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New insights into the dynamic impact of sectoral growth on sustainable economic development in Saudi Arabia: Evidence from the autoregressive distributed lag model

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ABSTRACT

Sustainable development (SUD) is an integral part of Vision 2030 introduced by the Kingdom of Saudi Arabia (KSA). However, the contributions of the industrial, agricultural, and service sectors to SUD remain largely unexplored. Accordingly, this research study attempted to explore the contributions of the industrial, agricultural, and service sectors to SUD by focusing on KSA. The paper utilized annual data for the period 1990–2024 and applied autoregressive distributed lag (ARDL) methods to extract results from the specified models. The study's results showed that the industrial, service, and agricultural sectors have improved SUD in the long run. Furthermore, we found that the impact of the industrial sector on SUD is the greatest compared to those of the service and agricultural sectors in the long run. In the short run, the results demonstrated that the impact of the service sector on SUD is more dominant than those of the industrial and agricultural sectors. Moreover, our results underscored that human capital has improved SUD both in the long run and in the short run. Furthermore, the results demonstrated that the inflation rate and the natural resource sector have improved SUD in the short run and deteriorated it in the long run. Moreover, trade openness has improved SUD in the long run and deteriorated it in the short run. Our findings indicate that the strategic alignment of sectoral growth with SUD is crucial for progress toward achieving the SDGs, as well as for achieving the important goals of KSA's Vision 2030.

Contribution/Originality: This research study attempted to examine the relative contribution of industrial, service and agriculture sectors towards SUD, which is an important but under-researched area in the existing body of knowledge. Based on the findings, the study offers valuable suggestions for promoting SUD which are aligned with the Vision 2030 of KSA.

1. INTRODUCTION

Achieving a higher level of sustainable development (SUD, hereafter) has become one of the main policy objectives worldwide in recent years, particularly after the launch of the 17 Sustainable Development Goals (SDGs) by the United Nations (2015). According to the United Nations (1987), the term SUD means "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Generally, SUD goes beyond material well-being and focuses on three main pillars: economic growth, environmental protection, and social well-being. SUD brings enormous benefits, including improvements in development patterns, and further tackles issues linked with the natural resource sector, biological systems, the environment, global warming, and quality of life, as endorsed by Darvishi, Karami, and Goodarzian (2023). Ortiz, Castells, and Sonnemann (2009) opined that SUD positively impacts people's lives and ensures that people enjoy a healthy environment for future generations. The main lesson stemming from the mentioned studies is that SUD is indeed the only way forward for the survival of humans and animals on this planet. Therefore, efforts by policymakers and government authorities are required immediately to improve SUD.

The relationship between sectoral development and SUD has recently received some attention from researchers and policymakers. The agricultural sector generally addresses the problem of food insecurity, provides employment opportunities, and alleviates poverty, specifically in developing economies. However, it is also a fact that the agricultural sector is responsible for significant CO2 emissions and contributes to global warming and climate change, as endorsed by Ali, Khamisa, and ur Rehman (2025). In addition, the agricultural sector is also responsible for water depletion and land degradation. The agricultural sector is the backbone of many developing and emerging economies, and it positively contributes to the attainment of the SDGs.

The industrial sector is one of the main determinants of growth and development, as it is an integral part of the production process. The industrial sector directly contributes to productivity, creates jobs, and further encourages technological progress. Recent research documented that industrialization, which is linked with the growth of manufacturing sectors and technological improvement, contributes positively to SUD (Luan, Tang, Aderemi, & Osabohien, 2025). However, it is an undeniable fact that increased industrialization is responsible for worsening environmental quality, as it generates huge amounts of CO_2 emissions. For instance, the research of Liu and Bae (2018) empirically demonstrated that a 1 percent increase in industrialization is responsible for a 0.3 percent increase in CO2 emissions. In contrast, the study of Yang and Khan (2022) demonstrated quantitatively that both industrialization and capital formation improve SUD. Finally, the service sector also has the potential to impact SUD. Unlike the agricultural and industrial sectors, the service sector is less dependent on resource use, generally promotes the knowledge-based economy, and plays an important role in economic diversification, which ultimately enhances the transition towards SUD.

The Kingdom of Saudi Arabia (KSA, hereafter) launched Vision 2030 to diversify the economy and promote SUD. The objective of Vision 2030 is to lessen dependence on the oil sector, empower citizens, and develop a vibrant environment for local and foreign investors (Saudi Vision, 2030). Developing new sectors and reducing dependence on natural resources are key components of Vision 2030. To achieve the objective of economic diversification, the roles of several sectors, such as the industrial, service, and agricultural sectors, are indeed important. Several reforms have been initiated by KSA in recent years to advance the pace of diversification, focusing on the development of key sectors. However, despite these developments in recent years, the extent to which the industrial, service, and agricultural sectors contribute to SUD has yet to be researched, specifically from the perspective of their short-run and long-run dynamics.

In Figure 1, we have graphed the performance of the industrial, service, and agricultural sectors, as well as SUD, for the period 1990–2024. The purpose of the graph is to provide an overview of sectoral performance and SUD in KSA. Figure 1 indicates an upward trend in the level of SUD "(Adjusted net savings, including particulate emission damage (% of GNI)" in KSA. This means that KSA is moving in the right direction by making significant progress towards SUD. On the other hand, the performance of the service sector "Services, value added (% of GDP)" has also improved in recent years in KSA. In addition, the performance of the agricultural sector "(Agriculture, forestry, and fishing, value added (% of GDP)" remained stagnant during the study period. Finally, the performance of the industrial sector "Industry (including construction), value added (% of GDP)" declined during the study period.

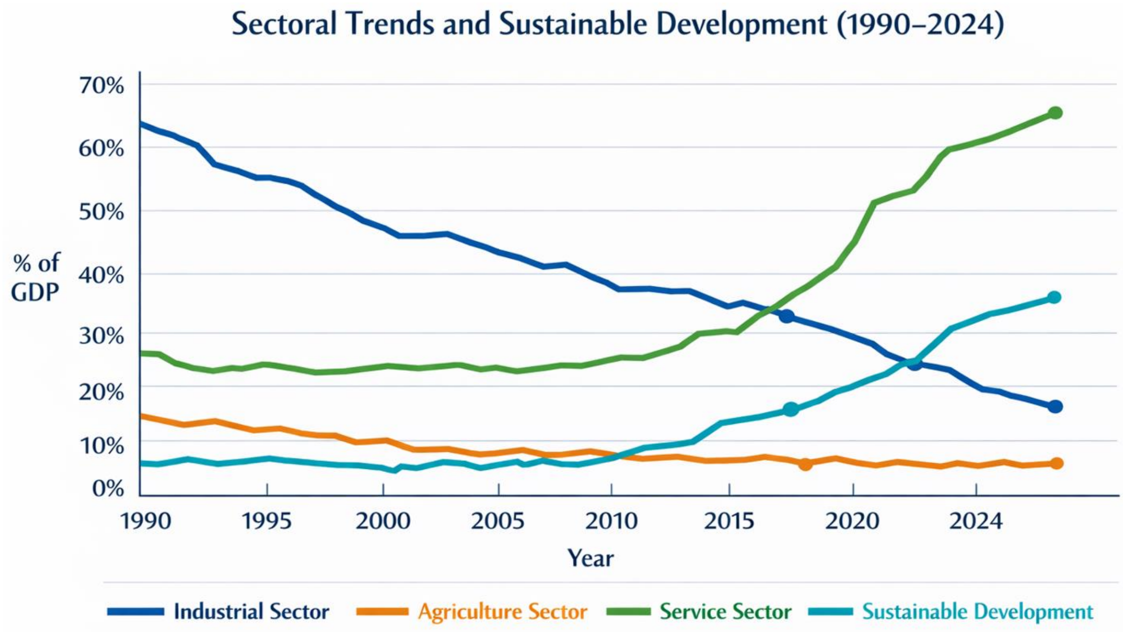

Figure 1. Sectoral Trends and Sustainable Development in KSA.

Some studies have been conducted in the literature to examine the determinants of SUD by focusing on several key sectors. However, the available studies have mainly focused on individual sectors to examine their influence on SUD. For instance, Yang and Khan (2022) highlighted the role of the industrial sector, while Hassoun, Sahed, Adda, and Sebbane (2020) focused on the service sector's contribution to SUD. On the other hand, Haibo, Ayamba, Udimal, Agyemang, and Ruth (2020) focused on the role of the tourism sector in shaping SUD in China. However, a comprehensive study linking the industrial, service, and agricultural sectors to SUD has yet to be conducted in the literature. Secondly, the literature evidence on KSA is not only limited but also fragmented. Both sectoral development and SUD are key objectives specifically outlined in Vision 2030. Therefore, this study attempts to evaluate the specific and explicit impacts of the industrial, service, and agricultural sectors on SUD in both the long and short run.

Amid this backdrop associated with the existing body of knowledge, this research paper attempts to examine the explicit impacts of the industrial, service, and agricultural sectors on SUD, which is interesting but a less explored research area in the available literature. More specifically, the study focuses on KSA to examine the role of sectoral output in SUD in both the long run and the short run, which is aligned with Vision 2030. In addition, this study aims to compare the relative importance of each sector from the perspective of SUD over both long-run and short-run horizons. Finally, our study will offer valuable policy suggestions based on the relevant results for the consideration of policymakers and government authorities in KSA. To achieve the aforementioned research objectives, the study will utilize suitable econometric techniques that produce both long- and short-run dynamics and further accommodate potential endogeneity and multicollinearity issues.

The research study attempts to enrich the existing strand of literature in several ways. Firstly, the sectoral determinants of SUD are rarely researched in the existing body of literature. Secondly, the present study enriches the literature contextually by focusing on the resource-abundant economy of Saudi Arabia, where both economic diversification and SUD have been major policy issues in recent years, specifically after the launch of Vision 2030. Thirdly, it adds to the literature by focusing on both the long-run impacts and the short-run dynamics through the application of advanced time-series cointegration methodology. Hence, determining the relevant contributions of important sectors, such as the industrial, service, and agricultural sectors, will help policymakers formulate appropriate policies to accelerate SUD. Lastly, based on the study's outcomes, the study provides important policy suggestions for aligning sectoral growth policies with SUD, consistent with Vision 2030.

The remaining part of this article consists of several interconnected sections. The study provides a detailed literature review in Section Two. In the third section, the study focuses on model specification and variable descriptions. The penultimate section of the study reports and discusses the results. The final section of the study presents summary remarks on the main findings, offers policy implications for authorities and policymakers, highlights the unavoidable limitations, and finally suggests some avenues for future research.

2. LITERATURE REVIEW

2.1. Theoretical Literature Review

The pursuit of a higher level of SUD has drawn sufficient attention worldwide, particularly after the Industrial Revolution. Several benefits are associated with an enhanced level of SUD, including better economic performance, improved environmental quality, and a better quality of life. The SDGs are closely aligned with SUD. SUD is a preferred development model over conventional economic performance, as it ensures improved environmental quality, which is important for the survival of humans on this planet. Policymakers and government authorities worldwide have taken several steps to increase the pace of SUD. In this regard, the roles of different important sectors, such as the industrial, service, and agricultural sectors, need to be highlighted, as they have played important roles in conventional models of economic performance. The Environmental Kuznets Curve (EKC, hereafter) is an important theory that supports the role of the industrial sector in shaping the level of SUD (Kuznets, 1955). At the initial stages of industrialization, economies degrade the environment through rapid and unplanned industrialization activities. In other words, industrialization is responsible for the poor performance of economies on the path to SUD initially. However, after reaching the threshold level, the process of industrialization improves environmental quality through the use of advanced technologies and more rational behavior towards the environment, which ultimately enhances the pace of SUD. Put differently, there is an inverted U-shaped relationship between industrialization and the level of SUD. Therefore, it is important for policymakers to understand the true impacts of industrialization on SUD in order to formulate suitable policies.

The endogenous growth theory could also be used to explain the potential impacts of different sectors on SUD (Romer, 1990, 1994). Technological innovations, knowledge spillovers, and improvements in human capital are key factors in promoting economic performance, which ultimately translates into SUD across economies. The industrial sector promotes technological innovations, the service sector creates a knowledge-based economy, while the agricultural sector adopts advanced technologies. Taken together, improvements in these sectors have a positive impact on the overall level of SUD. Therefore, economies need to pay significant attention to developing new sectors in order to accelerate the pace of SUD. More importantly, the issue of sectoral development is relevant for KSA, where economic diversification is the main challenge for policymakers.

The structural transformation theory predominantly supports the relationship between sectoral factors and SUD. Samaniego and Sun (2016) endorsed the view that SUD is essentially a combination of economic performance and economic restructuring. Therefore, structural transformation appears to be an important mechanism explaining how sectoral factors shape the process of SUD. The process of SUD responds positively when economies shift from the low-performing agricultural sector towards the high-performing industrial and service sectors. In other words, structural transformation generally promotes the process of SUD mainly through the generation of employment opportunities, increased efficiency, and higher income levels. The research of Samaniego and Sun (2016) demonstrated that economies experience productivity growth after embracing structural transformation. However, it is imperative to mention that the impacts of sectors on SUD may vary. For instance, advancement in the agricultural sector helps economies overcome the problem of food insecurity and generates employment opportunities for the rural population, which ultimately improves income and welfare. Similarly, an improved service sector also contributes to SUD by helping economies develop a knowledge-based economy through digitalization, creativity, and innovation. In other words, progress in the service sector is an essential part of the smooth transformation towards SUD. Likewise, the industrial sector is no less important from the perspective of improving SUD. A developed industrial sector is generally considered more productive than other sectors of the economy, and it brings numerous benefits in the form of increased employment, productivity, technological advancement, and infrastructure. It can be concluded that all three sectors generally shape the pace of SUD through employment generation, technological advancement, efficiency, knowledge creation, infrastructure development, and food security. However, empirical investigation is needed to determine the true impacts of the industrial, service, and agricultural sectors on SUD. Therefore, this study attempts to explore the true and explicit impacts of the industrial, service, and agricultural sectors on SUD in both the long- and short-run horizons, using the ARDL methodology and data from KSA covering the period from 1990 to 2024.

2.2. Empirical Literature

During the last couple of decades, the research literature on the determinants of SUD has expanded significantly. Koirala and Pradhan (2020) researched the factors of SUD using panel data from 12 Asian economies. The study's findings showed that income and financial development play positive roles in shaping SUD. Moreover, the research of Ali, Xiangyu, and Radulescu (2025) found that SUD responds negatively to persistent unemployment and income, and positively to increased human development. Finally, Pardi, Salleh, and Nawi (2015) highlighted the positive impact of financial development on SUD.

Some studies have focused on the role of the industrial sector in shaping the pace of SUD. For instance, the study by Fang (2023) focused on the Chinese economy to examine the roles of industrialization, green technology, and economic complexity in SUD using the two-step GMM estimation. The study's findings demonstrated that economic complexity, renewable energy, and industrialization are essential factors in facilitating SUD, as they are linked with reductions in CO_2 emissions. Industrialization and its structural transformation are important for sustaining economic performance (Alcorta, 2015). In contrast, using data from Bangladesh, Raihan et al. (2022) found that SUD responded negatively to increased urbanization and industrialization, while responding positively to renewable energy use, forest area, and technological innovations. In addition, the research of Udemba and Keleş (2022) focused on data from the Turkish economy to assess the roles of industrialization, urbanization, and FDI in shaping SUD. Their results demonstrated the adverse impacts of industrialization and urbanization on SUD owing to increased CO2 emissions. These contrasting results regarding the impact of industrialization on SUD call for additional research.

Similarly, the service sector can also shape the pace of SUD in economies. The service sector generally supports the transformation towards SUD due to its relatively lower energy requirements. Through digitalization and innovation, the service sector may actually contribute positively to SUD. Haqnazarova and Numanovna (2025) pointed out that the role of services is important in the transformation towards SUD. The study by Antony (2025) analyzed data from the Indian economy and demonstrated the positive impact of the service sector on SUD. However, recent research has also demonstrated the adverse impacts of the service sector from the perspective of SUD. For instance, the study by Ehigiamusoe, Lee, and Lean (2025) found that service sector development is responsible for poor environmental quality. The study further confirmed that government expenditures are effective in mitigating the adverse consequences of the service sector for SUD. Generally, the lesson from the literature is that the service sector contributes to the growth process, but its environmental consequences, including those for SUD, are ambiguous.

Moreover, some studies have attempted to identify the role of the agricultural sector in shaping the level of SUD across countries. The recent research by Atapattu, Ranasinghe, Nuwarapaksha, Udumann, and Dissanayaka (2024) also supports the positive consequences of the sustainable agriculture sector for SUD. Quoc and Le Quoc (2025) also demonstrated the positive impact of the service sector on economic growth. In summary, the specific role of the service sector in SUD has not been extensively researched in the available literature. In other words, establishing a relationship between the agricultural sector and SUD is an under-researched but indeed important research area in the literature.

Several studies are available on the determinants of SUD in KSA. Omri, Euchi, Hasaballah, and Al-Tit (2019) used data from KSA to examine the determinants of SUD. Their results demonstrated the presence of the EKC hypothesis and further found that trade, FDI, and GDP are harmful to environmental sustainability. Similarly, Hamdi, Touati, and Alsharif (2024) demonstrated the importance of the tourism sector in shaping SUD in KSA. On the other hand, Tahir, Hayat, and Burki (2022) found that income level, urbanization, and the natural resources sector have degraded environmental quality and worsened the pace of SUD in KSA. Finally, the study of Albassam (2021) highlighted the role of institutional factors in promoting SUD in KSA. However, the specific role of sectoral factors in shaping SUD has yet to be researched in the KSA economy.

This brief review of the literature has highlighted the scarcity of research on the impacts of the industrial, service, and agricultural sectors on the pace of SUD. More specifically, the linkages between the industrial, service, and agricultural sectors and SUD have yet to be researched in the KSA. While economic diversification through the development of new sectors and the promotion of long-run SUD are key pillars of the Kingdom's Vision 2030, research on these sectoral contributions remains limited. Therefore, to enrich the literature by addressing the aforementioned research gaps, this study attempts to determine the roles of the industrial, service, and agricultural sectors in SUD in both the long and short run.

3. ECONOMETRIC MODELING AND ESTIMATION STRATEGY

3.1. Model Specification

To quantify the contribution of the industrial, service, and agricultural sectors to SUD, the study attempts to design a suitable econometric model in this section. SUD is the dependent variable, while the contributions of the industrial, service, and agricultural sectors are the key independent variables. However, according to previous research studies, SUD responds to several factors in one way or another (Belloumi & Alshehry, 2020; Chen, Sun, Xu, & Xu, 2025; Xu et al., 2020). Therefore, the role of trade openness should be considered when modeling the determinants of SUD. Moreover, ample evidence indicates that human capital contributes to advancing SUD (Omelchuk, Vatras, Podra, & Savenko, 2020; Spirin, Grishaeva, Matantseva, & Tkacheva, 2021). In addition, some studies have highlighted the role of the inflation rate in shaping the pace of SUD (Abouzeed & Abubakr, 2025; Li, Wang, & Qin, 2024). Finally, the role of natural resources in promoting SUD is particularly important in a resource-rich economy such as KSA (Omri & Omri, 2025; Yang, Yuan, & Yi, 2022). The study begins the development of model using the following functional form as represented by Equation 1.

$$\mathrm{SUD} = \mathrm{F}(\mathrm{INDS}^{a}, \mathrm{SER}^{b}, \mathrm{AGR}^{c}, \mathrm{EDU}^{d}, \mathrm{TRD}^{e}, \mathrm{NRS}^{f}, \mathrm{INF}^{g}) \quad (1)$$

The functional form presented above indicates that SUD in KSA is a function of the industrial, service, and agricultural sectors, human capital, openness to global trade, and the contribution of natural resources. In the next step of model design, we use the traditional logarithmic transformation to express the coefficients as elasticities and accommodate likely nonlinearity. Hence, the function presented earlier is transformed into Model 2, as shown in Equation 2.

$$\mathrm{SUD}_t = \beta_0 + \beta_1\mathrm{INDS}_t + \beta_2\mathrm{SER}_t + \beta_3\mathrm{AGR}_t + \beta_4\mathrm{EDU}_t + \beta_5\mathrm{TRD}_t + \beta_6\mathrm{NRS}_t + \beta_7\mathrm{INF}_t + \varepsilon_{it} \quad (2)$$

Model-2 is the modified version specified for estimation purposes. In Model-2, the dependent variable, SUD, is approximated. The independent variables include the contributions of the industrial, service, and agricultural sectors. In addition, Model-2 also includes education, trade openness, natural resources, and the inflation rate. In Table 1, the study reports complete information on variable operationalization and data sources.

Table 1. Description of variables.

Variables	Construction	Sources of Data
SUD_t	Adjusted net savings, including particulate emission damage (% of GNI)	*WDI
$INDS_t$	Industry, value added (% of GDP)	WDI
AGR_t	Agriculture, forestry, and fishing, value added (% of GDP)	WDI
SER_t	Services, value added (% of GDP)	WDI
EDU_t	Secondary School enrollment (% gross)	WDI
TRD_t	Trade (% of GDP)	WDI
NRS_t	Natural resources rents (% of GDP)	WDI
INF_t	The growth of consumer price index	WDI

Note: WDI*: World Development Indicators.

3.2. Estimation Techniques

The data gathered for selected variables concerning the economy of KSA constitutes a time-series structure. One of the main problems researchers face when modeling time-series data is the unit-root problem (Tahir et al., 2022). The presence of the unit-root problem is undesirable because it does not permit the use of Ordinary Least Squares (OLS). Hence, time-series data pose several challenges in the estimation process. In the presence of the unit-root problem, it is recommended that the methodology of cointegration be adopted. Cointegration analysis is specifically designed for variables suffering from the unit-root problem.

Three main cointegration techniques have been developed over the years to address the issue of unit roots associated with time-series variables. The Engle and Granger (1987) cointegration technique is designed to accommodate two variables with unit roots. Similarly, the Johansen (1988) test is designed to accommodate more than two variables suffering from the unit-root problem. Both tests require all variables to be integrated of the same order, one. However, sometimes the order of integration of the variables may not be uniform. To handle variables of different orders, Pesaran, Shin, and Smith (2001) developed the "Autoregressive Distributed Lag (ARDL)," an alternative cointegration technique that can accommodate variables despite differences in their orders of integration. More specifically, ARDL modeling does not require pre-testing for unit roots because it can handle variables with different orders of integration. Finally, the use of ARDL is also preferred when the number of observations is small.

3.3. ARDL Model Designing

In this section, the study aims to convert the specified Equation 2 into the ARDL framework. The ARDL framework requires all variables to be treated as dependent variables, one at a time. Model 2 is rewritten using the ARDL framework, with each variable used as the dependent variable sequentially. Equations 3-10 are basically the ARDL representation based on Equation 2.

$$\Delta SUD_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta SUD_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta INDS_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta SER_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (3)$$

$$\Delta INDS_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta INDS_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta SER_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (4)$$

$$\Delta SER_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta SER_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (5)$$

$$\Delta AGR_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta AGR_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (6)$$

$$\Delta EDU_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta EDU_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (7)$$

$$\Delta TRD_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta TRD_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (8)$$

$$\Delta NRS_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta NRS_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta TRD_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (9)$$

$$\Delta INF_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta INF_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta TRD_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta NRS_{t-i} + \pi_1 SUD_{t-1} + \pi_2 INDS_{t-1} + \pi_3 SER_{t-1} + \pi_4 AGR_{t-1} + \pi_5 EDU_{t-1} + \pi_6 TRD_{t-1} + \pi_7 NRS_{t-1} + \pi_8 INF_{t-1} + U_t \quad (10)$$

The models presented above (3–10) include both the long-run $(\pi_1 - \pi_8)$ and short-run coefficients $(\beta_1 - \beta_8)$. In the ARDL framework, the assessment of the cointegration relationship among the selected variables is usually conducted with the help of an F-test. The F-test value from the ARDL output should be compared with the values developed by Narayan (2004). Three potential outcomes are possible. In scenario 1, researchers accept cointegration if the F-test value exceeds the upper critical value. In scenario 2, if the F-test value does not exceed the lower critical value, the absence of cointegration is accepted. In the final scenario, the evidence of cointegration is ambiguous if the F-test exceeds the lower limit but does not cross the upper critical value. For simplicity, two hypotheses, namely the null and alternative hypotheses, have been used in prior studies to assess cointegration among the variables. The null hypothesis assumes no cointegration, whereas the alternative hypothesis rejects the absence of cointegration.

The next step after confirming cointegration is to identify the speed of adjustment at which short-run disequilibrium can be corrected. For this purpose, the recommended procedure is to develop and estimate an error correction model (ECM). In addition to measuring the speed of adjustment, the ECM is also effective in providing precise information about short-run dynamics. Equations 11-18 are the ECM models that are designed to capture short-run dynamics and speed of adjustment.

$$\Delta SUD_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta SUD_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta INDS_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta SER_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (11)$$

$$\Delta INDS_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta INDS_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta SER_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (12)$$

$$\Delta SER_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta SER_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta AGR_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (13)$$

$$\Delta AGR_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta AGR_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta EDU_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (14)$$

$$\Delta EDU_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta EDU_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta TRD_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (15)$$

$$\Delta TRD_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta TRD_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta NRS_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (16)$$

$$\Delta NRS_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta NRS_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta TRD_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta INF_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (17)$$

$$\Delta INF_t = \beta_0 + \sum_{i=1}^{n1}\beta_{1i}\Delta INF_{t-i} + \sum_{i=0}^{n2}\beta_{2i}\Delta SUD_{t-i} + \sum_{i=0}^{n3}\beta_{3i}\Delta INDS_{t-i} + \sum_{i=0}^{n4}\beta_{4i}\Delta SER_{t-i} + \sum_{i=0}^{n5}\beta_{5i}\Delta AGR_{t-i} + \sum_{i=0}^{n6}\beta_{6i}\Delta EDU_{t-i} + \sum_{i=0}^{n7}\beta_{7i}\Delta TRD_{t-i} + \sum_{i=0}^{n8}\beta_{8i}\Delta NRS_{t-i} + \pi_1 ECT_{t-1} + U_t \quad (18)$$

In the ECM models (11-18), the term $(\pi_1 ECT_{t-1})$ measures the speed of adjustment. Normally, the coefficient of the ECT should be negative and statistically significant $(\pi_1 < 0)$. All other variables are explained in earlier specifications.

4. RESULTS AND INTERPRETATIONS

4.1. Descriptive Findings of Selected Variables

In Table 2, descriptive statistics are presented. According to the statistics, the SUD has an average value of 14.552, while its standard deviation is 10.991. The KSA experienced its highest SUD value (31.686) in 2011 and its lowest value (-8.623) in 1991. This indicates that SUD increased in KSA from 1991 to 2011. However, recent data indicate a downward trend in SUD in KSA.

The statistics of the agricultural sector indicate that its average contribution to the GDP of KSA was 3.760 during the study period, with a standard deviation of 1.479. The contribution of the agricultural sector reached its highest level (6.140) in 1998. In contrast, its lowest contribution to GDP (2.026) was recorded in 2011. Since 2011, the agricultural sector has made some progress, and its contribution to GDP reached 2.535 percent in 2024.

Similarly, the descriptive analysis showed that the industrial sector contributed approximately 51.748 percent to the GDP of KSA, on average. The contribution of the industrial sector reached its highest level (66.429 percent) in 2008. In contrast, the contribution of the industrial sector declined continuously, reaching its lowest level (38.000 percent) in 2020. However, according to recent statistics from 2024, the contribution of the industrial sector reached 44.934 percent. Industrialization is indeed an important factor in the overall growth performance of KSA. Given the economic and resource structure of KSA, the process of industrialization must be accelerated, as it will help achieve economic diversification. Economic diversification is one of the main rationales for policy choices in resource-abundant economies, including KSA.

The contribution of the service sector remained, on average, 42.713 percent of GDP. According to the demonstrated statistics, the contribution of the service sector to GDP reached its peak level of 54.587 percent in 2020 and its lowest level of 30.511 percent in 2008. After 2008, the service sector progressed well in terms of its contribution to GDP. Recent statistics from 2024 demonstrate that the contribution of the service sector to the GDP of KSA is slightly above 47 percent. Overall, the indicators of the service sector reflect that it has grown significantly in KSA.

Moreover, the statistics indicated that natural resources contributed approximately 34.340 percent to the economy of KSA, while their standard deviation was 10.448. KSA experienced the highest contribution from natural resources (55.024) in 2008. Likewise, the lowest value for natural resources (17.318) occurred in 2020. Over the years, KSA has taken a keen interest in the process of economic transformation. Hence, the observed decline in natural-resource rents could be explained by economic diversification. This means that the contributions of other sectors to the economy of KSA have increased in recent years.

Furthermore, the trade statistics indicated that KSA had implemented relatively open trade policies over the years. The mean value of trade openness was slightly above 69 percent during the study period. The economy of KSA experienced its highest value of trade openness (96.102) in 2008. Since 2008, a declining trend has been observed in trade openness. Current statistics indicate that the value of trade openness is 54.678 percent, which is still higher than that of developing and emerging economies. Overall, the trade statistics are reasonable and, hence, could be responsible for KSA's observed better economic performance.

Finally, the inflation statistics demonstrated the better economic management achieved by KSA. The average inflation rate in KSA was 2.007 percent between 1990 and 2024. The highest inflation rate (9.870) occurred in KSA in 2009, whereas the lowest inflation rate (deflation) was experienced in 1999. The statistics for 2024 indicated that inflation in KSA reached 1.687. Overall, inflation remained very stable in KSA, reflecting better management of policymakers. Lastly, the education statistics showed that the average gross enrollment rate at the secondary level was 94.067. The highest enrollment occurred in 2022, while the lowest occurred in 1990. This means that education improved consistently in KSA during the study period.

Table 2. Descriptive results.

Descriptive statistics	SUD_t	AGR_t	$INDS_t$	SER_t	NRS_t	TRD_t	INF_t	EDU_t
Mean	14.552	3.760	51.748	42.713	34.340	69.159	2.007	94.067
Maximum	31.686	6.140	66.429	54.587	55.024	96.102	9.870	119.970
Minimum	-8.623	2.062	38.300	30.511	17.318	47.533	-1.333	72.000
Std. Dev.	10.991	1.479	6.900	5.831	10.448	12.657	2.432	11.184
Observations	35	35	35	35	35	35	35	35

4.2. Unit Root Results

Identifying the unit root problem and determining the integration order of variables are important in applied research studies, as they help researchers choose the appropriate estimator. Following prior studies, the present study used the Augmented Dickey-Fuller test (ADF) to determine unit roots. The outcome of the unit root test, demonstrated in Table 3, indicated that, except for the inflation rate, the unit root problem was associated with all selected variables. However, it is important to mention that, at first difference, all variables were free from the unit root problem. In addition, the results rejected the presence of any variable having an integration order greater than 1, which is desirable for implementing cointegration techniques.

Table 3. Unit root analysis.

Variables	Level	First difference	Level	First difference	Conclusion
SUD_t	-1.543	-6.435***	-1.430	-6.422***	I(1)
AGR_t	-1.495	-5.133***	-1.628	-5.098***	I(1)
$INDS_t$	-2.102	-6.337***	-1.950	-6.868***	I(1)
SER_t	-2.277	-5.884***	-2.331	-6.173***	I(1)
EDU_t	-1.824	-3.332**	-1.613	-3.232**	I(1)
TRD_t	-1.271	-4.703***	-1.272	-4.633***	I(1)
NRS_t	-2.01	-5.890***	-1.190	-4.766***	I(1)
INF_t	-3.265**	-9.401***	-3.266**	-9.245***	I(0)

Note: The asterisk (***) and (**) denote 1 percent and 5 percent significance levels, respectively.

4.3. Lag Length Determination

Before conducting the ARDL test, the study attempted to determine the exact number of lags to be used. The outcome of the lag selection is presented in Table 4. The Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and FPE criterion indicated that using two lags was suitable. In addition, the FPE criterion confirmed the appropriateness of using two lags. Hence, the study used two lags in the ARDL estimation.

Table 4. Lag length.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	200.066	NA	1.22e-15	-11.640	-11.277	-11.518
1	400.590	291.671*	3.47e-19	-19.914	-14.644	-18.815*
2	479.388	76.410	3.03e-19*	-20.811*	-16.649*	-18.736

Note: The asterisk (*) demonstrates the suitability of number of lags for the ARDL estimation.

4.4. Cointegration Findings

The cointegration results for the selected variables are presented in Table 5. The critical values are generated by considering a restricted intercept and no trend (Narayan, 2004). The F-test indicated that cointegration is confirmed for the models having SUD, the service sector, the agriculture sector, trade openness, and natural resources as dependent variables. Likewise, cointegration is not confirmed for the models having the industrial sector, education, and the inflation rate as dependent variables. However, it is important to mention that cointegration is confirmed for the main model having SUD as the dependent variable.

Table 5. The ARDL results.

Specifications	F-Score	Decision
$SUD_t / INDS_t, SER_t, AGR_t, TRD_t, EDU_t, NRS_t, INF_t$	7.151	Yes
$INDS_t / SUD_t, SER_t, AGR_t, TRD_t, EDU_t, NRS_t, INF_t$	4.110	No
$SER_t / SUD_t, INDS_t, AGR_t, TRD_t, EDU_t, NRS_t, INF_t$	5.311	Yes
$AGR_t / SUD_t, SER_t, INDS_t, TRD_t, EDU_t, NRS_t, INF_t$	11.434	Yes
$TRD_t / SUD_t, SER_t, AGR_t, INDS_t, EDU_t, NRS_t, INF_t$	7.220	Yes
$EDU_t / SUD_t, SER_t, AGR_t, TRD_t, INDS_t, NRS_t, INF_t$	3.282	No
$NRS_t / SUD_t, SER_t, AGR_t, TRD_t, EDU_t, INDS_t, INF_t$	8.280	Yes
$INF_t / SUD_t, SER_t, AGR_t, TRD_t, EDU_t, NRS_t, INDS_t$	2.261	No
Level of Significance	I (0)	I(1)
1 Percent	4.140	4.24
2.5 Percent	2.60	3.84
5 Percent	2.32	3.50
10 Percent	2.03	3.13

Note: The critical values are produced by Eviews-12 which considers only restricted intercept and no trend.

4.5. Interpretation of Long Run Findings

The study reports the long-run results based on the ARDL methodology in Table 6. It is found that, among the three main sectors of the economy, the impact of the industrial sector's contribution on SUD is the highest. The coefficient of the industrial sector in the estimated equation is both positive and statistically significantly different from zero. The results show that a 1 percent increase in the industrial sector is responsible for a 0.296 percent increase in SUD, which is remarkable. Our study's findings are well supported by the recent research of Fang (2023), who also revealed similar results using data from the Chinese economy. Therefore, following the footsteps of other economies, the KSA needs to embrace the process of industrialization wholeheartedly, which is aligned with Vision 2030. Similarly, the service sector has also proved its worth in uplifting the process of SUD. The variable used to approximate the service sector's contribution possesses a positive and statistically significant coefficient. The point estimate indicates that a 1 percent rise in service sector development is linked with a 0.05 percent increase in the level of SUD, which is satisfactory. Recent research by Haqnazarova and Numanovna (2025) also supports the positive influence that the service sector has on the pace of SUD. The mentioned study also highlighted the role of several enablers, such as public-private partnerships, institutional support, consumer awareness, and digitalization. This means that SUD could also be accelerated through advancements in the service sector. The research of Ström (2024) highlighted the importance of the service sector for SUD and stated that it is one of the largest sectors of the economy worldwide. Moreover, according to the results, the agriculture sector has also played an impressive role in shaping the pace of long-run SUD in the KSA. The study identified a positive and statistically significant coefficient for the agriculture sector variable. The numerical value of the estimate indicates that a 1 percent rise in the agriculture sector is responsible for a 0.02 percent increase in long-run SUD. Recent research has demonstrated that sustainable agricultural practices generally promote environmental stewardship, address challenges, and support socioeconomic progress, all of which are aligned with the United Nations SDGs (Huzenko & Kononenko, 2024). In this scenario, the policymakers of the KSA must encourage sustainable agriculture, which will help achieve the goals included in Vision 2030.

Furthermore, we found that human capital has played an important positive role in shaping the level of SUD in KSA. The results demonstrated that the coefficient of human capital in the estimated model is both positive and statistically different from zero, confirming its dominant role in the transition towards SUD. Boeve-de Pauw, Gericke, Olsson, and Berglund (2015) highlighted the important role of human capital in uplifting the pace of SUD by creating awareness. Economies with advanced levels of human capital generally act more responsibly towards the environment, which ultimately advances the transition towards SUD. In addition, Spirin et al. (2021) opined that human capital is the main factor behind advanced economic development and quality of life. Therefore, the role of improved human capital in SUD needs the attention of policymakers.

Moreover, the study's quantitative findings revealed that trade openness has positively impacted the pace of SUD in KSA. According to the results, the coefficient of trade openness is positive, and this relationship is significant, demonstrating its favorable impact on the level of SUD. Previous studies (Xu et al., 2020) also proved the favorable impact of trade openness on SUD. There are various channels through which openness to global trade impacts the process of SUD. For instance, greater openness to global trade provides access to advanced production tools and expanded markets, and further improves energy efficiency, consequently advancing the process of SUD. Furthermore, in resource-rich economies like KSA, liberalized trade policies generally lead to the overutilization of natural resources and increase energy use, which needs to be carefully monitored.

Finally, the long-run results produced convincing evidence of the adverse impact of the inflation rate on SUD. The coefficient of the inflation rate in the estimated model is not only negative but also statistically significant. Our study's results are well supported by the research of Koirala and Pradhan (2020), who also found that SUD responds negatively to an increased inflation rate. An increased inflation rate generally adversely impacts the purchasing power of the population, increases poverty and income inequality, and consequently undermines the pace of SUD. Moreover, in the case of a resource-abundant country like KSA, a heightened inflation rate is a serious problem, as it adversely impacts investment in and initiatives related to renewable energy, which are essential factors for the successful transformation towards SUD. Therefore, keeping an eye on the rising price level, particularly after COVID-19, requires serious remedial measures on the part of policymakers and government authorities in KSA.

Table 6. Long Run Results.

Variables	Coefficients	Std. Error	t-Statistic
$INDS_t$	0.296***	0.062	4.740
SER_t	0.058***	0.012	4.644
AGR_t	0.024***	0.005	4.580
NRS_t	-0.011	0.010	-1.104
EDU_t	0.006***	0.001	5.003
TRD_t	0.007***	0.001	5.696
INF_t	-0.026***	0.005	-5.011
Constant	-4.272	0.199	-21.402

Note: The asterisks (***) demonstrate a 1 percent significance level.

4.6. The Short Run Analysis

The study reports the short-run relationships in Table 7. The short-run results indicate that the service and industrial sectors contribute to SUD. In contrast, the impact of the agricultural sector on SUD is negative but insignificant. The point estimates indicate that the impact of the service sector on SUD is higher than that of the industrial sector. The dominant role of the service sector compared with the industrial sector in the short run could be due to its lower dependence on resource and energy use. Generally, the service sector is not energy-intensive, unlike the industrial sector, which produces relatively more emissions. In addition, the service sector encourages digitalization, green finance, and research and development activities, which ultimately play important roles in improving the process of SUD.

Moreover, we observed that the impact of natural resources on SUD is both positive and significant. Possible reasons for this contrasting finding are that natural resources provide job opportunities and increase the government's fiscal space, which momentarily raises both GDP and SUD. However, in the long run, the overuse of natural resources degrades environmental quality through enormous emissions and adversely affects the quality of institutions, ultimately undermining progress toward achieving SUD. This view is consistent with resource-curse theory as well as the Dutch disease phenomenon.

Furthermore, the study's findings demonstrate that trade openness has a harmful influence on the pace of SUD, unlike its positive long-run impact. In the short run, trade openness generally worsens environmental outcomes due to increased production pressures, consistent with the pollution haven hypothesis. Specifically, in the context of KSA, higher hydrocarbon exports in the short run increase resource inflows, boosting both GDP and CO_2 emissions, which negatively affect SUD.

Finally, our results proved that the rate of inflation has a conducive impact on SUD in the short run, which is also in contrast to the long-run findings demonstrated earlier. Moderate inflation generally encourages economic activity, increasing employment and government revenues, which ultimately facilitates the process of SUD in the short run. More specifically, in the context of KSA, which is passing through a transitional phase, moderate inflation is necessary for pushing the pace of SUD in an upward direction. Lastly, our results proved that human capital has influenced the pace of SUD positively and significantly in the short run, which is well supported by the earlier long-run results. This means that human capital is an important and essential factor in promoting SUD in KSA. Hence, the policymakers and government authorities of KSA are advised to pay attention to improving both the quantity and quality of existing human capital in order to strengthen its contribution to SUD.

Table 7. Short Run Results.

Variables	Coefficients	Std. Error	t-Statistic
$\Delta INDS_t$	0.044***	0.003	12.286
ΔSER_t	0.086***	0.023	3.745
ΔAGR_t	-0.003	0.007	-0.434
ΔNRS_t	0.002**	0.0007	2.857
ΔEDU_t	0.007***	0.0007	10.494
ΔTRD_t	-0.015**	0.006	-2.301
ΔINF_t	0.042***	0.019	2.221
ECT (-1)	-0.435***	0.079	-5.482

Note: The asterisks (***, **) demonstrate significance levels at 1 percent and 5 percent, respectively.

4.7. Diagnostics Results

After presenting and interpreting the results, it is important to assess the validity of the models. For this purpose, the study utilized several important tests, and the findings are demonstrated in Table 8. Firstly, the model estimated in the present study is free from serial correlation, as evident from the LM test and its p-value. Similarly, the study found no evidence of heteroscedasticity in the estimated model, as confirmed by the White test and its p-value. Finally, the residuals are normally distributed, as endorsed by the Jarque-Bera test, while the functional form is also correctly specified, as indicated by the Ramsey test.

Table 8. Validity Testing.

Test	Test-Probability	Test Score	Conclusion
Jarque-Bera	0.864	0.648	Normal distribution
LM Test	1.745	0.196	No serial correlation
White Test	0.112	0.388	No heteroscedasticity
Ramsey Test	1.546	0.136	Correct functional form

4.8. Stability Testing

The stability of the residuals is further assessed using the CUSUM test and its square. Figure 2 displays the outcome of the CUSUM test, while Figure 3 demonstrates the outcome of the squared CUSUM test. We found that, in both figures, the estimated lines lie well within the critical lines at the 5 percent significance level. This means that the residuals remain stable throughout the study period. More specifically, both the long- and short-run results are valid and stable.

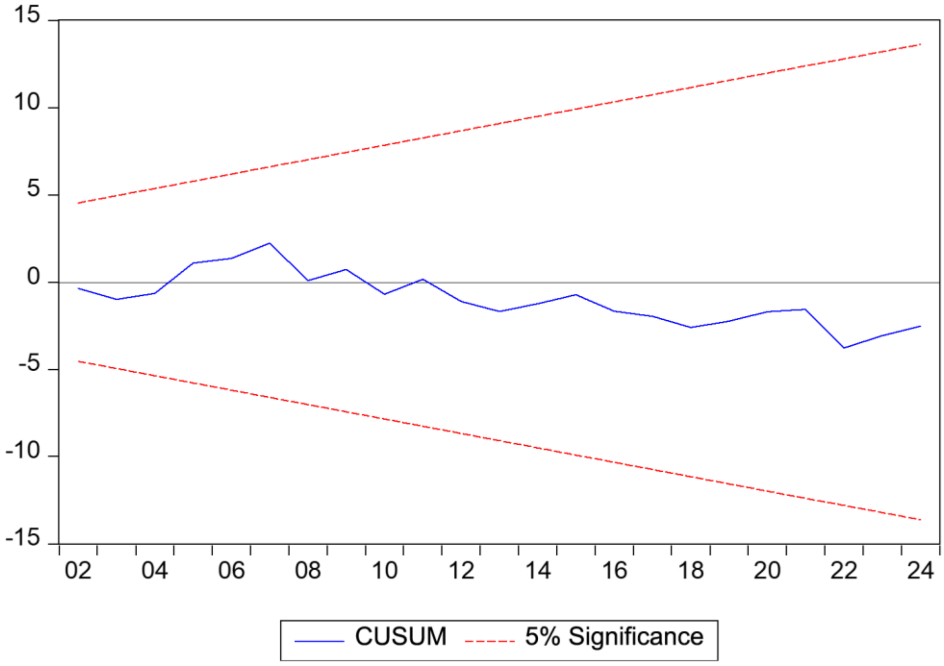

Figure 2. CUSUM test.

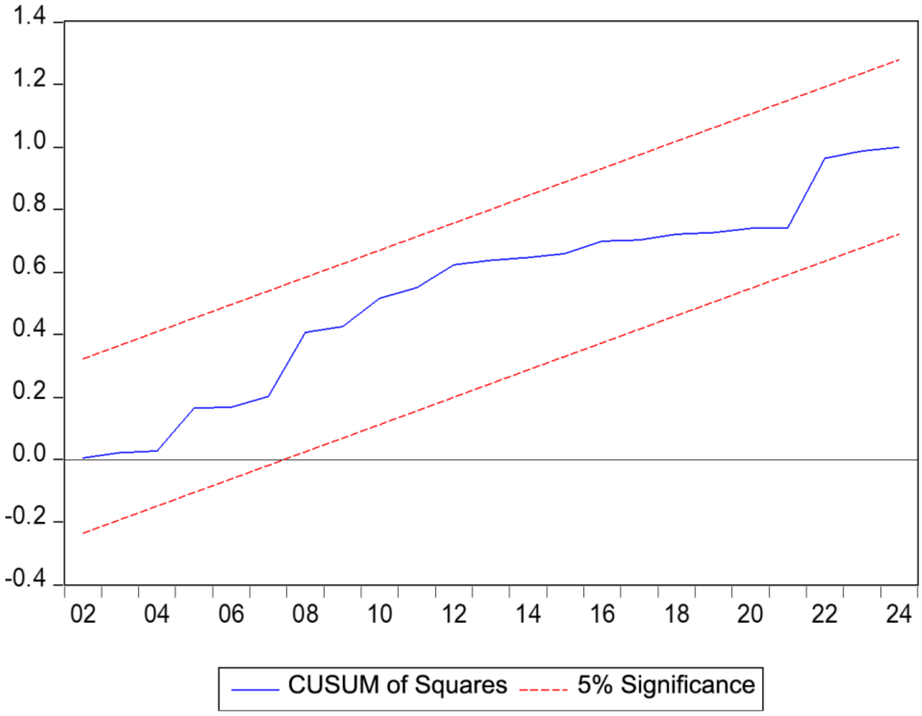

Figure 3. Square of CUSUM test.

5. CONCLUSIONS AND IMPLICATIONS

5.1. Conclusions

This research paper aimed to investigate the impact of the industrial, service, and agricultural sectors on SUD, which is an integral part of Vision 2030. The paper used annual data from 1990 to 2024 for the KSA economy. For data analysis, the study used the ARDL technique for time-series cointegration.

The findings of the research indicated that, for SUD, all three main sectors—industrial, service, and agricultural—matter. In terms of relative importance, the contribution of the industrial sector matters most, followed by the service and agricultural sectors in the long run. In the short run, the service sector dominated the industrial sector, while the agricultural sector lost its importance for SUD. In addition, in the long run, the study found that

SUD responds positively to increased human capital and trade openness, and negatively to increased natural resources and the inflation rate. Furthermore, in the short run, the findings indicated that the inflation rate, natural resources, and human capital are the main driving forces behind increased SUD in the KSA. Moreover, trade openness appeared to be a barrier to SUD in the short run. Finally, this research is aligned with the SDGs of the United Nations, as well as with the policy actions included in the Vision 2030 of the KSA, which emphasizes the promotion of equitable and sustainable SUD.

5.2. Policy Implications

To uplift the pace of SUD in the long run, the KSA must improve the industrial, service, and agricultural sectors. However, the industrial sector appeared to be more important for the performance of SUD than the service and agricultural sectors. Therefore, the main focus should be on the development of the industrial sector to achieve a higher level of SUD in the long run. In contrast, in the short run, we observed that the contribution of the service sector to SUD is more prominent than that of the industrial sector. Therefore, in the short run, KSA must focus on developing the service sector to achieve short-term gains related to SUD through the channels of rapid employment generation and economic diversification aligned with Vision 2030. Finally, the agricultural sector also needs the attention of policymakers, as it is an essential factor in long-term SUD. In summary, all three sectors must be expanded, as they are essential for shaping long-run SUD in KSA.

Similarly, the education sector has played an important role in both the long- and short-run SUD in KSA. In other words, the education sector has positioned itself as an integral part of SUD, which is well supported by Vision 2030. Therefore, the policymakers of KSA need to continue their effective policies towards the education sector to uplift the pace of SUD in the long run. Increased education generally enables individuals to act much more responsibly towards the environment, which ultimately improves SUD. An improved education sector will help policymakers develop a strong knowledge-based economy, which is one of the key components of Vision 2030. Incorporating sustainability-related courses into the existing education system, along with additional investment in the education sector, will further promote SUD in KSA.

In addition to human capital, natural resources appeared to be important in the short run but unimportant in the long run from the perspective of SUD. Therefore, policymakers need to utilize the revenues generated by natural resources for investment in the renewable energy sector, green technologies, and institutional improvement. Efficient management of natural resources and minimizing their adverse impacts are closely aligned with the goals of Vision 2030.

Finally, we found that trade openness is responsible for improving SUD in the long run. However, in the short run, trade openness worsens sustainability outcomes due to overdependence on natural resource exports, including a significant portion of fossil fuels. Therefore, KSA needs to diversify its export basket by including knowledge-based products. Similarly, existing production activities need to be shifted to renewable energy sources. Furthermore, policymakers need to strictly monitor production activities and introduce environment-related legislation to mitigate the adverse consequences of trade in the short run.

5.3. Limitations and Future Research Agenda

This study has several important, unavoidable limitations. For instance, the study has focused only on the economy of KSA to assess the role of different sectors in SUD. However, SUD is equally important for all resource-rich countries, including the GCC countries, Brunei Darussalam, and Malaysia. To address this issue, we suggest that future research should focus on all six GCC members and uncover more detailed, sectoral insights related to SUD and its determinants.

Secondly, our study's findings are based on conventional ARDL modeling. Therefore, we suggest that future studies should also explore the use of non-linear ARDL (NARDL) to provide more robust findings. Thirdly, our study's models include only the main factors of SUD. However, additional determinants of SUD were not included due to the limited number of observations. Therefore, future studies may also consider the roles of sustainable tourism, domestic investment, and FDI inflows in shaping the pace of SUD in KSA.

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