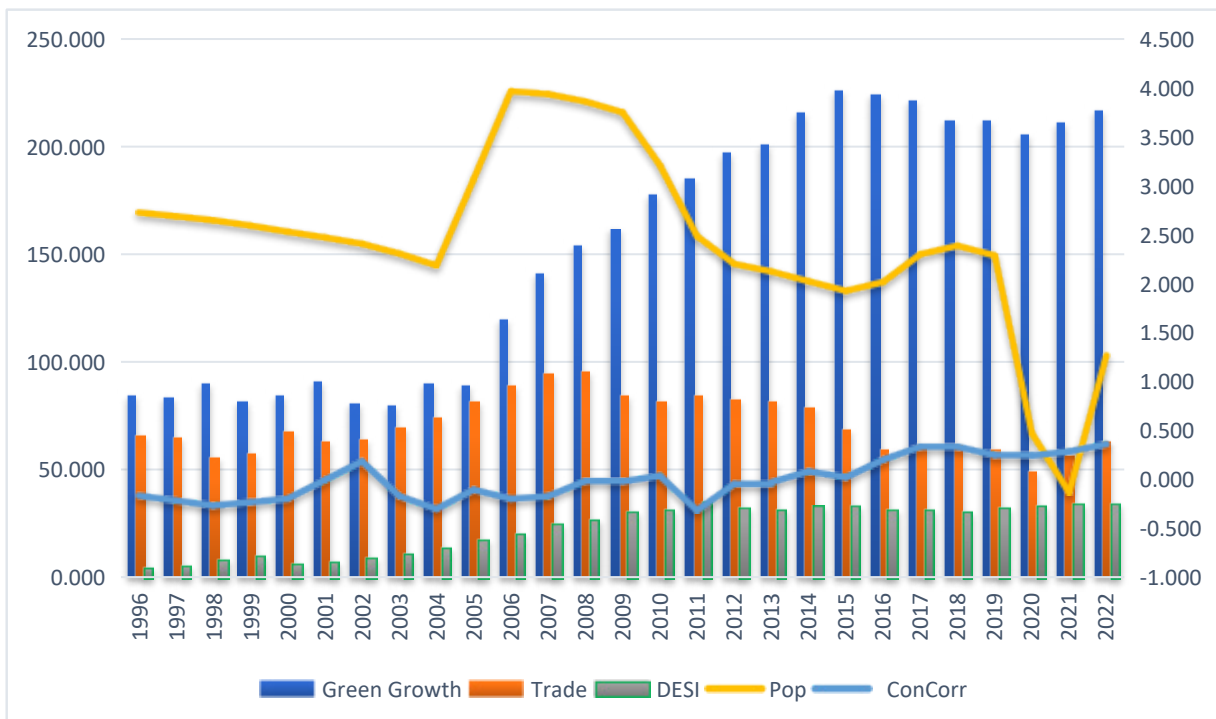
The table provides a snapshot of five variables across 27 observations, indicating their central tendency and variability. The means and medians indicate the overall levels of each variable, and the standard deviations and ranges indicate the level of dispersion. Most variables, such as *GG* and *DESI*, have high variation, suggesting variation by country or period. The skewness of some variables is apparent from the disparity between their means and medians. The control of Corruption is close to zero, showing no significant general direction of correlation. Overall, the

data shows a large spread of values with both symmetrical and skewed distributions, which can have serious implications for subsequent analysis and interpretation.

The graph illustrates the trajectories of five significant variables Green Growth (*GG*), Digitalization (*DESI*), Trade, control of Corruption (*IQCC*), and Population Growth (*POP*)-from 1996 to 2022. Green Growth exhibited a significant upward trajectory, seeing rapid expansion from 2004 to 2014, indicative of enhanced green economic performance and a reduction in CO₂ emissions, followed by a mild decline between 2016 and 2020.

The following Figure 1, present the evolution of Green Growth (*GG*), Digitalization (*DESI*), Trade, Institutional Quality (*IQCC*) represented by Control Corruption (*ConCorr* in figure 1), and Population Growth (*Pop*) in Saudi Arabia from 1996 to 2022.

Figure 1. Saudi Arabia Evolution of Green Growth (GG), Trade, DESI, Pop and ConCorr during 1996-2022



Source: Established by Authors, from data sources defined in 3

Trade integration has experienced fluctuations, rising consistently until 2008, followed by a decline, perhaps attributable to the global financial crisis, and subsequently dropping again around 2018–2020, maybe because to trade conflicts or the COVID-19 pandemic. The Digital Economy and Society Index (*DESI*) has risen consistently, reflecting the ongoing usage of digital technologies. The control of corruption (*ConCorr*) has been very consistent, with low change, which suggests ongoing governance issues. Population growth (*POP*) is seen to be practically stagnant, indicating a low or constant annual growth rate consistent with worldwide demographic patterns. In summary, Green Growth and Digitalization are advancing, Trade has shown volatility, Corruption control remains constant, and Population Growth is stagnant, indicating the fundamental economic and natural progression over time. Before moving to the estimation model, we would check the stationarity of the variables and cointegration relationships to help us choosing the suitable method of estimation.

3. 1. UNIT ROOT TESTS

The outcomes of the unit root test in Table 3 indicate that most of the variables—Green Growth, *DESI*, Trade, and Population—are non-stationary at level because their test statistics are lower than the critical values for significance, which suggests that they possess a unit root. Corruption is stationary at level $I(0)$ based on the ADF and PP tests when a trend is included, suggesting that it does not require differencing for stationarity. Taking the first difference $I(1)$ renders all the variables stationary since the test statistics are significant at the 1%, 5%, or 10% levels. This indicates that all variables except for Corruption are of order one $I(1)$, hence requiring differencing for regression and cointegration testing among other things.

Table 3. Results of Unit Root tests

Variables	Augmented Dickey –Fuller (ADF)			Phillips Perron (PP)			
	Level						
	None	Constant	Constant with trend	None	Constant	Constant with trend	stationarity
<i>GG</i>	1.2167	-0.8379	-1.4347	1.4506	-0.6759	-1.5708	No-Stas
<i>DESI</i>	1.3296	-1.2622	-1.0556	-1.3551	-1.3551	-0.9172	No-Stas
<i>Trade</i>	-0.2978	-1.6284	-1.2215	-0.29718	-1.1610	-1.2215	No-Stas
<i>IQCC</i>	-1.5992	-1.5191	-3.3102	-1.4287	-1.2040	-3.3365	No-Stas
<i>POP</i>	-0.8010	-2.8091	-3.1845	-0.9258	-1.5809	-2.0704	No-Stas
First difference I(1)							
Variables	None	Constant	Constant with trend	None	Constant	Constant with trend	
<i>GG</i>	-2.8901*	-3.4558*	-3.4047***	-2.7830*	-3.4157***	-3.3627***	I(1)
<i>DESI</i>	-4.2126*	-4.8635*	-4.9652*	-3.2147*	-3.9516*	-4.1547**	I(1)
<i>Trade</i>	-3.7214*	-3.6346**	-3.6136**	-3.6642*	-3.5723**	-3.4635***	I(1)
<i>IQCC</i>	-6.0307*	-6.0671*	-5.9712*	-6.9680*	-8.7981*	-10.446*	I(1)
<i>POP</i>	-4.7266*	-4.6411*	-4.5195*	-2.3088**	-8.5148*	-9.8182*	I(1)

Note: 1%, 5% and 10% levels of significance present***and **

Source: Author's calculation

The outcomes of the unit root test in Table 2 indicate that all of the variables; Green Growth, *DESI*, Trade, corruption and Population, are non-stationary at level because their test statistics are lower than the critical values for significance, which suggests that they possess a unit root. Taking the first difference $I(1)$ renders all the variables stationary since the test statistics are significant at the 1% or 5% levels. Even all variables are $I(1)$ and potentially cointegrated we should to Use Johansen Cointegration Test or Engle-Granger Two-Step Method to check for long-run relationships. If cointegration exists, the VAR model is suitable to capture both long-term equilibrium relationships between variables, as well as the short- term dynamics of these relationships. The Vector autoregressions (VARs) are flexible time series models that can capture complex dynamic interrelationships among macroeconomic variables (Giannone et al., 2015).

3. 2. DIAGNOSTIC TEST

Table 4 presents the test results for serial correlation, normality, and heteroscedasticity of the estimated model. The p-value for the serial correlation test is 0.3725, which is greater than 0.05, so we fail to reject the null hypothesis (H_0) and conclude that no serial correlation is significant in the residuals. The VAR Residual Normality Tests (Skewness, Kurtosis and Jarque-Bera) pro-

vides a p-value less than 5% for both Skewness and Jarque-Bera , meaning that the residuals are not normally distributed since we reject rejected H_0 .

Table 4. Diagnostic test statics

	Test –stats	Chi-sq	P-value
Serial correlation		0.8391	0.3725
VAR Residual Normality Tests	Skewness	13.45832	0.0194
	Kurtosis	6.086782	0.2979
	Jarque-Bera	19.54510	0.0339
Heteroscedasticity		0.8759	0.6080

Source: Author`s calculation

Similarly, the heteroscedasticity test provides a p-value of 0.6080, thus we cannot reject H_0 and conclude homoscedasticity, meaning equal variance in residuals. In general, the diagnostic tests indicate that the model is properly specified with no serious econometric issues, and this ensures the validity of the regression estimates.

3. 3. COINTEGRATION TEST AND LAG SELECTION AND ESTIMATION RESULTS

Table 5. Unrestricted Cointegration Rank Test and Lag selection

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.827356	86.87799	69.81889	0.0012
At most 1	0.589872	42.96492	47.85613	0.1334
At most 2	0.350461	20.68278	29.79707	0.3777
At most 3	0.258969	9.895486	15.49471	0.2889
At most 4	0.091633	2.402669	3.841465	0.1211
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.827356	43.91307	33.87687	0.0023
At most 1	0.589872	22.28214	27.58434	0.2062
At most 2	0.350461	10.78730	21.13162	0.6685
At most 3	0.258969	7.492817	14.26460	0.4326
At most 4	0.091633	2.402669	3.841465	0.1211

Source: Author`s calculation

According to Johansen test, there is only one long term cointegration, then the residuals are not normally distributed, so we move on to Bayesian VAR (BVAR) estimation method.

The dataset used in our analysis includes 27 annual observations from 1996 to 2022. As in the case of this study, table 5, one long-term cointegrating relationship between the variables was found after the Johansen cointegration test. Nevertheless, p-values for both skewness and the Jarque-Bera statistic were below the 5% cut off for residual diagnostic tests from the standard VAR model, namely the skewness, kurtosis, and Jarque-Bera tests, table 4. We conclude that one of the fundamental presumptions for trustworthy inference in conventional VAR models is violated when we reject the null hypothesis of normally distributed residuals.

We use the Bayesian Vector Autoregression (BVAR) method in light of these restrictions and

the comparatively small sample size. By incorporating prior distributions into the estimation process, BVAR improves the accuracy of parameter estimates in small samples and lowers the risk of overfitting. Because it enables more robust inference and better out-of-sample forecasting performance, BVAR is especially appropriate when residuals deviate from normality. Furthermore, when variables are cointegrated but non-stationary in levels, BVAR works well for modeling both short-term dynamics and long-term equilibrium relationships. Empirical practice in macroeconomic and financial time series analysis, where researchers frequently rely on Bayesian methods or robust standard deviation, also supports the use of BVAR in contexts with non-normal residuals. (Sims and Zha, 1998).

Earlier studies relied on cross-country regressions or sectoral analyses (e.g., N'dri et al., 2021). This study employs BVAR modelling and cointegration tests for Saudi Arabia-specific dynamics, offering a robust time-series analysis that prior works lacked.

Table 6. Estimation results using Bayesian VAR Estimates (BVAR)

Bayesian VAR Estimates					
Sample (adjusted): 1997 2022					
Included observations: 26 after adjustments					
	GREEN-GROWTH	DESI	CORR	TRADE	POP
<i>GG(-1)</i>	0.926843	-0.010152	0.000463	-0.054285	-0.001440
	(0.06385)	(0.01284)	(0.00094)	(0.03976)	(0.00364)
<i>DESI(-1)</i>	0.401096	0.991380	5.68E-05	0.113604	-0.003045
	(0.32435)	(0.06540)	(0.00477)	(0.20233)	(0.01849)
<i>IQCC(-1)</i>	-2.520404	0.692194	0.907361	0.489616	-0.032446
	(6.12150)	(1.23213)	(0.09094)	(3.82746)	(0.34993)
<i>TRADE(-1)</i>	0.173993	0.022443	0.000115	0.951134	0.002034
	(0.12467)	(0.02510)	(0.00184)	(0.07843)	(0.00713)
<i>POP(-1)</i>	0.344101	0.157807	-0.007071	-0.604861	0.918013
	(1.49087)	(0.30010)	(0.02197)	(0.93252)	(0.08586)
<i>C</i>	-6.281219	0.864415	-0.043760	10.54563	0.286542
	(10.6930)	(2.15077)	(0.15739)	(6.69936)	(0.61089)
R-squared	0.983663	0.973903	0.566070	0.823840	0.670573
Adj. R-squared	0.979579	0.967379	0.457588	0.779800	0.588216
Sum sq. resids	1374.945	77.30964	0.489451	736.0176	7.274060
S.E. equation	8.291397	1.966083	0.156437	6.066373	0.603078
F-statistic	240.8488	149.2749	5.218083	18.70664	8.142293
Mean dependent	156.3065	23.63858	0.001846	71.67566	2.419269
S.D. dependent	58.02186	10.88560	0.212410	12.92768	0.939807

Source: Author's calculation

The results from Table 6 of the Bayesian VAR estimation show that all variables—*GG*, *DESI*, *IQCC*, *TRADE*, and *POP*—are mostly influenced by their own lags, i.e., what happened before is a good predictor of what is happening now. *GG* is highly affected by historical values (coefficient: 0.9268), and the correlation with other variables is weak or even negative, especially for *IQCC* (-1), which has a large negative coefficient (-2.5204), indicating that higher corruption levels may inhibit green growth. *DESI* also shows significant potential to stay constant over time (0.9914), although it has some effect from *GG* and *IQCC*, suggesting that economic digitization, sustainability, and governance relate to each other. *IQCC* is largely auto-dependent (0.9074) but positively related to *DESI* and negatively to *GG*, suggesting that digital develop-

ment may be connected with perceived corruption while green growth may reduce it. *Trade* is primarily influenced by its own previous values (0.9511) and secondarily by *GG* and *IQCC*, showing its own internal momentum and little immediate external influence from the other variables. *POP* is strongly persistent (0.918013), with strong negative influence from *Trade* (-0.6049), showing that trade can exert an influence over population change or slowing population increase. The R-squared values are very high for *GG* (0.9837) and *DESI* (0.9739), indicating that the data matches these models closely, while *IQCC* (0.5661), *Trade* (0.8238), and *POP* (0.6706) explain the data to a moderate extent. Generally, the results show that each of the variables has strong internal correlations and strong significant relationships with other variables, particularly between corruption and sustainability and between trade and population trends.

3. 4. VARIANCE AND HISTORICAL DECOMPOSITION OF GREEN GROWTH USING CHOLESKY FACTORS AND WEIGHTS

By using variance and historical decomposition of green growth using Cholesky weights and factors, researchers and policymakers can find out which underlying determinants affect green growth most over time, focus their investments in the digital economy, anti-corruption reforms, trade policy, or demographic planning, and see how green growth changes in response to real-world events like technological change or key policy changes. We shall break down how variance decomposition and historical decomposition of green growth would be done using observed variables under a BVAR model framework and how Cholesky decomposition comes into play (Table 7 and Figure 2).

Table 7. Variance decomposition of green growth using Cholesky factors

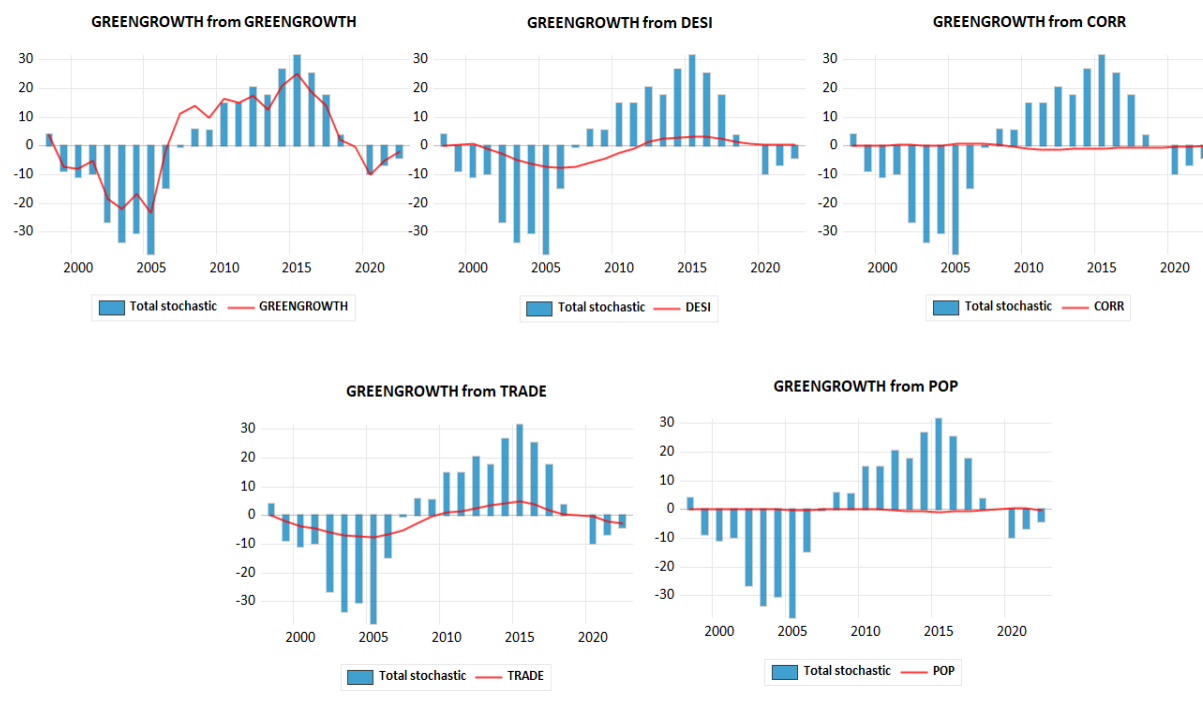
Period	S.E.	GG	DESI	IQCC	TRADE	POP
1	7.519765	100.0000	0.000000	0.000000	0.000000	0.000000
2	10.60191	98.94628	0.363747	0.060941	0.606580	0.022448
3	12.95667	96.30039	1.294185	0.195830	2.144795	0.064797
4	14.95648	92.44234	2.675125	0.362873	4.407461	0.112200
5	16.73671	87.76511	4.379361	0.528857	7.172379	0.154291
6	18.35956	82.61556	6.289130	0.671445	10.23850	0.185364
7	19.85635	77.27803	8.303402	0.778123	13.43705	0.203394
8	21.24364	71.97309	10.33992	0.844336	16.63366	0.208987
9	22.53063	66.86413	12.33421	0.871493	19.72571	0.204450
10	23.72303	62.06697	14.23723	0.865198	22.63753	0.193072
Cholesky One S.D. (d.f. adjusted) Innovations						
Cholesky ordering: GG DESI IQCC TRADE POP						

Source: Author's calculation

The table 7 has the variance decomposition of green growth for a period of 10 by using the Cholesky decomposition in a VAR model. It shows the extent to which green growth forecast error variance (*GG*) is accounted for by its shocks and the shocks of other variables: wealth (*WTH*), the Digital Economy and Society Index (*DESI*), corruption (*IQCC*), trade (*Trade*), and population (*POP*). In the early phase, ordering according to Cholesky signifies that the shocks due to green growth itself explain 100% of its variance. With the progression of time, the variance explained by green growth itself decreases - 100% during period 1 to 62.07% during period 10 - and outside variables start playing a larger role. By period 10, trade is the largest external driver at 22.64%, followed by *DESI* at 14.24%, indicating that trade and digital development increasingly contribute to green growth. Corruption, wealth, and population have minimal contributions, with respective percentages of 0.87%, 0%, and 0.19% by the tenth period. These

findings suggest that augmenting trade openness and investment in the digital economy will tend to be strong mechanisms for underpinning green growth over the long term, while wealth, corruption, and population change have weaker long-run relationships.

Figure 2. Historical Decomposition of green growth using Cholesky Weights



Source: Authors established

Figure 2 illustrates the historical decomposition of green growth with Cholesky weights, indicating the individual contribution of various structural shocks - i.e., the own dynamics of green growth, the Digital Economy and Society Index (*DESI*), *CORR* (most likely corruption or corporate responsibility), trade, and population (*POP*) - from 2000 to 2020. Blue bars represent the stochastic contribution of each factor, and the red lines represent the trajectory of green growth attributed to each variable. The shock panel of green growth recommends a largely negative effect in the decade of the 2000s, followed by an extremely large positive effect until 2015 and a sharp decline thereafter due to the endogenous cyclical nature of green growth. *DESI* recommends a growing positive effect from 2005 to 2015, with the digitalization having a pivotal role in accelerating the green growth during this period, though its effects appear to decline after 2015. Similarly, control of corruption positively contributed from 2005 to 2015, suggesting that good governance or corporate practice assisted in a supporting capacity. Trade was initially negative until around 2005 but was a robust positive driver from then on until 2015, presumably due to the growth of environmentally sustainable trade practices. Population dynamics also reversed from a negative to a positive contribution around the year 2005, peaking at their contribution around the year 2015, apparently due to urbanization or favourable demographic change, before gradually declining thereafter. Overall, between the years 2005 and 2015 was a time when digitalization, governance, trade, and demographic change all came together to foster green growth, and there was a discernible fall in these contributions after the year 2015.

4. FINDINGS AND DISCUSSION

The results strongly confirm both Hypothesis 1 - that digitalization (as measured by DESI) has significantly promote green growth stimulus - and Hypothesis 2 - that the digital economy spurs inclusive green growth, although the latter's confirmation is less direct.

Starting with *Hypothesis 1*, the Bayesian VAR (BVAR) estimates show that DESI is stable over the long term, with a high autoregressive coefficient of 0.9914, meaning it keeps its effect over time. More importantly, green growth (GG) shows a strong positive relationship with itself over time (0.9268), and although the immediate effect of DESI on GG is small, the Cholesky-based variance decomposition provides more useful details. More importantly, green growth (GG) shows a strong positive autocorrelation (0.9268), and although the immediate effect of DESI on GG is small, the Cholesky-based variance decomposition provides more useful insights. In a 10-period forecast, DESI's contribution to the forecast error in green growth increases steadily to 14.24%, making it the second strongest external factor after trade (22.64%). In a 10-period horizon, the contribution of DESI to the variance of forecast errors in green growth rises steadily to 14.24%, making it the second-strongest external driver after trade (22.64%). This result corroborates that digitalization is a rising and significant driver of green growth in the long term.

Historical decomposition (Figure 2) also confirms *Hypothesis 1*. Between 2005 and 2015, *DESI* made a clearly rising positive contribution to green growth, in line with the time when digital transformation began to gain strong momentum globally, particularly in emerging economies. While the effect decreases somewhat after 2015, perhaps due to saturation or the need for policy renewal, the decade boost from *DESI* is a testament to the fact that digitalization has indeed played a crucial role in facilitating green growth.

These findings showing that digitalization (measured via DESI) is a significant long-term determinant of green growth in Saudi Arabia by driving GDP growth, productivity, and macroeconomic performance. These results align with Sabbagh et al., (2012); Katz et al., (2014) and Evangelista et al., (2014). DESI explains 14.24% of green growth variation in the long run, reinforcing the broader macroeconomic benefits highlighted in the literature. Katz et al. (2014) specifically noted that a 10% increase in digitalization correlates with GDP increases ranging from 2.5% to 3.1%, depending on country groups. N'dri et al. (2021) found ICT reduces environmental degradation in lower-income economies. Similarly, Hang (2024) identified synergies between digitalization and green growth, emphasizing structural efficiency and pollution reduction. Noting that the digitalization induces structural transformation and sustainability, aligning with the literature's focus on reduced emissions and industrial efficiency. The role of DESI in driving green growth mirrors the environmental benefits discussed by N'dri et al. (2021).

To *Hypothesis 2*, concerning the contribution of the digital economy to inclusive green growth, evidence is more interpretative but remains consistent. Even though the result is not a direct indicator of inclusivity, BVAR estimation does capture correlations among green growth, *IQCC* (control corruption), and *DESI* (which has to do primarily with institutional effectiveness and fair development). The control corruption is positively correlated with *DESI*, whereas there is a strong negative coefficient (coefficient: -2.520) of *GG*, suggesting that digitalization may reinforce transparency and good governance in breaking exclusivity hurdles by driving inclusive growth. Additionally, past evidence shows that from 2005 to 2015, better digital infrastructure (*DESI*) and less corruption helped promote green growth, along with changes in trade and population that aimed for greater inclusiveness. This combination of impacts suggests an inclusive digital space that fosters more inclusive and sustainable development.

This study addresses literature gaps on governance especially institutional and policy roles in digital-green growth. While prior research (Hang, 2024) proposed integration frameworks,

empirical tests on control corruption mediation were absent. This study bridges that gap by demonstrating empirically that reduced corruption and improved governance as critical mediators, alongside aligned trade and labour policies for digitalization's green potential.

Generally, *Hypothesis 1* has widespread support based on evidence of a clear and rising role for digitalization to power green growth, especially in the medium to long term. *Hypothesis 2* also finds support, though less evidently, through the interaction of how digitalization, governance, and the underlying factors of inclusive growth work together, as represented by the changing interactions and historical breakdowns. The report indicates that promoting the digital economy - while concomitantly addressing governance and demographic shifts - can be a winning formula for bringing about green growth that is both sustained and inclusive.

This study contributes to previous literature by quantifying the importance of digitalization on promoting green growth, rather than merely emphasizing traditional economic growth. It identifies governance as a key mediator in the connection between digitalization and environmental sustainability, emphasizing the necessity of harmonizing Vision 2030's digital transformation agenda with broader sustainability objectives. In contrast to previous research, the study challenges the notion that the benefits of digitalization are consistently distributed over time, highlighting the necessity of institutional reforms to achieve meaningful green outcomes. Saudi Arabia can strategically invest in digital education and green technology to drive sustainable growth and align with Vision 2030. In digital education, expanding high-speed internet, integrating digital literacy in curricula, and partnering with global EdTech companies can modernize learning and equip youth with future-ready skills. Simultaneously, targeting green tech investments - particularly in renewable energy, green hydrogen, and sustainable infrastructure - can diversify the economy and reduce carbon emissions. Government incentives, public-private partnerships, and R&D centres will be essential in fostering innovation in both sectors. Projects like *NEOM* offer ideal platforms to showcase smart, green technologies, while training programs can build a skilled workforce to support these emerging industries. Leveraging the Public Investment Fund and collaborating with international institutions can further accelerate progress. By focusing on these areas, Saudi Arabia positions itself as a regional leader in sustainability and technology, ensuring long-term economic resilience and environmental stewardship.

5. CONCLUSION, POLICY IMPLICATIONS AND LIMITS

This study examined the impact of the digital economy on green growth in Saudi Arabia by testing two key hypotheses: first that digitalization, measured via DESI, significantly enables green growth; and second, that the digital economy enables inclusive green growth using data for the period 1996-2022. Drawing on a rich literature and a strong empirical analysis, the study strongly supports the first hypothesis and offers important, though more interpretative, support for the second. The literature has extensively documented macroeconomic digitalization benefits, in particular that it increases GDP growth, productivity, and innovation. Fewer works, however, have directly associated digital transformation with green environmental sustainability, and fewer yet with green development inclusiveness. Research by [Hang \(2024\)](#), [Kong and Li \(2022\)](#), and [Dong & Ullah \(2023\)](#) shows that more people are interested in how digitalization affects the green economy, focusing on factors like technology improvements, the quality of institutions, and changes in population.

This study builds and extends that literature by applying advanced econometric methods, such as Bayesian VAR and Cholesky-based decompositions, to offer a more nuanced explanation of the digital economy's role in green growth dynamics. The empirical results confirm that DESI is a long-run, stable variable whose significance for green growth is increasing. The variance decomposition analysis shows that by the tenth period, DESI explains 14.24% of green growth

variation—the second-largest external driver, after trade. Historical decomposition also confirms this finding, showing that from 2005 to 2015, DESI had a strong and increasing positive impact on green growth, at the same time as there was a global acceleration of digital transformation. Though this impact decreased somewhat after 2015, the past ten years leave little question that digitalization has made a significant contribution to enhanced environmental sustainability. Support for the second hypothesis—of inclusiveness—is a bit more complicated. The cross-interaction of DESI with control corruption (a governance and equity proxy) shows that digitalization indirectly contributes to inclusive green growth through better transparency and institutional quality. The negative correlation between green growth and corruption, and the positive correlation between digitalization and governance, supports the proposition that the digital economy facilitates economic and environmental, as well as socially inclusive, development. This conclusion is consistent with previous research by [Imansyah et al., \(2023\)](#) and [Ma et al., \(2024\)](#), which stresses the importance of coordinating ICT development with inclusive policy environments to prevent worsening inequality.

In general, the study offers robust empirical evidence that digitalization is a key driver of green growth and a probable enabler of inclusive development. Digital infrastructure, trade openness, institutional quality, and demographic transition all affect the effectiveness of green growth policies collectively. While the benefits of digitalization are evident, making them inclusively accessible requires supportive governance reforms and visionary policy planning. Future efforts should therefore target not only the extension of digital technologies but also the creation of enabling environments where innovation, equity, and sustainability meet.

This study's limitations include its dependence on data from 1996 to 2022, which may not comprehensively reflect long-term or recent advancements in digitalization and green growth, and its utilization of DESI as the principal metric for digitalization, possibly neglecting qualitative dimensions. While sophisticated econometric techniques enhance the analysis, determining definitive causality remains difficult, and unobserved variables may affect the outcomes. Furthermore, the emphasis on Saudi Arabia constrains the applicability of findings to alternative contexts, and the endorsement of the inclusiveness hypothesis is still interpretative rather than definitive, necessitating further investigation into the mechanisms and scope of social inclusiveness. The research does not explore particular policy interventions or consider the possible adverse externalities of digitalization, including digital divides or the environmental consequences of digital infrastructure.

Founding

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