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Extending the Solow Growth Paradigm in Pakistan: The Dynamic Role of Digitalization, Green Investment, and Institutional Quality in Sustainable Economic Growth

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Abstract

Digitalization, environmental transformation, institutional governance, and global integration increasingly shape economic growth in developing economies. This study examines the effects of digital capital, green investment, human and physical capital, Institutional Quality (IQ), and Trade Openness (TO) on Pakistan's economic growth from 2000 to 2024. Grounded in the extended Solow Growth Model, which incorporates digital transformation, environmental investment, and institutional performance alongside traditional growth factors, the study employs the ARDL bounds testing approach and an error-correction model to analyze long-run and short-run dynamics. The long-run ARDL results reveal that TO, digital capital, green investment, and physical capital exert significant negative effects on growth, whereas IQ positively influences growth, and human capital shows a weak positive effect. In the short run, lagged digital capital, IQ, TO, and lagged physical capital significantly enhance growth, while green investment and human capital remain insignificant. The strongly negative and significant ECM coefficient confirms rapid adjustment toward the long-run equilibrium. Granger causality findings further indicate that digital capital, green investment, physical capital, and TO cause economic growth unidirectionally. Overall, the findings highlight the critical roles of IQ, digital readiness, and external sector dynamics in shaping Pakistan's growth trajectory, emphasizing the need for efficient capital allocation, stronger export competitiveness, and better integration of green and digital investments into productive sectors.

Keywords: Institutional quality, Green investment, Digital capital, Economic growth, Granger causality, ARDL, Pakistan.

1 | Introduction

The Solow Growth Model has been the fundamental framework for understanding long-term economic growth since its creation. The Solow paradigm has significantly influenced the theoretical and empirical

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understanding of growth processes by highlighting capital accumulation, labor expansion, and exogenous technical advancement as the primary determinants of production [1]. However, since the model's creation, the world economy has experienced significant structural changes [2]. The definition of sustainable growth has changed due to the emergence of the digital economy, the need for green investment, and the realization that Institutional Quality (IQ) is a key factor in efficiency [3]. These advancements show that, despite its exquisite simplicity, the classic Solow framework falls short of capturing the intricate relationships between technology, the environment, and governance that underlie contemporary growth trajectories [4].

In the twenty-first century, digitalization has emerged as a crucial factor in determining productivity and structural change [5]. The way economies gather information, use resources, and improve efficiency has changed as a result of the integration of digital technology across industries, financial systems, and governance processes [6]. By increasing transparency and lowering transaction costs, digitalization not only fosters innovation but also fortifies institutional capability [7]. Concurrently, a structural shift toward sustainability is marked by the global shift toward green investment [8]. To achieve long-term resilience and mitigate environmental deterioration, investments in low-carbon infrastructure, resource efficiency, and renewable energy are now essential [9]. However, the quality of institutions has a significant impact on how well digitization and green investment promote sustainable growth [10]. While poor governance structures can obstruct the potential benefits of technology and green initiatives, strong institutions foster a climate where these activities convert into actual economic gains [11]. Thus, beyond the traditional Solow assumptions, the relationship between digitalization, green investment, and IQ offers a deeper comprehension of growth mechanisms [12]. The main goal of this study is to explore how the Solow growth model can be expanded to include these three contemporary growth-enhancing dimensions in the context of a developing economy: Digitalization, green investment, and IQ [13]. Pakistan presents an especially strong argument for putting this extended growth paradigm to the test. Despite its substantial potential in digital transformation, renewable energy development, and institutional reform, Pakistan's economic growth has remained volatile and uneven [14]. The country faces persistent structural bottlenecks, including weak institutional frameworks, energy inefficiencies, and low technological adoption, which constrain its capacity to achieve sustainable development [15]. A strategic move toward more equitable and sustainable economic planning is also indicated by Pakistan's Vision 2030 and associated digital and green growth efforts [16]. Yet, the empirical data relating digitization, green investment, and IQ within a cohesive growth model remains scant [17]. In order to advance theoretical understanding and develop workable policy measures that are in line with the Sustainable Development Goals (SDGs), it is imperative that this gap be filled [18].

The rationale for this research lies in the need to bridge the gap between classical growth theory and the realities of contemporary economic transformation in Pakistan. By extending the Solow growth paradigm to integrate digitalization, green investment, and IQ, this study contributes to both the theoretical enrichment of growth models and the empirical understanding of sustainability-oriented economic policies [19]. The findings will provide policymakers with evidence-based insights into how digital and green transitions can be leveraged through institutional reforms to ensure long-term, inclusive, and environmentally responsible growth [20]. Ultimately, this research aspires to redefine the theoretical boundaries of the Solow framework, offering a modernized vision of sustainable growth that aligns with the evolving structure of Pakistan's economy and the broader global development agenda.

This study is important because it expands on the classic Solow economic Model by incorporating contemporary factors into Pakistan's economic framework, such as digitalization, green investment, and IQ. It offers new perspectives on how these elements work together to support inclusive and sustainable economic growth. The study emphasizes how economic development is changing by examining the significance of human and physical capital in addition to newly developing digital and environmental aspects. It aids policymakers in comprehending how productivity may be increased by investments in sustainability and technology. The inclusion of IQ highlights how crucial stability and governance are to attaining long-term growth. The impact of Trade Openness (TO) on innovation and competitiveness is also analyzed. The results provide important direction for developing growth policies that are balanced and in line with the objectives of global sustainability.

Additionally, the study adds to the body of empirical research on developing nations like Pakistan. It closes the gap between modern economic reality and conventional growth theory. All things considered, the report offers a thorough strategy for attaining robust and sustainable growth in Pakistan [21].

Accordingly, this study investigates some research questions. As an endogenous driver of productivity under the extended Solow growth paradigm, digitalization is essential to Pakistan's sustainable economic growth. Through innovation, knowledge development, and digital learning, it converts technological advancement from an external input into an internally generated output [22]. Digital technology integration improves efficiency, lowers transaction costs, and increases total factor productivity in production and services, promoting long-term economic growth [23]. According to, digitalization also improves access to online education and skill development, increases human capital, and allows businesses to innovate, embrace cutting-edge technologies, and become more competitive [24]. Accordingly, the first research question is as follows: (RQ1) How does digitalization contribute to sustainable economic growth in Pakistan when considered as an endogenous driver of productivity within the extended Solow growth framework?

Green investment complements traditional capital accumulation by linking economic growth with environmental sustainability in Pakistan [25]. It channels resources into renewable energy, sustainable infrastructure, and clean technologies that reduce fossil fuel reliance and improve efficiency. These initiatives lower costs, create jobs, and promote innovation while preserving natural resources. By mitigating environmental degradation and climate risks, green investment ensures long-term economic stability. Combined with traditional capital accumulation, it fosters balanced, inclusive, and resilient growth. Ultimately, green investment makes Pakistan's economic progress both sustainable and future-oriented [26]. Therefore, the second core question is as follows: (RQ2) To what extent can green investment complement traditional capital accumulation in fostering long-term economic growth and environmental sustainability in Pakistan?

By guaranteeing sound governance and stable policies, IQ increases the influence of digitization and green investment on sustainable growth [27]. Efficiency, creativity, and investor confidence are all fostered by strong institutions. On the other hand, Pakistan's sustainable development is slowed by poor institutions, which obstruct these beneficial impacts [28]. Accordingly, the question is as follows: (RQ3) How does the relationship between digitization, green investment, and sustainable economic growth in Pakistan get influenced or moderated by IQ?

In light of the above explanations, the primary objectives of this study are to use an extended Solow model to experimentally evaluate how digitalization contributes to long-term economic development and productivity enhancement. Moreover, this study seeks to assess how green investment affects sustainable growth, with an emphasis on how it interacts with capital accumulation and technical advancement. Additionally, we examine how IQ affects how well digitization and green investment contribute to Pakistan's sustainable growth.

2 | Literature Review:

2.1 | Physical Capital, Human Capital, and Economic Growth Nexus

Human and physical capital are widely recognized as key drivers of economic growth, mainly through their roles in improving productivity, innovation, and efficiency. Similarly, Ruth Judson [29] reports that human capital positively and significantly contributes to per capita GDP growth, although with relatively low elasticity. Teles [30] demonstrates that education contributes more strongly to growth when combined with trust and social capital, while Dinda [31] finds that education promotes social trust, which subsequently improves economic growth and income levels. Regarding sustainable growth, Ockwell [32] argues that economic expansion remains closely linked to energy consumption and highlights the importance of cleaner energy transitions. Dias and Tebaldi [33] show that strong structural institutions foster long-run growth through human capital development. More recently, Saha and Das [34] confirm that both human and physical capital positively affect India's growth, although human capital generates stronger and more sustainable long-run effects.

2.2 | Digital capital, Green Investment, and Economic Growth Nexus

Berkhout and Hertin [35] analyze the environmental implications of digital technologies through direct, indirect, and structural channels. Their study shows that digitalization can reduce resource consumption through de-materialization, although these benefits are often offset by rebound effects and increased energy use. Similarly, Fuchs [36] argues that ICTs are not inherently environmentally friendly because increased electronic waste, shorter device lifecycles, and higher energy consumption may outweigh sustainability gains unless supported by effective environmental policies. Shirazi et al. [37] further demonstrate that ICT expansion promotes economic freedom in eleven Islamic Middle Eastern countries, especially when supported by higher education and flexible regulations. Focusing on Pakistan, Nizam et al. [38] find that ICT expansion and energy consumption stimulate short-run growth under the Digital Pakistan initiative, although rising carbon emissions negatively affect long-run sustainability. Ren et al. [39], using data from 282 Chinese cities, report that digital-economy agglomeration enhances inclusive green growth through efficiency gains, technological upgrading, and pollution reduction. More recently, Hung [27] demonstrates that digitalization, financial development, and green investment significantly improve economic sustainability in Vietnam, highlighting the importance of technological innovation and green resource investment for sustainable development.

2.3 | Institutional Quality, Trade Openness, and Economic Growth Nexus

Using a broad cross-country sample, Rodrik, Subramanian, and Trebbi [40] argue that IQ is far more important than geography or trade integration in explaining income disparities. Countries with stronger property rights, effective governance, and the rule of law achieve higher levels of development regardless of geographic location. Similarly, Tabellini [41] highlights that capable and development-oriented states, particularly those observed in East Asia, achieve stronger and more sustainable growth than countries with weak or fragmented institutions. Law & Saini [42] find that stronger institutions, including the rule of law and efficient regulation, significantly promote financial-sector development in emerging economies. Similarly, Giri and Mohapatra [43] conclude that IQ strengthens the positive growth effects of TO in India. More recently, Chhabra et al [44] examine BRICS economies and find that TO and IQ jointly stimulate growth in the short run, whereas weak governance reduces the long-run benefits of openness. Overall, the literature suggests that IQ and TO generally exert favorable effects on economic growth. Accordingly. The conceptual framework of this study is visualized in *Fig. 1*.

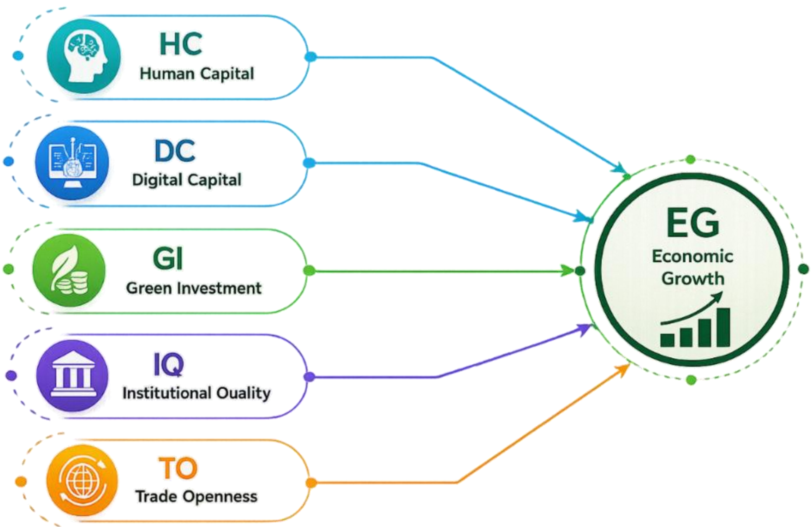

Fig 1. Conceptual framework of the study.

2.4 | Research Gaps

Despite the extensive literature on economic growth, several important gaps remain regarding the integrated roles of digitalization, green investment, IQ, and TO in developing economies such as Pakistan: 1) Most previous studies examine these variables independently within fragmented frameworks, focusing separately on traditional growth determinants, digital transformation, environmental sustainability, or governance quality. Consequently, limited attention has been given to how digital capital, green investment, and IQ jointly interact within a unified extended Solow Growth framework, despite their growing importance in shaping modern production systems, innovation capacity, and sustainable economic transformation, 2) a significant regional gap exists because the majority of empirical evidence is concentrated in developed economies, OECD countries, East Asia, or large emerging economies such as China and India, while South Asian economies, particularly Pakistan, remain largely underexplored. Given Pakistan's unique structural characteristics, including weak institutional performance, uneven digital development, energy inefficiencies, and slow progress toward green transformation, findings from other regions cannot be directly generalized to its economic environment, 3) an inter-temporal gap is evident, as much of the existing growth literature relies on outdated datasets and pre-digital theoretical structures that fail to capture the recent expansion of digital infrastructure, renewable-energy investments, and institutional reforms. As a result, earlier conclusions may no longer adequately explain contemporary growth dynamics in the twenty-first-century economy; and 4) a methodological gap persists because many empirical studies rely on simple linear models, bivariate relationships, or fragmented econometric specifications that overlook the structural complexity and dynamic adjustment mechanisms underlying long-run growth processes. Few studies have theoretically and empirically extended the Solow Growth Model to simultaneously incorporate digital capital, green investment, IQ, and TO within a coherent dynamic framework. Therefore, this study contributes to the literature by addressing these variable, regional, inter-temporal, and methodological gaps through the development of an augmented Solow-based model estimated with modern dynamic econometric techniques for the case of Pakistan.

3 | Theoretical Framework

3.1 | Extending the Solow Growth Paradigm in Pakistan

Traditionally, the Solow Growth Model has been used as a fundamental framework for examining long-term economic growth fueled by labor, physical capital, and technical advancement. However, the traditional causes alone cannot adequately explain the current growth trends in developing economies, particularly in Pakistan. Sustainable economic results are being shaped by a number of key factors, including rapid digital transformation, green development initiatives, institutional reforms, and openness to international markets. By adding these extra factors to the Solow paradigm, the model is able to account for structural shifts in Pakistan's economy, such as increased digitalization, commitments to environmental policies, reforms in governance, and global integration. These factors support long-term sustainable growth, productivity improvement, and technological advancement [45].

3.2 | Standard Solow Model

The classical Solow production function is defined in *Eq. (1)*:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}. \quad (1)$$

This formulation describes output per period as a function of capital stock K_t, labor l_t and A_t technology. Technological progress is treated as exogenous, implying that long-run growth is primarily driven by improvements in A_t. But for Pakistan, where digitalization, green investment, institutions, and openness strongly influence productivity, the traditional specification becomes restrictive [46].

3.3 | Extending the Solow Model

To adapt the model for Pakistan's structural characteristics, the production function is expanded by incorporating Physical capital (K), Human capital (H), Digital capital (D), Green investment (G), IQ, and TO. These factors have been widely acknowledged as growth-augmenting inputs and improve productivity, efficiency, and sustainability [47]. Thus, the extended production function is defined as *Eq. (2)*:

$$Y_t = K_t^{\alpha} H_t^{\beta} D_t^{\Upsilon} G_t^{\delta} IQ_t^{\theta} TO_t^{\lambda} \left(A_t L_t\right)^{1-(\alpha+\beta+\Upsilon+\delta+\theta+\lambda)}. \tag{2}$$

Each additional component influences output via pathways such as technological diffusion, energy efficiency, government stability, and global market access [48].

3.4 | Log-Linearized Empirical Model for Estimation

To estimate the extended Solow model using macroeconomic time-series data, the following log form is used:

$$InY_t = \alpha InK_t + \beta lnH_t + \gamma InD_t + \delta InG_t + \theta InIQ_t + \lambda InTO_t + \varepsilon_t \tag{3}$$

This transformation allows for the direct calculation of output elasticities with respect to each explanatory variable. It also makes the model consistent with normal econometric procedures used in growth regressions.

3.5 | The Final Theoretical Growth Model for Pakistan

By summarizing the extended model, we have *Eq. (4)* as follows:

$$EG_t = f(K_t, H_t, D_t, G_t, IQ_t, TO_t). \tag{4}$$

This formulation combines traditional and modern growth factors, aligning with Pakistan's goals of digital transformation, environmental sustainability, governance reforms, and global integration.

4 | Data and Methodology

4.1 | Data Description

This study expands on the Solow Growth Model by examining modern determinants of Pakistan's long-term economic growth. The dependent variable is economic growth, and the independent variables are physical capital, human capital, digital capital, green investment, IQ, and TO. All variables are measured using established macroeconomic indicators that are compatible with international datasets. This analysis is entirely based on annual country-level macroeconomic data from the World Development Indicators (WDI) database produced by the World Bank [49]. The operational definitions explain how each variable is quantified for empirical modeling in accordance with the extended Solow Growth Framework. Economic growth is defined as the expansion of real economic activity over time and is measured by annual real GDP growth rates. It measures long-term productivity gains and structural changes in the economy.

Physical capital is the accumulation of productive assets such as machinery, infrastructure, and equipment that contribute to increased output. Gross capital formation is widely used as a proxy for GDP. Human capital reflects the knowledge, education, health, and skills of the labor force. It improves labor productivity and innovative capability and is usually quantified using human capital indices or average years of schooling. Digital capital refers to ICT infrastructure such as internet access, mobile penetration, broadband subscriptions, and digital connectivity that improve technological adoption and efficiency. Green investment refers to expenditures and investments that support renewable energy, environmental protection, energy efficiency, and low-carbon development. IQ is measured by governance performance, regulatory efficacy, rule of law, corruption control, and government stability. It is measured using governance indicators offered by international statistics bodies. TO shows the degree of international integration of the economy and is measured by the sum of exports and imports as a percentage of GDP. The data is described in *Table 1*.

Table 1. Variables and sources.

Variable	Symbol	Unit of Measurement	Data Source
Economic growth	EG	Real GDP growth (Annual %)	WDI [50]
Physical capital	PC	Gross capital formation (% of GDP)	WDI [50]
Human capital	HC	Human capital index/education indicators	WDI [50]
Digital capital	DC	Internet users (%), mobile subscriptions, broadband penetration	WDI [50]
Green investment	GI	Renewable energy use (%), environmental investment indicators	WDI [50]
Institutional quality	IQ	Governance indicators (rule of law, regulatory quality, government effectiveness)	WDI [50]
Trade openness	TO	(Exports + imports) % of GDP	WDI [50]

4.2. Methodology

In this study, we use the ARDL approach for evaluating the relationship between our study variables using *Eq. (5)* as follows:

$$\begin{aligned}\Delta EG_t = \alpha_0 &+ \sum\alpha_i\Delta EG_{t-i} + \sum\beta_{t-i}\Delta DC_{t-i} + \sum\Upsilon\Delta GI_{t-i} + \sum\delta\Delta HC_{t-i} + \sum\varphi_i\Delta IQ_{t-i} \\ &+ \sum\theta\Delta PC_{t-i} + \sum\psi\Delta TO_{t-i} \\ &+ \lambda(EG_{t-1} - \beta_1 DC_{t-1} - \beta_2 GI_{t-1} - \beta_3 HC_{t-1} - \beta_4 IQ_{t-1} - \beta_5 PC_{t-1} \\ &- \beta_6 TO_{t-1}) + \varepsilon_t\end{aligned} \tag{5}$$

The integrated ARDL model shows that the short-run dynamics of economic growth are reflected by several variables of digital capital, green investment, human capital, IQ, physical capital, and TO, which reflect immediate adjustments in reaction to shocks. The long-run relationship is represented by the error correction component, which depicts how economic growth returns to equilibrium with its drivers. A negative and significant ECT coefficient confirms long-term cointegration of the variables. This finding indicates that changes in digitization, investment, and openness have an immediate impact on Pakistan's economic growth, but they also tend to stabilize over time. The presence of a long-run equation shows that the growth elements are linked sustainably. Overall, the ARDL findings confirm that both short-run adjustments and long-run equilibrium influence Pakistan's economic growth tendency.

The ARDL Bound Test equation assesses whether there is a long-run cointegrating relationship between economic growth and the explanatory factors. The test examines the joint significance of lagged level factors to see if the variables move together over time. If the estimated F-statistic exceeds the upper critical constraint, cointegration is proven, demonstrating long-term stability of the variables. If it goes below the lower bound, no long-run relationship exists, and values between the two bounds are inconclusive. As a result, the Bound Test is an important step in determining if long-run estimates in the ARDL model are accurate.

The VAR-based Granger Causality/Block Exogeneity Wald test is used in this study to determine the causative relationship between economic growth, digital capital, green investment, human capital, IQ, physical capital, and TO. This causal examination is crucial in the context of Pakistan's growth dynamics as the study aims to integrate digitalization, green investment, IQ, and classical Solow determinants into an extended growth model. The Granger causality analysis identifies several significant directional linkages between the variables in Pakistan's growth framework. Digital capital, green investment, physical capital, and TO all have a substantial impact on economic growth, demonstrating their predictive power for the future. TO appears to be the most sensitive variable, influenced by changes in growth, digitization, green investment, human capital, and physical capital. IQ improves human capital, whereas digital capital helps to improve institutional performance. Other variables have little effect on green investment, which stimulates physical capital formation. Overall, the findings support the extended Solow model, demonstrating that digitization, sustainability, and institutional efficiency are critical drivers of Pakistan's economic success. The impulse response between the variables is as follows: response of economic growth to shocks (see *Eq. (6)*), response of physical capital to shocks (see *Eq. (7)*), response of human capital to shocks (see *Eq. (8)),* response of digital capital to shocks (see *Eq. (9)*), response of green investment to shocks (see *Eq. (10)*), response of IQ to shocks (see *Eq. (11)*), and response of TO to shocks (see *Eq. (12)*).

$$EC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, DC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, GI_{t-i} + \sum_{i=1}^{q} \alpha_{6i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{6}$$

$$PC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, DC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, GI_{t-i} + \sum_{i=1}^{q} \alpha_{6i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{7}$$

$$HC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, DC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, GI_{t-i} + \sum_{i=1}^{q} \alpha_{6i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{8}$$

$$DC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, DC_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, GI_{t-i} + \sum_{i=1}^{q} \alpha_{6i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{9}$$

$$GI_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, GC_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, DC_{t-i} + \sum_{i=1}^{q} \alpha_{6i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{10}$$

$$IQ = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, IQ_{t-i} + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, DC + \sum_{i=1}^{q} \alpha_{6i}\, GI + \sum_{i=1}^{q} \alpha_{7i}\, TO_{t-i} + \varepsilon_t^{EC}, \tag{11}$$

$$TO = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\, TO + \sum_{i=1}^{q} \alpha_{2i}\, EC_{t-i} + \sum_{i=1}^{q} \alpha_{3i}\, PC_{t-i} + \sum_{i=1}^{q} \alpha_{4i}\, HC_{t-i} + \sum_{i=1}^{q} \alpha_{5i}\, DC + \sum_{i=1}^{q} \alpha_{6i}\, GI + \sum_{i=1}^{q} \alpha_{7i}\, IQ + \varepsilon_t^{EC}. \tag{12}$$

Additionally, the Augmented Dickey-Fuller (ADF) test is used to establish the order of variable integration and prevent producing false regression findings.

5 | Results and Discussion

Table 2 shows that EG has a mean value of 1.887 with a maximum value of 5.202 and a minimum value of -3.038 with a standard deviation value of 2.159. The mean values of DC, GI, HC, IQ, PC, and TO are 11.301, 46.064, 0.778, -0.719, 14.052, and 28.451, respectively.

Table 2. Descriptive samples.

	EG	DC	GI	HC	IQ	PC	TO
Mean	1.887	11.301	46.064	0.778	-0.719	14.052	28.451
Median	1.721	8.100	46.600	0.800	-0.688	13.940	28.602
Maximum	5.202	27.375	51.500	0.840	-0.479	16.572	34.348
Minimum	-3.038	1.318	41.600	0.690	-1.049	11.225	21.459
Std. Dev.	2.159	7.588	3.142	0.057	0.132	1.255	3.610
Skewness	-0.306	0.836	0.051	-0.635	-0.543	0.160	-0.120
Kurtosis	2.527	2.708	2.065	1.841	2.970	2.937	1.950
Jarque-Bera	0.623	3.006	0.919	3.081	1.232	0.111	1.208
Probability	0.732	0.222	0.631	0.214	0.540	0.945	0.546

Table 3 shows that, except for physical capital, the remaining variables have an order of integration of 1, while physical capital is level stationary.

Table 3. Unit root test results.

Variables	Level Constant and Trend	First Difference	Decision
EG	-3.621375 (0.0137)	-5.573106 (0.0002)	I(0)
PC	-4.931104 (0.0047)	-4.137811 (0.0042)	I(0)
HC	-1.047197 (0.9166)	-5.452679 (0.0002)	I(1)
DC	0.178823 (0.9926)	-2.695516 (0.0907)	I(1)
GI	-2.599622 (0.2834)	-4.671361 (0.0012)	I(1)
TO	2.152658 (0.4926)	-5.078974 (0.0005)	I(1)

Under the restricted constant and no-trend specification, the long-run estimates show a statistically significant cointegrating relationship between economic growth and the explanatory variables. The results are reported in *Tables 4* and *5*. The significance of the F-statistic in the bounds test confirms cointegration, as the reported value of 30.41 is far above both I(0) and I(1) upper critical bounds at all significance levels, indicating a strong long-run association among the series.

Table 4. Long-run results.

Levels Equation				
Case 2: Restricted Constant and No Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GI	-1.102479	0.424450	-2.597431	0.0266
IQ	12.01569	5.314255	2.261031	0.0582
DC	-0.272859	0.110337	-2.472955	0.0687
HC	10.11481	9.704538	1.042276	0.3561
TO	-0.143080	0.057030	-2.508871	0.0661
PC	-0.885096	0.342770	-2.582186	0.0612
C	25.82883	16.31818	1.582826	0.1886

Table 5. ECM regression results.

Case 2: Restricted Constant and No Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(EG(-1))	0.160718	0.044827	3.585317	0.0231
D(DC)	-0.899443	0.120360	-7.472961	0.0017
D(DC(-1))	2.497181	0.143249	17.43246	0.0001
D(GI)	-0.138951	0.076872	-1.807570	0.1450
D(HC)	1.913048	7.501030	0.255038	0.8113
D(IQ)	9.051405	1.085922	8.335225	0.0011

Table 5. Continued.

Case 2: Restricted Constant and No Trend				
Variable	**Variable**	**Variable**	**Variable**	**Variable**
D(IQ(-1))	2.758962	1.238793	2.227138	0.0899
D(TO)	0.345827	0.054808	6.309798	0.0032
D(TO(-1))	0.094580	0.047426	1.994269	0.1169
D(PC)	-0.015557	0.144927	-0.107346	0.9197
D(PC(-1))	2.481612	0.141468	17.54192	0.0001
CointEq(-1)*	-1.865028	0.072100	-25.86716	0.0000

In the level's equation, green investment has a negative and significant long-run effect, implying that increased investment in environmentally sustainable projects may initially slow growth due to high adjustment and compliance costs. IQ has a relatively strong positive coefficient, implying that better governance, regulatory reforms, transparency, and strong institutional frameworks contribute to improving productivity and maintaining human capital. Human capital positively highlights its potential contribution through skill development, creativity, and knowledge production, whereas insignificance suggests that benefits may take longer to materialize or be dependent on other complementary elements. TO appears negative in the long run, indicating possible import dependence or a lack of export competitiveness, whereas physical capital also exhibits a negative coefficient, which could occur when capital is inefficiently allocated or when economic conditions reduce the marginal impact of capital accumulation.

In short-run dynamics, digital capital exhibits both significant positive and negative effects. The error correction coefficient is negative and highly significant, indicating that deviations from long-run equilibrium are rapidly corrected each period. The magnitude of 1.86 suggests a more than complete adjustment in a single period, resulting in fast convergence back to equilibrium whenever a short-run shock occurs. IQ has a substantial and immediate positive short-run effect, and its lagged importance supports the claim that institutional improvements result in direct productivity spillovers and long-term economic benefits. TO has a favorable short-term impact on GDP, demonstrating that external market exposure, competitive pressures, and foreign sector engagement all contribute to economic activity. The positive lagged impact demonstrates how trade-related gains accumulate over time as domestic enterprises adjust, learn, and integrate into global networks.

Green investment has a minimal short-run impact, implying that environmental spending may not instantly enhance output, most likely due to project maturity and technological transition stages. Human capital stays unimportant in the near run, which could be attributed to systemic flaws in educational quality, skill mismatch, or sluggish productivity change. Physical capital has a negligible short-run contemporaneous effect, but the lag term is highly substantial and positive, indicating that investment-driven expansion takes time to transfer into growth rather than generating immediate results. The positive reaction following a lag emphasizes the necessity of ongoing capital accumulation for long-term output growth.

Taken together, the findings show that technological adoption, institutional reforms, productive investments, and openness to foreign markets all contribute to economic growth in the selected economy, although the benefits vary with time. The findings are consistent with growth theory, which holds that physical and human capital accumulation, technical innovation, and high-quality institutions drive long-term production. In keeping with earlier empirical findings, digital transformation initially disrupts but later increases production efficiency, while institutional strength improves the ability to absorb investment and technology. When properly integrated, trade contributes favorably, whereas green transitions initially stifle growth but eventually assist sustainability-driven expansion. The overall model statistics, including high R-squared and significant coefficients, provide substantial explanatory power and solid short- and long-run links within the growth framework.

Table 6. VAR Granger causality/block exogeneity Wald tests.

Excluded	Chi-sq	df	Prob.
Dependent variable: EG			
DC	8.483064	2	0.0144
GI	10.75097	2	0.0046
HC	0.814532	2	0.6655
IQ	4.586659	2	0.1009
PC	11.36540	2	0.0034
TO	6.135129	2	0.0465
All	56.15143	12	0.0000
Dependent variable: DC			
EG	1.352732	2	0.5085
GI	2.037633	2	0.3610
HC	1.639225	2	0.4406
IQ	1.769698	2	0.4128
PC	0.065161	2	0.9679
TO	12.83855	2	0.0016
All	19.76813	12	0.0716
Dependent variable: GI			
EG	0.743873	2	0.6894
DC	4.693059	2	0.0957
HC	1.058478	2	0.5891
IQ	1.524920	2	0.4665
PC	0.204683	2	0.9027
TO	0.264510	2	0.8761
All	14.85689	12	0.2494
Dependent variable: HC			
EG	0.833490	2	0.6592
DC	2.200342	2	0.3328
GI	0.881591	2	0.6435
IQ	6.075293	2	0.0479
PC	0.932434	2	0.6274
TO	2.834827	2	0.2423
All	15.71982	12	0.2044
Dependent variable: IQ			
EG	3.371381	2	0.1853
DC	10.13309	2	0.0063
GI	0.931766	2	0.6276
HC	0.543655	2	0.7620
PC	1.042093	2	0.5939
TO	1.669586	2	0.4340
All	24.91881	12	0.0152
Dependent variable: PC			
EG	1.260619	2	0.5324
DC	4.921635	2	0.0854
GI	7.613176	2	0.0222
HC	2.097845	2	0.3503
IQ	2.587189	2	0.2743
TO	0.048379	2	0.9761
All	25.74520	12	0.0117
Dependent variable: TO			
EG	7.222672	2	0.0270
DC	7.884449	2	0.0194
GI	20.99891	2	0.0000
HC	14.01386	2	0.0009
IQ	0.438445	2	0.8031
PC	8.203134	2	0.0165
All	66.56646	12	0.0000

The Granger causality results, reported in *Table 6*, show that digital capital, green investment, physical capital, and TO all significantly contribute to economic growth, implying a one-way causal flow. IQ is moderately relevant, while human capital has no causal effect on growth. TO is strongly influenced by economic growth, digital capital, green investment, human capital, and physical capital, indicating a feedback loop in external sector dynamics. TO is the primary driver of digital capital, whereas digital capital influences IQ. Physical capital is highly impacted by green investment, demonstrating policy-driven investment links. Overall, growth is primarily influenced by technological, investment, capital, and trade elements in the system. The main empirical findings of the study are visually summarized in *Fig. 2*.

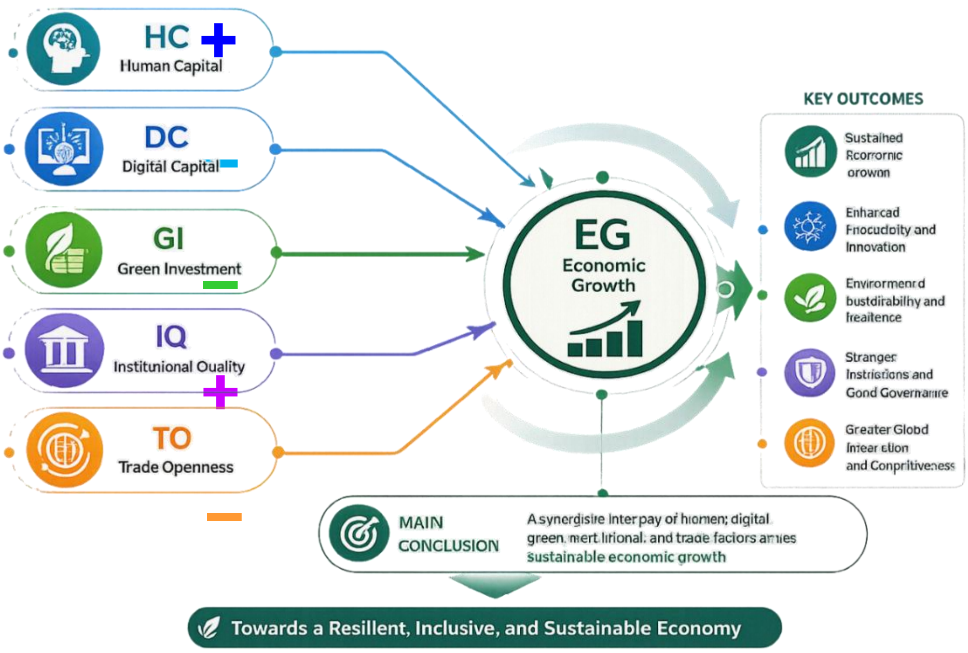

Fig. 2. Graphical summary of the findings.

Table 7. Impulse response.

Period	EG	DC	GI	HC	IQ	PC	TO
1	1.245209	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	(0.18360)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
2	0.104605	0.398261	-1.226852	0.216651	0.139877	0.157467	-0.337165
	(0.44990)	(0.59469)	(0.39325)	(0.25812)	(0.20564)	(0.36183)	(0.14548)
3	0.368915	-0.044250	0.131250	0.262757	-0.168699	-0.483592	0.293750
	(0.54453)	(0.72377)	(0.49039)	(0.35442)	(0.28953)	(0.48836)	(0.20876)
4	-0.675064	-0.299634	1.653182	-0.193076	0.235967	-0.118209	-0.106978
	(0.65382)	(0.73633)	(0.52381)	(0.38823)	(0.27750)	(0.43721)	(0.23821)
5	-1.282032	-0.836172	-0.019180	-0.029427	-0.185302	0.161526	-0.200312
	(0.72623)	(1.09790)	(0.67991)	(0.41720)	(0.40781)	(0.66189)	(0.32450)
6	-0.084708	-0.313582	0.151624	0.015842	-0.198949	-0.531880	0.243459
	(0.78597)	(1.11296)	(0.79787)	(0.37997)	(0.41430)	(0.66687)	(0.33694)
7	-0.024271	0.274564	0.494939	-0.194999	0.175183	0.122804	0.030071
	(0.75945)	(0.92078)	(0.81352)	(0.32906)	(0.35906)	(0.56617)	(0.32193)
8	0.068059	-0.311408	-0.562031	0.128278	0.019198	0.075602	-0.060661
	(0.72369)	(0.78157)	(0.76936)	(0.30036)	(0.30885)	(0.55231)	(0.33568)
9	0.569507	-0.184447	-0.287162	0.015500	-0.056522	-0.128224	0.117723
	(0.70202)	(0.71509)	(0.83281)	(0.32045)	(0.26779)	(0.57140)	(0.32120)
10	0.390767	0.351413	-0.129024	0.002275	0.011142	0.323928	-0.022290
	(0.70029)	(0.66307)	(0.89556)	(0.25816)	(0.23434)	(0.47060)	(0.28657)

The impulse response study demonstrates that an economic growth shock has a substantial immediate positive impact in period one, but the reaction thereafter swings, turning negative in mid-periods before eventually stabilizing. A shock to digital capital and TO has conflicting short-term consequences on growth, moving between positive and negative reactions over time. Green investment shocks are very volatile, with severe negative effects early on and noticeable positive surges later, indicating delayed benefits. IQ and physical capital impulses have tiny, alternating impacts, indicating a poorer transmission into growth dynamics. Overall, economic growth is vulnerable to shocks, resulting in short-term volatility, but tends to converge in later periods.

5 | Conclusion and Policy Recommendations

5.1 | Conclusion

This study looked into the dynamic relationship between Pakistan's economic growth and its primary factors, which included digital capital, green investment, human capital, physical capital, TO, and IQ. This research was motivated by rising digital transformation, increased environmental policy shifts, institutional reforms, and a growing interest in sustainable development. To achieve this goal, the key objectives were to investigate how these determinants affect economic growth in both the short and long run, to test the presence of long-run cointegration across variables, and to assess how quickly the economy returns to equilibrium after shocks.

The Solow Growth Model serves as the study's theoretical framework, explaining growth through capital accumulation, labor, and technical innovation. To address modern growth drivers and sustainability issues, this model was expanded to include digital capital, green investment, and IQ. Human and physical capital served as traditional Solow inputs, whereas TO connected growth to global economic integration. Thus, the theoretical framework influenced the development of hypotheses and informed the empirical model.

The ARDL results demonstrated varied long-term effects. Green investment, digital capital, physical capital, and TO all had a negative impact on long-term economic growth, showing structural inefficiencies, adjustment costs, and a potential lack of technical readiness. IQ had a favorable long-run influence, emphasizing the role of governance on growth progression, whereas human capital was positive but small. In the short run, digital capital (lag), IQ, TO, and physical capital (lag) all had a substantial impact on growth, demonstrating that prompt policy and technological interventions provide speedier results. Green investment and human capital remained small in the near run, indicating that advantages accrue gradually over time. The ECM term was negative and highly significant, indicating strong convergence and rapid correction to the long-run equilibrium. Diagnostic testing confirmed the model's resilience. The F-Bounds test significantly validated variable cointegration, and R-squared and modified R-squared demonstrated the model's outstanding explanatory strength. The Durbin-Watson statistic revealed the absence of significant autocorrelation difficulties. Overall, the findings support the long-term link and robust adjustment dynamics among the variables examined.

5.2 | Policy Recommendations

Based on the ARDL long-run and short-run estimates, this paper makes many policy recommendations to improve Pakistan's sustainable economic growth. Given that IQ has a large beneficial impact on growth, policymakers should prioritize strengthening governance structures, improving regulatory frameworks, decreasing bureaucratic delays, and ensuring openness in public administration. Efficient and responsible institutions will attract investment, boost corporate confidence, and promote long-term growth. The findings indicate that while digital capital has short-term growth potential, its long-term influence is modest or negative, highlighting the need for digital infrastructure expansion, adoption of new ICT technologies, and skill development initiatives. Policies should prioritize improving digital literacy, providing affordable internet access, and encouraging digital-based entrepreneurship so that technology leads to increased productivity and innovation-led growth. Green investment had a negative long-term impact, demonstrating that environmental projects require timely planning and productive deployment. As a result, the government should promote green finance mechanisms, invest in renewable energy technologies, and encourage cleaner industrial practices, while ensuring that environmental rules do not stifle productive sectors throughout the transition period. Incentives for green projects, tax breaks for eco-friendly firms, and research support in low-carbon technology might all help turn environmental investment into future prosperity.

Human capital, while favorable, was insignificant, demonstrating a mismatch between education and economic performance. Policymakers should prioritize the quality of education, technical and vocational training, and curriculum alignment with labor-market demands. Investing in research, innovation, and skill-upgrading programs will boost the workforce's long-term productivity. Physical capital and TO harmed long-term growth, indicating structural inefficiencies. As a result, it is critical to direct capital allocation toward productive sectors, upgrade industries, and promote capital deepening using advanced machinery and technology. Trade policy should attempt to increase export competitiveness by transitioning from low- to high-value commodities, encouraging industrial diversification, reducing import dependency, and obtaining advantageous trade agreements. Streamlining customs procedures and assisting export-oriented SMEs could boost global integration even further. Finally, because the ECM term exhibited rapid convergence toward equilibrium, interventions in the aforementioned areas are expected to result in rapid economic changes. A coordinated plan that includes institutional changes, digital transformation, capital productivity, education advancement, and green transition would be the most effective way to achieve long-term growth.

Although this study contributes to understanding Pakistan's economic growth dynamics, several limitations remain. The analysis relies on annual macroeconomic data, which may not fully capture short-term fluctuations, sectoral differences, or regional disparities. Future studies could incorporate additional variables such as financial development, innovation capacity, environmental quality, labor-market conditions, and consumer behavior to improve explanatory power. Methodologically, while the ARDL framework effectively identifies short- and long-run relationships, advanced approaches such as nonlinear ARDL, structural VAR, or machine-learning techniques may better capture asymmetries and structural breaks. Since the study focuses solely on Pakistan, comparative analyses across South Asian economies and sector-specific investigations would improve generalizability and provide deeper insights into sustainable development pathways.

Authors' Contributions

A. N.: Writing-original draft, Methodology, Data Curation, Conceptualization, Software, and Visualization, and Validation. **K. Z.:** Writing-original draft, Formal Analysis, Investigation, and Writing-Review & Editing. The authors have read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

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Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The authors have given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

The authors confirm that this research did not involve human participants or animal subjects.

References

[1] Lin, J. Y., & Fu, C. (2024). Transformation and upgrading of economic structure is the key to development. *Demystifying the world economic development* (pp. 71–132). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-97-5632-2_3

[2] Vlados, C., & Chatzinikolaou, D. (2024). The emergence of the new globalization: The approach of the evolutionary structural triptych. *Journal of global responsibility*, *16*(1), 139–161. https://doi.org/10.1108/JGR-04-2023-0063

[3] Chen, Z., & Xing, R. (2025). Digital economy, green innovation and high-quality economic development. *International review of economics & finance*, *99*, 104029. https://doi.org/10.1016/j.iref.2025.104029

[4] Michaelides, P. G. (2024). The solow growth model. *21 equations that shaped the world economy: understanding the theory behind the equations* (pp. 185–197). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-76140-9_16

[5] Cook, S., & Rani, U. (2025). Platform work in developing economies: Can digitalisation drive structural transformation? *The Indian journal of labour economics*, *68*(2), 395–416. https://doi.org/10.1007/s41027-024-00541-1

[6] Wang, Z., & Wu, H. (2025). Research on the influence mechanism of digital economy based on neural networks on corporate governance model. *Journal of the knowledge economy*, *16*(2), 10104–10135. https://doi.org/10.1007/s13132-024-02287-z

[7] Kemal, A. A., & Shah, M. H. (2023). Digital innovation in social cash organizations – the effects of the institutional interactions for transforming organizational practices. *Information technology & people*, *37*(5), 2092–2126. https://doi.org/10.1108/ITP-02-2023-0176

[8] Maghyereh, A., Boulanouar, Z., & Essid, L. (2025). The dynamics of green innovation and environmental policy stringency in energy transition investments. *Journal of cleaner production*, *487*, 144649. https://doi.org/10.1016/j.jclepro.2024.144649

[9] Zhou, B., Wu, W., Dong, S., Zhang, X., & Li, J. (2024). Sustainable integration of mineral resources, low carbon transition, and economic resilience in China. *Resources policy*, *98*, 105336. https://doi.org/10.1016/j.resourpol.2024.105336

[10] Yang, C., Qi, H., Jia, L., Wang, Y., & Huang, D. (2024). Impact of digital technologies and financial development on green growth: Role of mineral resources, institutional quality, and human development in South Asia. *Resources policy*, *90*, 104699. https://doi.org/10.1016/j.resourpol.2024.104699

[11] Li, X., & Tong, X. (2024). Fostering green growth in Asian developing economies: The role of good governance in mitigating the resource curse. *Resources policy*, *90*, 104724. https://doi.org/10.1016/j.resourpol.2024.104724

[12] Behera, B., Haldar, A., & Sethi, N. (2024). Investigating the direct and indirect effects of Information and Communication Technology on economic growth in the emerging economies: Role of financial development, foreign direct investment, innovation, and institutional quality. *Information technology for development*, *30*(1), 33–56. https://doi.org/10.1080/02681102.2023.2233463

[13] Gao, J., Hua, G., & Huo, B. (2025). Digital technology, green innovation, and high-quality economic development: mechanism analysis and empirical evidence. *Journal of the knowledge economy*, *16*(3), 12011–12047. https://doi.org/10.1007/s13132-024-02355-4

[14] Ali, N., Butzbach, O. K., Katohar, H. A., & Afridi, H. I. (2024). Structural and external barriers to pakistan's economic growth: Pathways to sustainable development. *World*, *5*(4), 1120–1129. https://doi.org/10.3390/world5040056

[15] Michailidis, M., Zafeiriou, E., Kantartzis, A., Galatsidas, S., & Arabatzis, G. (2025). Governance, energy policy, and sustainable development: Renewable energy infrastructure transition in developing MENA countries. *Energies*, *18*(11), 2759. https://doi.org/10.3390/en18112759

[16] Sohail, H. M., Ullah, M., Tang, C., & Moudud-Ul-Huq, S. (2025). Role of ICT in achieving pakistan sustainable development goals. *Fudan journal of the humanities and social sciences*, *18*(4), 803–829. https://doi.org/10.1007/s40647-024-00436-x

[17] Deng, X., Bakhsh, S., Ali, K., & Anas, M. (2025). How does green investment, financial inclusion, and digitalization drive environmental sustainability in China? A perspective based on quantile-on-quantile regression and wavelet coherence analysis. *Environment, development and sustainability*, *27*(12), 29743–29774. https://doi.org/10.1007/s10668-024-04894-x

[18] Githui, F. K., & Njuru, J. W. (2024). The role of public management in the achievement of sustainable development goals. *International journal of science and business*, *31*(1), 64–75. https://d1wqtxts1xzle7.cloudfront.net/118222486

[19] García-Vidal, G., Loredo-Carballo, N. A., Pérez-Campdesuñer, R., & García-Vidal, G. (2025). Economic convergence analyses in perspective: A bibliometric mapping and its strategic implications (1982–2025). *Economies*, *13*(10), 289. https://doi.org/10.3390/economies13100289

[20] Allam, Z., & Cheshmehzangi, A. (2024). Technological innovation and sustainable transitions. *Sustainable futures and green new deals* (pp. 55–79). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-63642-4_3

[21] Jameel, S., Rasheed, B., & Shaikh, P. A. (2025). Impact of institutional quality on the economic growth of pakistan. *Policy research journal (PRJ)*, *3*(1), 1–11. https://www.researchgate.net/profile/Balach-Rasheed/publication/388045142

[22] Qingran, G., Razi, U., Ramzan, M., Cuicui, D., & Vasa, L. (2025). Digital economy and export complexity: Unveiling its role in transforming china's manufacturing industry. *Environment, development and sustainability*. https://doi.org/10.1007/s10668-025-06742-y

[23] Noah, A., & David, O. (2025). Does ICT adoption moderate the impact of entrepreneurship on economic growth in Africa? *Administrative sciences*, *15*(3), 88. https://doi.org/10.3390/admsci15030088

[24] Hossain, M. B., Rahman, M. U., Čater, T., & Vasa, L. (2024). Determinants of SMEs' strategic entrepreneurial innovative digitalization: Examining the mediation role of human capital. *European journal of innovation management*, *28*(7), 2733–2760. https://doi.org/10.1108/EJIM-02-2024-0176

[25] Zervas, I., & Stiakakis, E. (2024). Economic sustainable development through digital skills acquisition: the role of human resource leadership. *Sustainability*, *16*(17), 7664. https://doi.org/10.3390/su16177664

[26] Song, C., Wu, Z., Dong, R. K., & Dinçer, H. (2023). Greening south Asia: Investing in sustainability and innovation to preserve natural resources and combat environmental pollution. *Resources policy*, *86*, 104239. https://doi.org/10.1016/j.resourpol.2023.104239

[27] Hung, N. T. (2023). Green investment, financial development, digitalization and economic sustainability in Vietnam: Evidence from a quantile-on-quantile regression and wavelet coherence. *Technological forecasting and social change*, *186*, 122185. https://doi.org/10.1016/j.techfore.2022.122185

[28] Muhammad Irfan, Adnan Ahmad, & Syed Mohsin Ali Shah. (2025). Bridging institutional gaps: social entrepreneurship and sustainable development in Pakistan. *Journal of management science research review*, *4*(3), 1483–1520. https://jmsrr.com/index.php/Journal/article/view/153

[29] Judson, R. (2002). Measuring human capital like physical capital: What does it tell us? *bulletin of economic research*, *54*(3), 209–231. https://doi.org/10.1111/1467-8586.00150

[30] Teles, V. K. (2005). The role of human capital in economic growth. *Applied economics letters*, *12*(9), 583–587. https://doi.org/10.1080/13504850500077013

[31] Dinda, S. (2008). Social capital in the creation of human capital and economic growth: A productive consumption approach. *The journal of socio-economics*, *37*(5), 2020–2033. https://doi.org/10.1016/j.socec.2007.06.014

[32] Ockwell, D. G. (2008). Energy and economic growth: Grounding our understanding in physical reality. *Energy Policy*, *36*(12), 4600–4604. https://doi.org/10.1016/j.enpol.2008.09.005

[33] Dias, J., & Tebaldi, E. (2012). Institutions, human capital, and growth: The institutional mechanism. *Structural Change and Economic Dynamics*, *23*(3), 300–312. https://doi.org/10.1016/j.strueco.2012.04.003

[34] Saha, S., & Das, P. (2023). Contribution of human and physical capital to the economic growth in india: post-reform scenario. *Public policies and sustainable development in post-reform India: Regional responses and the way forward* (pp. 267–300). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-3696-0_15

[35] Berkhout, F., & Hertin, J. (2004). De-materialising and re-materialising: Digital technologies and the environment. *Futures*, *36*(8), 903–920. https://doi.org/10.1016/j.futures.2004.01.003

[36] Fuchs, C. (2008). The implications of new information and communication technologies for sustainability. *Environment, Development and Sustainability*, *10*(3), 291–309. https://doi.org/10.1007/s10668-006-9065-0

[37] Shirazi, F., Gholami, R., & Añón Higón, D. (2009). The impact of information and communication technology (ICT), education and regulation on economic freedom in Islamic Middle Eastern countries. *Information & Management*, *46*(8), 426–433. https://doi.org/10.1016/j.im.2009.08.003

[38] Nizam, H. A., Zaman, K., Khan, K. B., Batool, R., Khurshid, M. A., Shoukry, A. M., …, & Gani, S. (2020). Achieving environmental sustainability through information technology: "Digital Pakistan" initiative for green development. *Environmental science and pollution research*, *27*(9), 10011–10026. https://doi.org/10.1007/s11356-020-07683-x

[39] Ren, S., Li, L., Han, Y., Hao, Y., & Wu, H. (2022). The emerging driving force of inclusive green growth: Does digital economy agglomeration work? *Business Strategy and the environment*, *31*(4), 1656–1678. https://doi.org/10.1002/bse.2975

[40] Rodrik, D., Subramanian, A., & Trebbi, F. (2004). Institutions rule: The primacy of institutions over geography and integration in economic development. *Journal of economic growth*, *9*(2), 131–165. https://doi.org/10.1023/B:JOEG.0000031425.72248.85

[41] Tabellini, G. (2005). The role of the state in economic development. *Kyklos*, *58*(2), 283–303. https://doi.org/10.1111/j.0023-5962.2005.00289.x

[42] Law, S. H., & Azman-Saini, W. N. W. (2012). Institutional quality, governance, and financial development. *Economics of Governance*, *13*(3), 217–236. https://doi.org/10.1007/s10101-012-0112-z

[43] Giri, A. K., & Mohapatra, G. (2022). Do institutional quality and trade openness influence economic growth? an empirical evidence from India. *Studies in International Economics and Finance: Essays in Honour of Prof. Bandi Kamaiah* (pp. 165–182). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-16-7062-6_9

[44] Chhabra, M., Giri, A. K., & Kumar, A. (2023). What shapes economic growth in BRICS? Exploring the role of institutional quality and trade openness. *Economic papers: A journal of applied economics and policy*, *42*(4), 347–365. https://doi.org/10.1111/1759-3441.12378

[45] Humayun, T., Li, S., Niazi, G. R., Humayun, S., & Younas, W. (2025). An empirical analysis of Pakistan's economic growth from the perspective of strong sustainability. *Natural resources forum*, *49*(1), 244–273. https://doi.org/10.1111/1477-8947.12369

[46] Ullah, S., Ozturk, I., Majeed, M. T., & Ahmad, W. (2021). Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. *Journal of cleaner production*, *316*, 128239. https://doi.org/10.1016/j.jclepro.2021.128239

[47] Wang, J., Yang, J., & Yang, L. (2023). Do natural resources play a role in economic development? Role of institutional quality, trade openness, and FDI. *Resources Policy*, *81*, 103294. https://doi.org/10.1016/j.resourpol.2023.103294

[48] Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalization and economic growth: A comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications policy*, *44*(2), 101856. https://doi.org/10.1016/j.telpol.2019.101856

[49] World Bank. (2022). *World development report 2022*. https://www.worldbank.org/en/publication/wdr2022

[50] World Bank. (2024). *World Development indicators*. https://databank.worldbank.org/source/world-development-indicators