Article

An Ideology of Sustainability under Technological Revolution: Striving towards Sustainable Development

Syed Abdul Rehman Khan 1,2,*, Ridwan Lanre Ibrahim 3, Abul Quasem Al-Amin 4 and Zhang Yu 5,6

1 School of Management and Engineering, Xuzhou University of Technology, Xuzhou 221006, China
2 Beijing Key Laboratory of Urban Spatial Information Engineering, Beijing 102616, China
3 Department of Economics, University of Lagos, Lagos 100213, Nigeria; lanrid23@gmail.com
4 Department of Geography and Environmental Management, Faculty of Environment, University of Waterloo, Waterloo, ON N2L 3G1, Canada; Al.amin@aceps.ca
5 School of Economics and Management, Chang’an University, Xi’an 710064, China; zhangyu19@foxmail.com
6 Department of Business Administration, ILMA University, Karachi 75190, Pakistan

* Correspondence: Sarehman_cscp@yahoo.com

Abstract: The recent decades have witnessed an unprecedented surge in global warming occasioned by human anthropogenic activities. The ensuing effects have brought devastating threats to human existence and the ecosystem, with the sustainability of the future generations highly uncertain. Resolving this pervasive issue requires evidence-based policy implications. To this end, this study contributes to the ongoing sustainable development advocacy by investigating the impacts of renewable energy and transport services on economic growth in Germany. The additional roles of digital technology, FDI, and carbon emissions are equally evaluated using data periods covering 1990 to 2020 within the autoregressive distributed lag (ARDL) framework. The results show the existence of cointegration among the variables. Additionally, renewable energy and transport services positively drive economic growth. Furthermore, economic growth is equally stimulated by other explanatory variables, such as digital technology and carbon emissions. These outcomes are robust for both the long-run and short-run periods. More so, departures in the long run are noted to heed to corrections at an average of 60% speed of adjustment. The estimated models are confirmed to be valid based on the outcomes of the postestimation tests. Policy implications that support the path to sustainability are highlighted based on the findings.

Keywords: renewable energy; transport system; economic growth; environmental sustainability

1. Introduction

That the world is committed to achieving economic progress that is safe for both the present and future generations is neither new nor strange to the empirics’ growth. This ideological proposition has ignited numerous efforts from governments, developmental economists, policymakers, international organizations, and research pundits alike under a joint and ambitious goal of “(. . . ) Transforming our World: The 2030 agenda for Sustainable development” [1]. In parallel consideration for these goals is the unflinching need to “promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all” as entrenched in goal 8 of the sustainable development goals [2].

The ideology behind the concept of sustainable development goals (SDGs) is the need to achieve a development path that is safer for human lives and promotes a quality environment. Consequently, pursuing SDGs becomes crucial because failure to do so could be detrimental to human existence, endanger the present environmental status, and dampen the sustainability of the future generations [3]. Hence, a policy initiative that seeks to enhance the growth and sustainability of any economy may remain an illusion if adequate provisions are not in place to resolve the environmental effects that surface thereafter [4]. In recognition of this view, SDG 8 posits that economic growth should be a progressive tool for
the environment and should not harm it. This standpoint has long constituted the primary reference point for drawing a demarcation line between the drivers of economic growth that are sustainable-development-enhancing and sustainable-development goals-retarding.

Among the several factors that have been advanced in the highlighted cases of growth drivers, transport services (TS) and renewable energy (RE) are not hard to notice. The role of transport services in the attainment of sustainable economic growth can hardly be overemphasized for at least three reasons. First, development can hardly take place without a decent transportation system [5]. This is because economic activities largely rely on transport services to connect production processes, in terms of delivery of raw materials from the market down to the factory and distribution of the finished or semifinished goods to the consumer [6]. Second, the increasing need for intensive infrastructures further underscores the importance of the transport sector as a key component of the economy [7,8]. This becomes highly important considering the fact that economic opportunities and gains are connected to the movement of people and freight [9]. Third, a well-structured and maintained transport system and networks have been identified as growth stimulators [10]. Overall, the importance of the transport services to economic growth cut across the macro and micro levels of the economy. Regarding renewable energy, its contributions to economic growth are enormous and three prominent ones are thus illustrated. First, renewable energy enhances the production system with cost-effective energy sources [11]. Second, aside from stimulating growth, renewable energy enables the achievement of growth with little or no harm on the environment, thus making it a key component of sustainable development [12–14]. Third, renewable energy constitutes a perfect solution for achieving energy security [15] which is necessary for sustainable growth.

Given above these narratives, it is not surprising that a plethora of empirical studies have focused on the environmental impacts of both RE and TS in the last few decades [16–18]. Conversely, studies explicating the growth effects of these two indicators are still in their early stages. The theoretical and empirical perspectives establishing TS-growth and RE-growth nexuses are based on four hypotheses: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. Regarding the RE-growth nexus, the growth hypothesis applies when RE drives economic growth (EG), implying unidirectional causality [19]. The conservation hypothesis posits that EG drives RE without the reverse case existing. In this case, a unidirectional causality running from EG to RE exists [20]. The feedback hypothesis postulates the situation where RE drives EG, and the reverse equally applies, indicating a bidirectional causality running from both ends [21]. The neutrality hypothesis supports no causality case, which implies that no significant relationship exists between RE and EG [22]. Similar views have been advanced for the TS-EG nexus [23]. Effective transportation services constitute a fundamental factor in achieving sustainable development for any country [24]. Additionally, achieving rapid urbanization and economic growth requires the functionality of the transportation system [25].

Two significant submissions are apparent from the preceding arguments. First, despite the essential roles of both RE and TS in pursuing SD, the extant studies have explicated their impacts on the environmental dimension rather than the economic aspect [26]. For instance, the research interest in [27] focuses on the role of renewable energy in the validation of environmental Kuznets curve (EKC) hypothesis in Brazil, Russia, India, and Canada, with the interplay of natural resources and globalization. In addition, Ref. [28] provides substantial evidence to justify the nexus between transport services and the environment. The empirical studies illustrating the nexus of RE and TS on the economic angle are budding, implying limited and narrow understandings of the relationship [29]. Second, the few available studies on the RE-EG and TS-EG nexuses are filled with inconclusive results [30]. These two deductions provide a soft landing for the present study to further elaborate on the issue in the most recent time.
Research Objectives and Contributions

The research interest of the present study lies within the context of SDG 8, which seeks to promote sustained, inclusive, and sustainable economic growth, full of productive and decent work for all. The primary objective of this study is to examine the impacts of transport services (TS) and renewable energy (RE) on economic growth (EG) in Germany for the period spanning 1990–2020. In addition, the substantial roles of digital technology (DT), foreign direct investment (FDI), and carbon emissions (CO₂) are evaluated. The necessity of this study emanates from the dearth of empirical studies examining the growth impacts of either transport services or renewable energy. A survey of the available research reveals that much attention has been paid to examining how the highlighted variables of interest in this paper impact the environment. In contrast, the growth effect has been largely neglected. Understandably, the impact of global warming is alarming and highly disastrous, which could justify why the preponderance of studies focused on the environmental dimension of SDGs. This study argues that by neglecting the economic and social dimension, efforts to resolve the unrelenting surge in global greenhouse gas (GHG) emissions might fail to heed the expected results. The reason is that economic growth itself is a significant player in determining environmental sustainability. Consequently, the present study is the right step in rerouting the research focus towards prominent but less investigated sustainable development factors.

The contributions of this study to the literature are four-fold. First, this would constitute the first study to examine the combined impacts of transport services, renewable energy, digital technology, and foreign direct investment on economic growth. The existing studies have considered either one or a few of these indicators [26,30]. In most cases, when these variables are evaluated, the focus has been chiefly on the environment [17,18,26]. Second, there is no consensus among the existing studies investigating the hypotheses of economic growth drivers on the best proposition to advance among the four views [31]. Consequently, this study hopes to contribute to the debates and provide a more precise direction on policy implications that are all-inclusive and pragmatic to achieve sustainable development in the most recent time.

Third, the study contributes to the literature by choice of research scope through period and sample observation. In the former case, the study contributes to the long period and recency of data from 1990 to 2020. This is necessary to detect the patterns of the variables over time effectively. By doing so, the functional relationships between economic growth and the regressors are evaluated more clearly with the provision of concise and exact results. In the latter case, the choice of Germany is motivated by the following reasons. First, Germany is in the group of economies that are categorized as the most developed and as world leaders, such as the Group of Seven (G7) and the Group of Twenty (G20) [32–34]. Second, Germany is rated fourth in the global ranking of the largest economies, and its social market is noted as the most sophisticated and most extensive in Europe [35]. Further, renewable energy has seen progressive improvements in Germany with solar, wind, and biomass sources and in terms of photovoltaic capacity, it ranks fifth globally [36]. In addition, it ranked third in wind installation in 2018, and above all, Germany has earned global recognition as the first leading renewable energy economy [37]. The contributions of Germany to the worldwide transportation system can hardly be overemphasized [38,39]. For instance, while the country ranked sixth in rail transport services by network and size in 2017, continuous development saw the economy ranking first in the global logistic performance index (LPI) rating in 2018 [40]. Fourth, the choice of the methodology adopted by this study is worth lauding. By employing the ARDL bounds testing to cointegration, this study can estimate the variation in economic growth in the short- and long-run nexuses.

The rest of the study is structured as follows: Section 2 reviews relevant literature, Section 3 details the method, and Section 4 presents and discusses the results. Conclusions and recommendations are presented in Section 5.
2. Literature Review

This section focuses on a review of recent studies illustrating the functional relationship between renewable energy and economic growth on the one hand and transport services on the other hand. The lacunas identifiable from these studies are identified at the end of the review.

2.1. Renewable Energy-Economic Growth Nexus

In this subsection, the effects of energy consumption entailing nonrenewable energy consumption (NREC), renewable energy consumption (REC), and nuclear energy consumption (NEC) on economic growth (EG) and other growth outcomes are assessed.

To start, Ref. [41] examined the functional nexus between renewable energy and retail electricity prices for a panel of 34 selected OECD economies. The empirical outcomes of the study provide substantial evidence to support the increasing effects of renewable energy on retail electricity prices. This implies that an increase in renewable energy significantly escalates the prices of retail electricity. The escalating effects are however noted to be marginal and are projected to significantly decline in the nearest future. Furthermore, Ref. [31] probed the functional effects of REC, NREC, and carbon emissions on EG in twenty-six selected European economies from 1990 to 2018. The study embarked on pretest analyses of the data employed using unit root for stationarity test and panel cointegration to assess long-run existence in the model. Significant outcomes from the analyses show clear evidence for a long-run connection among the variables. In addition, causality tests were equally conducted, and the results provide empirical backing for the divergence of causality among the variables. For instance, bidirectional causality was reported between EG and REC. In addition, the causality running from REC to NREC was noted to be bidirectional. On the other hand, REC and CO$_2$ emissions record unidirectional causality. More so, the study supports the existence of a substitutional and interdependence nexus between REC and NREC. Similarly, Ref. [30] explored the association among REC, NREC, and EG in selected Organization of Economic Co-operation and Development (OECD) and non-OECD countries from 1995 to 2015. The study employed a nonparametric modeling estimator to account for time variation impacts of REC and NREC on EG. Findings from the analyses indicate that NREC positively impacts EG in OECD economies while REC provides substantially smaller incentives on EG. Furthermore, the effects of REC and NREC prove to be significant promoters of EG in non-OECD economies. In a bit dimensional analysis, Ref. [26] evaluated the disaggregated effects of energy efficiency (EE), REC, and other selected indicators on the EG of Brazil, Russia, India, China, and South Africa (BRICS) for a 1990–2014 period. The empirical fallouts suggest that EE is a positive predictor of EG across all the estimated quantiles but with differences in the level of quantiles (particularly in the 50th and 60th quantiles) of EG. In contrast, REC negatively predicts EG in BRICS countries, with the effects showing more severity from the 60th to 90th quantiles. Next, Ref. [42] evaluated the impacts of EG, REC, and NREC on carbon emissions (CE) and economic growth (EG) in twenty-five developing Asian countries from 2000 to 2016 by employing the OLS-based random effect (RE) estimator with selection subjected to Hausman–Taylor Regression (HTR). Results of the study show that REC and NREC positively and significantly promote EG. Moreover, the effects of energy consumption (RE and NRE) are divergent on carbon emissions. For instance, while REC negatively influences CE, NREC positively impacts it. In terms of causality, EG and REC are positively connected in the short and long run, suggesting the feedback hypothesis’ confirmation. In [43], researchers examined the significant role played by NREC and REC in promoting EG with particular reference to services and manufacturing sector growth in one hundred and seven countries from 1984 to 2019. The empirical evidence, which was subjected to the system GMM estimator, reveals that REC promotes the development of the services sector in high-income countries. More so, positive effects of REC are reported in the manufacturing sector of middle-income countries. The results for the high-income countries show that
REC and NREC are complementary in promoting EG while they turn out to be substitutes in middle-income countries.

In addition to the preceding reviews, Ref. [44] examined the driving factors of EG with the consideration of NREC and REC in a cross-section of five South Asian economies over the 1990–2014 period. To check for long-run association in the estimated models, the study employed [45,46]. Further, the functional relationship among the indicators was examined using fully modified OLS (FM-OLS) and dynamic OLS (DOLS) estimators. The results from the estimated models reveal that REC, NREC, and fixed capital formation positively and significantly drive EG. More so, the results of causality tests based on [47] provide strong empirical support for the existence of unidirectional causality from EG to REC. Next, Ref. [48] assessed the nexuses among REC, FDI, and gross domestic product (GDP) in thirty-one Chinese provinces for the period spanning 2000 to 2015. The estimation procedures adopted entailed unit root for stationarity, cointegration test for long-run existence, and causality test using the Granger causality estimator. Findings from the study reveal the presence of sturdy and steady equilibrium among the variables of interest. In addition, short-run analyses show no significant causality between FDI and REC. At the same time, the long-run results show causality between the two, and equally, causality running from GDP to REC. In [49], researchers conducted a replication of the study in [50], which examined the association between REC and EG in OECD economies with the adoption of the OLS fixed effect (FE) technique for the 1990–2010 period. The replication was conducted using similar data and estimation techniques together with a recent estimator, which accounts for the issue of heterogeneity inherent in the REC-EG nexus. The results reveal that REC positively drives EG in the lower and low-middle quantiles. In contrast, adverse impacts became evident when REC was measured by absolute value. Ref. [51] explored the functional effect of RE on EG and the environment in fifteen REC-based economies by employing FMOLS and VECM estimators. The results emanating from the FMOLS estimator indicate that REC promotes EG but moderates carbon emissions. Similarly, findings from the VECM Granger causality estimator reveal a series of diverging causality among the variables. Most importantly, one-way causality is evident in EG-REC, suggesting the confirmation of the feedback hypothesis. More so, lack of causality is reported in the carbon emissions-REC nexus in the long run, while a one-way nexus is confirmed for EG and carbon emissions. Ref. [52] examined the nonlinear association between REC and EG in the OECD economies. The study equally considered this nexus using threshold regression models. Nonrenewable energy intensity, urbanization level, and per capita income are used as threshold variables to explore the internal mechanism of renewable energy for economic development. The results of the study reveal that REC promotes EG. Ref. [53] equally supported the growth-enhancing role of energy consumption in the case of the Chinese economy from 1995 to 2016.

Some studies on the REC-EG nexus explore a combination of a long-run estimator and heterogeneity tests. In this line of view, Ref. [54] examined the effects of REC on EG for seventeen emerging countries for the period spanning 1990–2016 by employing the bootstrap panel causality test, which accounts for the estimation challenge of cross-sectional dependence and coefficient heterogeneity. The findings reveal empirical support for the neutrality hypothesis for the selected economies except for Poland, where the growth hypothesis is proven. Ref. [55] evaluated the asymmetric impacts of REC and NEC on EG using annual data covering 1990–2016 in Pakistan. The empirical results from nonlinear ARDL reveal the existence of direct and indirect volatility to REC and NEC, which will bring about a positive effect on EG. In addition, while the significant contribution of capital formation to EG is empirically supported, oil consumption, on the other hand, adversely affects REC. Additional findings also reveal neutral effects of oil price on REC and NEC. Ref. [56] investigated the nexus between REC, carbon emissions, energy intensity, and EG in Romania using the ARDL estimator on quarterly data spanning 1990–2014. The study examined the different levels of causality among the variables by employing the Toda–Yamamoto model. The following results are evident from the empirical analyses. First,
the presence of long-run cointegration was discovered among the variables. Second, the causality test reveals empirical evidence that supports the existence of feedback causality between REC and EG, which further confirms the energy-led growth hypothesis.

Focusing on the relative importance of the REC-EG nexus in developing nations, Ref. [57] investigated the relationship between REC and EG in a dynamic panel comprising fifteen West African economies from 1995 to 2014. The empirical evidence based on dynamic OLS (DOLS) reveals that REC drags back the expectation acceleration rates of EG in the sample countries. Conversely, Ref. [58] examined the connection between REC and EG from 1990 to 2016 in Bulgaria by employing Toda–Yamamoto and ARDL in ascertaining the long-run effects and causality among the variables, respectively. Fallouts from the study reveal that REC drives EG. In a similar vein, Ref. [59] explored heterogeneous analyses of NREC and REC on EG in a panel study focusing on selected countries in the Asia-Pacific Economic Cooperation (APEC). The study estimated an empirical model based on annual data from 1990 to 2015 using second-generation tests involving cross-sectional dependence and stationarity tests. It also conducted a long-run test with the use of the Westerlund cointegration test. In estimating the long-run nexus, the study employed the newly developed continuously updated fully modified ordinary least square (CUP-FM) methods. Findings from the study reveal that NREC and REC enhance EG. The causality test supports the feedback effect in the connection between the variables.

2.2. Transport Services-Economic Growth Nexus

The relationship between transport services (TS) and economic growth (EG) is reviewed in the subsequent paragraphs. In particular, studies on different transportation measures such as transport infrastructure, transport energy consumption, railway transport system, freight, and marine transportation, among others, are evaluated.

In Refs. [59,60], researchers examined the effects of REC, TS, EG, and agriculture, forestry, and natural resources (AFNR) on tourism development (TD) in a panel of six selected countries in the Eastern European Economies (EEEs) for the period from 1995–2018. In conducting its empirical analyses, the study relied on second-generation-based estimators comprising cross-sectional dependence (CSD), CIPS stationarity test, and dynamic common correlated effect (DCCE). The results confirm the existence of CSD and stationarity of the variables at different levels. The main findings from the models estimated provide empirical support to advance for a positively significant effect of the regressors on international tourism. Refs. [59,61] probed the long-run asymmetric impact of social globalization (SG) and air transport (AT) on EG in Spain between 1970 and 2015. The empirical evidence relied on the recently advanced asymmetric ARDL estimator. The roles of REC and urbanization in stimulating expected growth were equally evaluated. Based on the analyses, it was discovered that AT, urbanization, and SG significantly drive EG. In contrast, REC drags EG due to the combined energy mix involving both REC and fossil fuel. Ref. [25] investigated the nexuses among transport infrastructure (TI), urbanization (URB), and information computer technology (ICT) on EG from 1961 to 2016 in G20 economies. By employing the VECM model, the study provides empirical support to advance the existence of sequential causal nexuses among the four indicators in the short and long run. Ref. [62] examined the effects of (TI) on sustainable economic development (SEG) in China from 2008 to 2018. The empirical analyses reveal transport by rail and investment in TI has the tendencies to promote SEG.

Ref. [23] investigated the impact of road transportation (RT) on EG in thirty-one selected Chinese provinces and municipalities from 1980 to 2015. Findings from the study provide empirical support for feedback hypothesis RT and EG. Furthermore, RT was reported to cause growth in selected cities such as Beijing, Shanghai, and Heilongjiang. In contrast, EG causes RT in Tianjin, Fujian, and Hunan, while no causality was evident between RT and EG in Tibet. Ref. [63] estimated the relationship between freight transportation (FT) and economic development (ED) in China from 1997 to 2017, with a focus on thirty selected provinces. Findings from the study reveal sturdy evidence supporting
the existence of a U-shaped nexus between FT and ED, particularly in Beijing, Shanghai, and Tianjin. Ref. [64] evaluated the impactful nexus between TI and socioeconomic development (SED) in China from 1982 to 2015. It mainly estimated the TI effects of inequality using the Gini coefficient and ascertained causality between the indicators. The empirical analyses reveal that TI is not consistent in driving EG. The study found that reducing TI inequality proves to be significant in resolving the menace of unequal EG among the regions in China.

In the TS-EG nexus, the roles of access to transport services in driving or dragging have been assessed. For instance, Ref. [65] estimated the functional association between EG, transport accessibility (TA), and the post-ten-year social impacts of high-speed railway (HRS) activities in Italy. Findings from the study reveal the significant contribution of HRS to improve TA in Italy at about +32 percent. Similarly, HRS enhances a near +2.6 percent increase in EG. More so, the effects of HRS on inequality captured by the Gini coefficient show that the former reduced the latter by 11 percent, with an anticipated improvement estimated at 29 percent. Consequently, HRS is an appropriate tool needed to enhance country-level advancement in Italy and beyond. In [66], researchers investigated the relationship between maritime transports (MP) and EG in the selected countries of Turkmenistan, Azerbaijan, Russia, Iran, and Kazakhstan. Findings reveal that a percentage of improvement in MP will bring about a corresponding increase in EG. Ref. [67] evaluated the association between TI and EG in the Belt and Road Initiative (BRI) economies, which denotes a representative group for counties in Asia, Europe, and Africa, from 2007 to 2016. Analyses in the study included the estimation of spatial-temporal features of TI and EG in the sample countries. The primary empirical assessments centered around static and scatterplot estimators for ascertaining the functional nexus between TI and EG. The results show that TI is essential in enhancing EG in the sample economies. Spatial spillover is equally reported among the neighboring economies with close features. Ref. [51] equally ascertained the growth-enhancing effects of transport services in a panel study for forty-six developing countries over the 2000–2016 period.

In furtherance of the examination of transport infrastructure (TI) impacts on EG, [68] evaluated the nexus between TI and economic performance (EF) in twenty-eight selected European Union economies for the period from 2000–2014. The study found significant impacts of TI on EF. Additionally, a unidirectional causality is equally supported between EG and TI, which confirms the conservation hypothesis. The computed TI index supports the growth hypothesis, which advances a significantly positive effect of TI on the EG. Ref. [69] illustrated the significance of managing transport services (TS), particularly railway of cities, towards enhancing persistent EG. In addition, the study focused on probing whether rail transport (RT) can be a perfect alternative for driving sustainable transport systems (STS) in cities and agglomerations. The study submitted that sustaining urban transport remains highly sacrosanct based on the rapid development of the urban areas. More so, enhancing STS through accessibility, reliability, efficiency, and mobility were suggested as the best practices needed to promote STS. Ref. [70] examined the nexuses among transport energy consumption (TEC), TI, and EG in a panel of economies in the Middle East and North Africa region (MENA) from 2000–2016 by employing the generalized method of moments (GMM). The results reveal that TEC drives EG positively. Similar growth-inducing effects are evident from TI.

The review of extant studies in the preceding paragraphs exposes some notable lacunas evident in the literature. First, the existing studies are replete with the REC-EG nexus, while the TS-EG relationship appears to be at its early stage of empirical investigation. Consequently, this study will undeniably be categorized among the early empirical research advancing the growth effects of transportation. However, regarding the sample country (Germany), it will constitute the first study. Second, it is worth mentioning that the joint consideration of REC and TS effects on EG is scarcely in existence. When we consider the pertinent roles of digital technology, carbon emissions, and foreign direct investment in the REC-TS-EG nexuses, this study will constitute the first of its kind in Germany and beyond.
3. Material and Method

This section illustrates the methodological approach adopted by the present study, including model specification, estimation strategy, and the a priori expectations of the nexuses among the variables.

3.1. Model Specification

The present study relies on [26,30] in modeling the functional effects of transport services (TS) and renewable energy consumption (REC) on economic growth, with modifications to align with the objectives of the study. The model is thus given:

$$\Delta \text{EG} = \alpha_0 + \alpha_1 \Delta \text{REC} + \alpha_2 \Delta \text{TS} + \alpha_3 \Delta \text{FDI} + \alpha_4 \Delta \text{PCCO}_2 + \alpha_5 \Delta \text{DT} + \varepsilon_t$$  \hspace{1cm} (1)

where EG denotes economic growth captured by GDP per capita growth (annual %). REC implies renewable energy consumption. TS represents transport services proxied by percentage of service exports. FDI represents foreign direct investment measured as a percentage of GDP. PCCO2 denotes carbon emissions per capita captured by metric tons per capita. DT means digital technology captured by individuals using internet as a percentage of the population.

3.2. Estimation Technique

3.2.1. Autoregressive Distributed Lag

This study employed the autoregressive distributed lag (ARDL) model to estimate the long-run and short-run nexus among the variables. Conceptually, the ARDL model advanced by Pesaran & Shin [71] is a linearly specified time-series-based model where the outcome and explanatory variables are both contemporaneously and historically (lagged) related.

Several factors justify the importance and appropriateness of the ADRL model over other conventional time-series estimators, such as Engle and Johansen and Granger. First, while the traditional estimator is only applicable to extensive sample data and their reliability is doubtful for small datasets, the ARDL test is efficient and consistent in both cases [72]. Second, the ARDL estimator does not require unified order of variables and can conveniently be applied when variables are of I(0) or I(1) order [73]. Third, ARDL can estimate both long-run and short-run estimates by combining the lag in substituting the dynamic error correction model by exploring a linear transformation [74]. ARDL can generate both long-run and short-run estimates by combining the lag in substituting the error lag terms [74]. Fourth, the ARDL bounds test is highly efficient in addressing the twin issue of serial correlation and endogeneity in a time-series model [75].

Following the preceding argument, this study employed the ARDL estimator in gauging the nexuses among renewable energy, transport services, FDI, digital technology, carbon emissions, and economic growth. The model is thus stated in Equation (2):

$$\Delta \text{EG}_t = \alpha_0 + \alpha_1 \sum_{i=1}^{p} \Delta \text{EG}_{t-i} + \alpha_2 \sum_{i=0}^{q} \Delta \text{REC}_{t-i} + \alpha_3 \sum_{i=0}^{q} \Delta \text{TS}_{t-i} + \alpha_4 \sum_{i=0}^{q} \Delta \text{FDI}_{t-i}$$

$$+ \alpha_5 \sum_{i=0}^{q} \Delta \text{PCCO}_2_{t-i} + \alpha_6 \sum_{i=0}^{q} \Delta \text{DT}_{t-i} + \sigma_1 \Delta \text{EG}_{t-1} + \sigma_2 \Delta \text{REC}_{t-1} + \sigma_3 \Delta \text{TS}_{t-1}$$

$$+ \sigma_4 \Delta \text{FDI}_{t-1} + \sigma_5 \Delta \text{PCCO}_2_{t-1} + \sigma_6 \Delta \text{DT}_{t-1} + \varepsilon$$  \hspace{1cm} (2)

Equation (3) represents the unrestricted error correction model connected to the ARDL test [72]. The AEG, ΔREC, TS, ΔFDI, ΔCO and Δ ln DT are the various values of economic growth, renewable energy, transport services, FDI, carbon emissions, and digital technology. The parameters measuring the short-run dynamic are given as $\alpha_2$, $\alpha_3$, $\alpha_4$, $\alpha_5$, and $\alpha_6$. Further, the parameters estimating the long-term dynamics are $\sigma_1$, $\sigma_2$, $\sigma_3$, $\sigma_4$, $\sigma_5$, and $\sigma_6$.

To examine the long-run cointegration, the F-statistic value is usually adopted in the bounds test. The test is based on the null hypothesis of no cointegration among the series and can be expressed as $H_0 : \sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = \sigma_5 = \sigma_6 = 0$. Conventionally, the null hypothesis of no cointegration is accepted when the value of the bound test F-statistic is...
less than the lower bound value. In contrast, if the value is greater than the upper bound value, the alternative hypothesis, which advances the presence of cointegration, is accepted. \( t - 1 \) represents the optimal lag for each of the variables obtained through the Akaike information criterion.

3.2.2. Error Correction Model

The causal nexus among the indicators is estimable within the error correction model. In addition, the lagged terms of the individual coefficient can be employed to obtain the short-term dynamics. In addition, details about the long-term dynamics are obtainable from the error correction term (ECT).

\[
\Delta EG_t = \alpha_0 + \alpha_1 \sum_{i=1}^{p} \Delta EG_{t-i} + \alpha_2 \sum_{i=0}^{q} \Delta REC_{t-i} + \alpha_3 \sum_{i=0}^{q} \Delta TS_{t-i} + \alpha_4 \sum_{i=0}^{q} \Delta FDI_{t-i} + \alpha_5 \sum_{i=0}^{q} \Delta CO2_{t-i} + \alpha_6 \sum_{i=0}^{q} \Delta DT_{t-i} + \phi ECT_{t-1} + \epsilon_t
\]

The error correction term (ECT), which indicates changes in the short-run, estimates the speed of adjustment from volatility to equilibrium. The standard criterion for the ECT ranges from negative to zero (-1 to 0). Similarly, ECT should be statistically significant and negative. Again, the stability of the model was tested using CUSUM and CUSUMSQ [76,77].

3.3. A Priori Expectations

The economic intuitions guiding the functional impacts among the variables in this study are thus illustrated. Drawing from Equation (1) above, renewable energy (RE) is expected to drive economic growth following its importance in enhancing sustainable development. Furthermore, since renewable energy is cost-effective and carbon-emission-free, its alternative source-to-energy consumption will play a significant role in strengthening economic growth. More importantly, the vital role of RE on economic growth (EG) has been empirically advanced in the literature [30,43,49]. Consequently, the positive effect is hypothesized between RE and EG so that \( \alpha_1 = \left( \frac{\partial EG}{\partial RE} > 0 \right) \). Relating to transport services (TS), it is essential to explain that transportation plays a significant role in the movement of people and goods in the economy. More so, the transfer of goods and services from the surplus area to the deficit area in an economy is actualized through transportation. Consequently, there is no gainsaying to assume that TS will positively drive EG. This assertion is well-documented among extant studies [23,70]. In such a case, \( \alpha_2 = \left( \frac{\partial EG}{\partial TS} > 0 \right) \).

The role of FDI in enhancing economic growth has been widely advanced in the literature. Empirically, the growth-inducing effects of FDI have been widely supported [53]. On this basis, we anticipate a positive FDI-EG nexus \( \alpha_3 = \left( \frac{\partial EG}{\partial FDI} > 0 \right) \). Carbon emissions are undoubtedly the resultant effects of growth outcomes. Hence, as production activities increase, the pollution emitted in that process corresponds with the productive activities. Accordingly, an increase in carbon emissions suggests total output increases [80,81]. As such, \( \alpha_4 = \left( \frac{\partial EG}{\partial CO2} > 0 \right) \). The role of technology in achieving sustainable growth is well-recognized in the literature [82,83]. Hence, \( \alpha_5 = \left( \frac{\partial EG}{\partial TECH} > 0 \right) \).

3.4. Data and Preliminary Analysis

This study employed time-series data to estimate the impacts of renewable energy and transport services on economic growth in Germany. Other variables such as FDI, digital technology, and carbon emissions are equally considered in the analysis. The choice of time-series data (TSD) was motivated by the fact that TSD can provide an appropriate and reliable analysis of the drivers of economic growth in a country-specific study such as Germany [84]. Consequently, thirty (30) years of data spanning 1990–2020 has been gathered to estimate a TSD-based ARDL model to ascertain the long-run and short-run
nexuses among the variables. Full details of the data employed and sources are given in Table 1 below.

Table 1. Data and sources (1990–2020).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCCO2</td>
<td>CO₂ emissions (metric tons per capita)</td>
<td>Climate Watch. 2020. GHG Emissions Data Base. Washington, DC, USA</td>
</tr>
<tr>
<td>FDI</td>
<td>Foreign direct investment, net inflows (% of GDP)</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>INT_U</td>
<td>Individuals using the internet (% of population)</td>
<td>International Telecommunication Union (ITU)</td>
</tr>
<tr>
<td>EG</td>
<td>Economic growth (GDP per capita growth annual %)</td>
<td>World development indicators</td>
</tr>
<tr>
<td>REC</td>
<td>renewable electricity net generation (billion kWh)</td>
<td>US energy information administration</td>
</tr>
<tr>
<td>TS</td>
<td>Transport services (% of service exports, BoP)</td>
<td>World development indicators</td>
</tr>
</tbody>
</table>

Note: WDI implies world development indicators.

The descriptive statistics of the variables considered in this study are presented in Table 2. Going by the mean values of all the variables, it is evident that they are all positively signed, which meets the earlier stated a priori expectations. Tentatively, we can aver that transport services, renewable energy, FDI, digital technology, and carbon emissions drive economic growth (EG) in Germany. Comparing these drivers of development, it is evident that renewable energy (REC) has the highest mean value (91.38), followed by digital technology (INT_U) with 51.16, then transport services (TS), which has an average value of 3.14. The average value of 9.89 for carbon emissions per capita (PCCO2) is next, followed by FDI, which is the lowest with 1.98. The overall statistical analysis of the dataset shows some substantial levels of normality. This is evident from insignificant probability values of the Jarque–Bera test confirmed, with the exception of FDI. Additionally, the normality status is further supported by majority of the outputs of both skewness and kurtosis. The observed positive signs in Table 2 are further corroborated by the results of the correlation matrix in Table 3.

Table 2. Descriptive statistics.

<table>
<thead>
<tr>
<th>Variables</th>
<th>EG</th>
<th>TS</th>
<th>REC</th>
<th>INT_U</th>
<th>FDI</th>
<th>PCCO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>67.57</td>
<td>22.13</td>
<td>91.38</td>
<td>51.16</td>
<td>1.95</td>
<td>9.89</td>
</tr>
<tr>
<td>Median</td>
<td>70.92</td>
<td>22.40</td>
<td>65.42</td>
<td>68.71</td>
<td>1.74</td>
<td>9.88</td>
</tr>
<tr>
<td>Maximum</td>
<td>88.43</td>
<td>26.28</td>
<td>250.80</td>
<td>89.81</td>
<td>12.76</td>
<td>12.03</td>
</tr>
<tr>
<td>Minimum</td>
<td>40.58</td>
<td>17.47</td>
<td>20.68</td>
<td>0.13</td>
<td>−0.73</td>
<td>7.96</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>17.03</td>
<td>1.93</td>
<td>72.66</td>
<td>36.00</td>
<td>2.33</td>
<td>0.95</td>
</tr>
<tr>
<td>Skewness</td>
<td>−0.25</td>
<td>−0.37</td>
<td>0.84</td>
<td>−0.42</td>
<td>3.29</td>
<td>0.15</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>1.49</td>
<td>2.96</td>
<td>2.38</td>
<td>1.42</td>
<td>16.23</td>
<td>2.70</td>
</tr>
<tr>
<td>Jarque-Bera</td>
<td>3.26</td>
<td>0.69</td>
<td>4.13</td>
<td>4.10</td>
<td>281.90</td>
<td>0.24</td>
</tr>
<tr>
<td>Probability</td>
<td>0.20</td>
<td>0.71</td>
<td>0.13</td>
<td>0.13</td>
<td>0.00</td>
<td>0.89</td>
</tr>
<tr>
<td>Observations</td>
<td>31.00</td>
<td>31.00</td>
<td>31.00</td>
<td>31.00</td>
<td>31.00</td>
<td>31.00</td>
</tr>
</tbody>
</table>

Table 3. Correlation matrix.

<table>
<thead>
<tr>
<th>Variables</th>
<th>EG</th>
<th>TS</th>
<th>REC</th>
<th>INT_U</th>
<th>FDI</th>
<th>PCCO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>0.52</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REC</td>
<td>0.65</td>
<td>−0.54</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INT_U</td>
<td>0.57</td>
<td>−0.54</td>
<td>0.62</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDI</td>
<td>0.20</td>
<td>−0.16</td>
<td>0.07</td>
<td>0.15</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PCCO2</td>
<td>0.68</td>
<td>0.60</td>
<td>−0.59</td>
<td>−0.60</td>
<td>−0.22</td>
<td>1</td>
</tr>
</tbody>
</table>
The preliminary analysis was equally assessed through trend analysis as shown in Figure 1. As evident in the trend, FDI displays a staggering movement in the last three decades with the highest inflows in 2000, while 2004 records a negative value. Corroborating the negative value of FDI, United Nations Conference on Trade and Development [85] reports that Germany experienced negative inflows of FDI valued at $38.6 billion since 1992. The trend in digital technology captured by individuals using the internet (% of population) reveals a persistently increasing rate over the last 30 years. This implies that the populace widely accepts technology in Germany, and it is not surprising to see the indicator contributing the most among the selected variables in this study. Supporting the trend displayed in Figure 1 on internet users, statistics by [86] indicate that 89.81 million individuals are on record as internet users in 2020 in Germany. Renewable energy and economic growth proxied by (TO) are among the indicators recording a persistent increase in the period under investigation. In contrast, transport services and carbon emissions have both maintained a declining trend in Germany since 1990.

Figure 1. Trend analysis of the variables.
4. Results and Discussion

4.1. Stationarity Test

The employment of secondary data in the analyses of the present study necessitates the need to conduct a unit root test to ascertain the stationarity status of the variables employed [84]. However, it is highly important to clarify that the traditional unit root tests are restricted when it comes to the issue of shocks and other structural changes that may significantly affect the behavior of macroeconomic indicators. The structural break test of stationarity has become a widely accepted medium of addressing the aforementioned issues with the primary aim of identifying the breakpoint years of major occurrences leading to distortions in the behavior of economic phenomena. Consequently, we employed both traditional and advanced (structural breakpoint) tests to jointly ascertain whether the data are spurious or not before engaging them in the empirical analyses and equally identify major distortions in their stability (stationarity). Overall, both results reveal that, aside from the few series that are stationary at level, all the variables are uniformly found to be stationary at first difference to bring the cointegration order to two (I(0) and I(1)).

Regarding the structural changes in the German economy that may significantly lead to permanent shocks capable of disrupting the stationarity of the dataset employed within the period of analysis, the breakpoint years are observed in relation with the variables as such: TO (2019), GDP (2008), REC (2011), INT_U (2002), FDI (2000), and PCCO2 (1996). The economic reunification that was occasioned by the implementation of Mikhail Gorbachev’s glasnost in the 1990s could be held as an explanation for the observable shocks of 1996. Particularly, the official reunification of the German economy on 3 October 1990 saw an unprecedented growth in economy until 1992 when significant declines were apparent. This event affected the upward and downward slope of economic growth in Germany up to the 21st century. The unification lingered to the early periods of the 21st century, specifically in relation to high unemployment, high taxation, and increase in public debt. The distortions of 2008 through 2011 can be attributed to the global financial crisis coupled with oil price shocks. Conclusively, the various highlighted shocks are duly accounted for in the structural break presented in Table 4 of this present study. Furthermore, it should be noted that the combined cointegration orders comprising I(0) and I(1) variables substantiates the adoption of the ARDL estimator.

Table 4. Unit root test.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Augmented Dickey-Fuller</th>
<th>Dickey-Fuller Break Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level</td>
<td>1st Difference</td>
</tr>
<tr>
<td>EG</td>
<td>−1.416</td>
<td>−3.778 **</td>
</tr>
<tr>
<td>TS</td>
<td>−1.429</td>
<td>−7.444 ***</td>
</tr>
<tr>
<td>REC</td>
<td>−0.007</td>
<td>−8.238 ***</td>
</tr>
<tr>
<td>INT_U</td>
<td>−0.282</td>
<td>−3.605 **</td>
</tr>
<tr>
<td>FDI</td>
<td>−3.839 ***</td>
<td>−7.206 ***</td>
</tr>
<tr>
<td>PCCO2</td>
<td>−0.781</td>
<td>−7.222 ***</td>
</tr>
</tbody>
</table>

*** indicate 1% and ** indicate 5% level of significance.

It is indispensable to note that that the dummy variables in the breakpoints are insignificant. Moreover, tests on model stability reveal that the model’s parameters are stable when the dummy variables are absent. Consequently, dummy variables were removed from the ARDL estimations.

4.2. Lag Length Criteria

Before estimating the long-run ARDL model, it is usually important to determine the appropriate lag length that should be observed. Hence, the available options of selection of appropriate lag lengths include final prediction error (FPE), Akaike information criterion
(AIC), and Schwarz information criterion (SC). The results in Table 5 show that the AIC based on lag 3 is the best for the model in this study.

Table 5. Lag length criteria.

<table>
<thead>
<tr>
<th>Lag</th>
<th>LogL</th>
<th>LR</th>
<th>FPE</th>
<th>AIC</th>
<th>SC</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-453.1890</td>
<td>5071345</td>
<td>7075421</td>
<td>32.79922</td>
<td>33.08469</td>
<td>32.88649</td>
</tr>
<tr>
<td>1</td>
<td>-302.6686</td>
<td>225.7807</td>
<td>2115.140</td>
<td>24.61919</td>
<td>26.61749</td>
<td>25.23009</td>
</tr>
<tr>
<td>2</td>
<td>-244.9045</td>
<td>61.89007</td>
<td>664.5097</td>
<td>23.06461</td>
<td>26.77575</td>
<td>24.19914</td>
</tr>
<tr>
<td>3</td>
<td>-153.3053</td>
<td>58.88521*</td>
<td>46.55599*</td>
<td>19.09324*</td>
<td>24.51721*</td>
<td>20.75140*</td>
</tr>
</tbody>
</table>

* Indicates lag order selected by the criterion, LR: sequential modified LR test statistic (each test at 5% level), FPE: final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion.

4.3. Long-Run Cointegration Test

To examine the long-run connection among the variables, we explored the ARDL bounds testing, and the outcomes are presented in Table 6. The decision criterion based on the null hypothesis that no cointegration exists among the indicators posits that the value of the F-statistics should be more than the upper critical value. The results reveal that an F-value of 12.23 is higher than the upper bound value of 4.15. Consequently, the study failed to accept the null hypothesis and approved the existence of significant cointegration between TS, RE, FDI, DT, CO, and EG.

Table 6. Result of ARDL cointegration.

<table>
<thead>
<tr>
<th>F Statistics</th>
<th>Significance Level</th>
<th>Critical Value for Bound Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.2312, K = 5</td>
<td>10%</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>2.5%</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>3.06</td>
</tr>
</tbody>
</table>

4.4. Long-Run and Short-Run Results

The results of the long-run and short-run relationships among the variables are indicated in Table 7. Starting with the long-run outcomes, it is evident that renewable energy positively impacts economic growth but it is not substantial enough to drive economic growth in Germany, suggesting that a proportionate increase in the former increases the latter. Consequently, we can aver that renewable energy is a positive driver of economic growth and would be highly instrumental in achieving sustainable development in Germany. This positive RE-EG nexus that emanates from the study corroborates the work of [43], which submitted that direct relationship between RE and development of service and manufacturing sectors among developed and developing economies. Similar empirical outcomes are evident in [30], who found that RE positively drives EG in a panel study of the South Asian economies. Other previous studies [48,49,51] also provide empirical support to advance the inducing effects of RE on EG.

Further, a positive relationship between transport services (TS) and economic growth is reported in Table 7, implying that TS promotes EG in Germany. Intuitively, a percentage rise in TS would bring about significant improvement on EG. This result is plausible and pro-intuitive since production activities that form the base of a gross domestic product are only considered completed when the goods and services produced reach the final consumptions. The process of completing production activities is enhanced through the transportation system. Hence, it is economically plausible to see TS promoting EG in Germany based on the outcome of this study, which equally confirms the submissions of [23,87], who studied the nexus between road transportation (RT) and economic growth (EG) in China. The study reported that RT positively drives EG. Ref. [67] equally reported the positive and significant impact of freight transportation on economic growth.
Table 7. Long-run and short-run estimations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>3.628</td>
<td>1.052</td>
<td>3.450</td>
<td>0.0182***</td>
<td>ΔTS</td>
<td>3.225</td>
<td>0.279</td>
<td>11.556</td>
<td>0.0001***</td>
</tr>
<tr>
<td>REC</td>
<td>0.541</td>
<td>0.108</td>
<td>5.023</td>
<td>0.0048***</td>
<td>ΔREC</td>
<td>−0.541</td>
<td>0.053</td>
<td>−10.204</td>
<td>0.0002***</td>
</tr>
<tr>
<td>INT_U</td>
<td>3.196</td>
<td>0.034</td>
<td>1.454</td>
<td>0.0027***</td>
<td>ΔINT_U</td>
<td>0.691</td>
<td>0.089</td>
<td>7.768</td>
<td>0.0006***</td>
</tr>
<tr>
<td>FDI</td>
<td>4.048</td>
<td>1.468</td>
<td>2.758</td>
<td>0.0399**</td>
<td>ΔFDI</td>
<td>2.187</td>
<td>0.134</td>
<td>16.319</td>
<td>0.0000***</td>
</tr>
<tr>
<td>PCCO2</td>
<td>1.065</td>
<td>0.541</td>
<td>1.965</td>
<td>0.8758***</td>
<td>ΔPCCO2</td>
<td>15.926</td>
<td>1.169</td>
<td>13.624</td>
<td>0.0000***</td>
</tr>
<tr>
<td>C</td>
<td>−44.797</td>
<td>66.043</td>
<td>−0.678</td>
<td>0.5277</td>
<td>ECT(−1)</td>
<td>−0.608</td>
<td>0.044</td>
<td>13.724</td>
<td>0.0000***</td>
</tr>
<tr>
<td>R²</td>
<td>Adj. R²</td>
<td>0.969</td>
<td>F &gt; 0.000</td>
<td></td>
<td>Observation: 28</td>
<td>Durbin Watson: 2.132</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** indicate 1% and ** indicate 5% level of significance.

The role of technology in promoting economic growth has been widely advanced theoretically following the Solow growth theory and the new growth theory, with empirical studies supporting these advocacies [82,83,88]. Digital technology (INT_U) positively and significantly affects economic growth (EG) in Germany, as evident in Table 7. In addition, carbon emissions appear to be positively and significantly related to economic growth. This supports prior studies, which held that an increase in carbon emissions would correspond with a significant rise in economic growth, thus alluding the positive carbon emissions economic growth interlock [80,81].

The role of foreign direct investment (FDI) in stimulating economic growth (EG) in Germany is confirmed to be positively significant. This suggests that, despite the declining FDI inflows to Germany, the few values on record provide substantial support for the growth of the German economy. This result supports the previously held notion that FDI enhances the transfer of knowledge and promotes technological diffusion [78,79], which fundamentally foster economic growth and development [53].

In conclusion, the above results provide empirically supported evidence to advance for significant and positive long-term impacts of renewable energy, transport services, FDI, digital technology, and carbon emissions on economic growth in Germany.

The short-run results are equally presented in Table 7 on the right-hand side. The results are robust for the long-run effects earlier illustrated. This implies that renewable energy, transport services, FDI, digital technology, and carbon emissions are relevant and fundamental in driving economic growth in Germany both in the short-run and long-run periods. The error correction term (ECT) is crucial to the short-run results, which is provided in Table 7. The ECT result, which shows a significant and negative value (−0.60), implies that the long-run equilibrium deviations are corrected at a 60% lag period. Furthermore, it is worth noting that the ECT result provides support to confirm the existence of long-run cointegration among the variables.

4.5. Diagnostic Test

Two categories of postestimation tests were conducted. The first entails an examination of the model’s stability based on the cumulative sum of recursive residuals (CUSUM). By standard, the values are expected to fall between 56 significance levels for the acute boundaries before confirming stability. The CUSUM and CUSUM square results are indicated in Figure 2, and both confirm that the models employed in the study’s analyses are stable both in the short run and long run.

The second category of tests involves identifying serial correlation, abnormality issues, and heteroscedasticity problems using the Pesaran and Pesaran (1997) LM serial correlation test. The results presented in Table 8 suggest the nonexistence of the above problems in the model.
Figure 2. Stability test results.

Table 8. Diagnostics test.

<table>
<thead>
<tr>
<th>Test</th>
<th>F Statistics and p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Breusch–Godfrey Serial Correlation LM test</td>
<td>F statistics = 0.7962, p-value = 0.1310</td>
</tr>
<tr>
<td>(B) Normality</td>
<td>Jarque–Bera = 0.1376, p-value = 0.9335</td>
</tr>
<tr>
<td>(C) Heteroscedasticity Test</td>
<td>F statistics = 1.0168, p-value = 0.550</td>
</tr>
</tbody>
</table>

4.6. Causality Nexus

It is important to reiterate the fact that the existence of a significant relationship between two variables does not imply causality at the same time. Hence, after having conducted the long- and short-run impacts, we examined the causal nexuses among the variables using the VECM causality test. Among many reasons, the ability of the test to provide a symmetric causal link between variables justifies the choice to adopt VECM [89]. Four hypotheses are evidently confirmed from the results in Table 9. The feedback hypothesis, which posits the existence of bidirectional causality running from transport services (TS), renewable energy (REC), and CO\textsubscript{2} emissions per capita (PCCO2) to economic growth (EG) on the one hand, is confirmed. Similarly, causal effects also run from EG to TS, REC, FDI, and PCCO2. By implication, economic policy implemented to promote improved transportation and enhance the consumption of renewable energy and carbon emissions will significantly affect economic growth. Conversely, policies implemented to promote economic growth will cause significant impacts. Further, the growth hypothesis that explains the presence of unidirectional causality running from technology to economic growth is confirmed in the results. The implication is that economic policies executed to improve the level of technological advancement will have a causal effect on economic growth. Additionally, the conservation hypothesis posits the existence of unidirectional causality running from economic growth to PCCO2 but the reverse case does not apply.
## Table 9. Causality tests results.

<table>
<thead>
<tr>
<th></th>
<th>Short-Run</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D(EG)</td>
<td>D(REC)</td>
<td>D(TS)</td>
<td>D(FDI)</td>
<td>D(INT_U)</td>
<td>D(PCCO2)</td>
<td>ECT</td>
</tr>
<tr>
<td>D(EG(−1))</td>
<td>-</td>
<td>0.639 **</td>
<td>0.151 ***</td>
<td>0.012 **</td>
<td>−0.094</td>
<td>−0.004</td>
<td>−0.123 **</td>
</tr>
<tr>
<td></td>
<td>(0.034)</td>
<td>(0.071)</td>
<td>(0.018)</td>
<td>(0.171)</td>
<td>(0.016)</td>
<td>(0.045)</td>
<td></td>
</tr>
<tr>
<td>D(REC(−1))</td>
<td>0.016 ***</td>
<td>-</td>
<td>−0.097 *</td>
<td>0.078 *</td>
<td>0.012 ***</td>
<td>−1.213 **</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.036)</td>
<td>(0.091)</td>
<td>(0.086)</td>
<td>(0.008)</td>
<td>(0.012)</td>
<td></td>
</tr>
<tr>
<td>D(TS(−1))</td>
<td>−0.055 ***</td>
<td>0.453</td>
<td>-</td>
<td>0.431</td>
<td>−0.071</td>
<td>−0.008 **</td>
<td>−2.992 ***</td>
</tr>
<tr>
<td></td>
<td>(1.212)</td>
<td>(0.454)</td>
<td>(0.431)</td>
<td>(0.041)</td>
<td>(0.002)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D(FDI(−1))</td>
<td>0.239</td>
<td>0.022</td>
<td>0.043 *</td>
<td>-</td>
<td>−0.898</td>
<td>0.012 **</td>
<td>−0.123 **</td>
</tr>
<tr>
<td></td>
<td>(0.309)</td>
<td>(0.555)</td>
<td>(0.082)</td>
<td>(0.197)</td>
<td>(0.018)</td>
<td>(0.045)</td>
<td></td>
</tr>
<tr>
<td>D(INT_U(−1))</td>
<td>−0.084 **</td>
<td>0.348 **</td>
<td>−0.071 *</td>
<td>0.151</td>
<td>-</td>
<td>−0.014 **</td>
<td>−2.123</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.037)</td>
<td>(0.065)</td>
<td>(0.164)</td>
<td>(0.014)</td>
<td>(0.145)</td>
<td></td>
</tr>
<tr>
<td>D(PCCO2(−1))</td>
<td>1.448 ***</td>
<td>−3.913 *</td>
<td>−1.079</td>
<td>−2.527</td>
<td>2.687</td>
<td>-</td>
<td>−1.123 **</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.052)</td>
<td>(0.931)</td>
<td>(2.342)</td>
<td>(2.224)</td>
<td>(0.023)</td>
<td></td>
</tr>
</tbody>
</table>

*** indicate 1%, ** indicate 5%, and * indicates 10% level of significance.

### 5. Conclusions

This study examined the long-run and short-run effects of transport services and renewable energy on economic growth in Germany for the period spanning 1990 to 2020 by employing the ARDL bounds testing model. The estimated model also considers other key variables, such as FDI, digital technology, and carbon emissions. Before embarking on the empirical model estimation, the data employed were subjected to pretests such as unit root and cointegration tests. The results indicate that the variables are of mixed orders comprising both I(0) and I(1). The variation in the order of stationarity further supports the need to employ an ARDL estimator, among other reasons. The bounds test to cointegration reveals the long-run association among the variables going the higher value of F-statistics than the upper bound critical value. Having confirmed the existence of long-run association, the study further examined the effects of the explanatory variables on the outcome variable in the long-run and short-run periods. The results indicate that all the explanatory variables are significantly positive in driving economic growth in Germany in both periods. Similarly, the distortions in the long run are bound to be corrected at a 60% speed of adjustments.

Based upon the empirical findings, the following recommendations are suggested to ensure sustainable growth and development in Germany.

i. The government should implement policies that promote investment in renewable sources of energy. This could involve subsidizing renewables to enhance low pricing, affordability, and accessibility across all income groups.

ii. There is the need for the policymakers to equally sponsor the enactment of a law that will enforce some minimum levels of renewable use by companies in production activities. This is necessary to ensure renewable energy is promoted on all fronts as inactions in this regard might imply the continued dependence on fossil fuel, which may jeopardize the expected results from renewable energy.

iii. The government should embark on policies that will promote green and efficient fuel vehicles in order to mitigate emission challenges.

iv. The government should incorporate local volunteers that will help inform the people in cities and rural areas on the need to embrace clean and renewable energy sources. Specifically, the country’s drive towards a carbonless growth (carbon neutrality) agenda should be made known to all and sundry in order to ensure all hands are on deck to achieve the set targets.

v. The transportation system in Germany should embrace renewable-induced means of transportation such as electric-trains, hybrid-electric vehicles, multiple-occupant vehicles, and service and fright vehicles, among others.
vi. Duty-free and tax exemption on green vehicles should be adopted to motivate firms and private car owners to buy into the transition to a renewable energy transportation system.

vii. The declining FDI implies that the external finances needed to supplement internal finance deficits are not coming in as expected. Furthermore, we could infer that the German economy does not attract foreign investors and multinational companies. Consequently, the government should look inward and promote economic policies that will pull investors and international companies to the country. In essence, the pull factors to FDI should be politically and economically enhanced while the push factors should be equally suppressed.

viii. Since digital technology proves to be growth-inducing and equally on the rise, the government should monitor the progress closely to sustain the strides and avoid any negativity from unchecked technology.

ix. The declining level of carbon emissions, which coincides with rising economic growth, implies some significant achievement in Germany’s decoupling. These strides should be monitored and ensure the progress is sustained. One of the ways to achieve this could be to continuously promote renewable energy.

x. Policies that promote green growth should be sponsored and implemented in order to achieve sustainable development. This could involve promoting improved waste management, low-carbon transport, clean technologies, and sustainable agriculture.

The present study was not without some restricted boundaries, two of which are thus clarified. First, the analyses in this study were based on the assumption of the homogeneity of the explanatory variables. Hence, future studies can explore disaggregated analyses of the regressors’ impacts on economic growth in Germany. For instance, while the study considered only export services as a proxy for transport services, the import angle was neglected. In addition, renewable energy can be further broken down into different components, such as wind, solar, and biomass. These variables are needed to see their individual effects on economic growth. Second, a panel analysis of this type of study is required, especially for the groups in which Germany forms a major participant, such as the G7 and G20, among others. These areas and others are open for future empirical verification.


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