Assessment of financial development on environmental degradation in KSA: how technology effect?

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Abstract
The discourse on the impact of financial development and its effects on environmental quality has been an important research area in the last few decades. The objective of this research attempts to test the technology effect hypothesis on environmental mitigation in the case of Saudi Arabia (KSA) over the period 1970–2016 and the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) with the Autoregressive Distributed Lag (ARDL) model used for empirical inquest. Unlike others, we insert additional variables such as technology, human capital, and the technology effects of financial development into the carbon dioxide emission model. We used the Ng–Perron unit root test to examine the stationary properties of the variables. Similarly, to examine the presence of the cointegration relationship between carbon dioxide emissions and its determinants, the Bound cointegration with multiple structural breaks approach is applied. First, The empirical findings show that financial development and technology have a negative and significant impact on environmental degradation. Second, the technology effects of financial development have an unfortunate effect on environmental mitigation. Finally, lower environmental mitigation is associated with a deepening in total population and affluence. Moreover, findings from the pairwise Granger causality test point that there is no causality running from both financial development and technology to the effect of technology among KSA. On the opposite, we looked at economic growth Granger, cause environmental quality. In addition, a unidirectional causality was seen running from environmental quality to financial development. Similarly, the relationship between affluence and financial development in KSA is unidirectional. Thus, various policy implications should be proposed to policymakers as enhancing the expansion of technology, especially in the industrial sector by incorporating renewable energy consumption to upgrade environmental quality.

Keywords Environmental quality · Financial development · CO2 emissions · Technology · STIRPAT

JEL classification O14 · O16 · Q55

Introduction
For the sake to survive, human devoted all his efforts to invent several and various means and tools shutting for making nature obedient to his will. Unfortunately, his selfishness and greediness do make him unaware and even reckless about the environment and ecosystem services. Accordingly, the economic growth of each country reveals such significant requirements and the fulfillment of some conditions.

Hence, anthropogenic activities boost demand and supply, magnify consumption, and enlarge fossil fuels combustion. Meanwhile, these activities have generated global warming and carbon dioxide emissions which are driven specifically by financial development, real GDP, urbanization, foreign trade, and fossil fuel energy.

Some studies pointed out that the speed of earth temperature is getting higher and even doubles to that of industrial development. In fact, CO2 emissions are regarded as a severe hazard not only to our environment but also to financial development. Global warming has recently captured the world interest since increasing CO2 emissions have caused significant and harsh effects on climate change and human welfare.
Thus, tremendous attention is turned on the linkage between financial development and environmental degradation which let policymakers feel trapped in having such a trade-off between boosting the economy and degrading the environment.

Moreover, the Paris Climate Agreement (PCA) has provided serious opinions and insights aiming at developing strategies to cut down carbon dioxide emissions. Besides, the rapid global economic development was considered the main cause of greenhouse gas emissions. Moutinho et al. (2018) stated that GDP per capita was the key impact of carbon dioxide emission growth. It is regarded also that power intensity, energy efficiency, and economic development were significant factors influencing carbon dioxide emissions in the power industry where the energy structure, economic growth, and population size exerted positive influence on carbon dioxide emissions, but the influence of energy intensity was negative.

Many other studies point that STIRPAT is regarded as a suitable analytic means for investigating the driving factors of ecosystem degradation in which GDP and urbanization impacted significantly CO2 emissions. Furthermore, the STIRPAT model not only was frequently used in investigating the influences of human activities on environmental conditions but also can be employed to check the hypotheses in an empirical way. In this framework, it is very important to consider that urbanization level, population size, GDP per capita, merchandise trade of GDP, and consumption of fossil energy have positive influence on carbon emissions. The later factor is viewed as the fundamental cause of climate degradation and global warning which does emit significantly carbon dioxide into air directly.

In addition, urban population exerts such a significant and positive effect on CO2 emissions resulting from the steady growth of population size and urbanization development proofing a positive correlation between urbanization and carbon emissions since rapid urbanization generates massive demand for power and resulting in an enormous carbon emission. Nevertheless, many studies pointed out that financial development has a significant negative correlation with carbon dioxide emissions where there was such an inverse N-shaped correlation between these basic variables.

Therefore, the big economic powers need to reduce the percentage of environmentally damaging energy and there is an imperative requirement to develop alternative energy, such as geothermal energy, wind power, nuclear energy, and solar energy, in order to solve carbon emission.

About Saudi Arabia, we consider that environment degradation appears basically influenced by various factors including financial development, technology, the technology effects of financial development, real GDP, and population intensity. Moreover, KSA maintains such a stable financial development depending a lot on fossil fuel energy that could cause substantial CO2 emissions. This study may help the kingdom of Saudi Arabia to control its carbon emission in the future and to alleviate global warming. Furthermore, the KSA attempts not only implementing such an innovation-oriented development strategy to encourage innovative firms but also accelerating the development of the service industry that helps to achieve the goal of economic growth as well as reducing environmental degradation, and encouraging investors to move toward the green industry. In order to resolve the dilemma between financial development and carbon emissions, it is necessary for the Saudi policy makers to devote significant efforts to ensure that alternative energy can compete with fossil fuel in the future.

To investigate this linkage relationship between KSA financial development and carbon dioxide emissions via the STIRPAT model valuating the stochastic influences of these factors, our study begins with a first section dealing with the literature review, later it introduces the data as well as methodologies about the STIRPAT model. Besides, results and conclusion point out valuable suggestions and insights for developing the strategies that help solving the issues of environmental sustainability in KSA.

**Literature review**

Building on the framework of Kuznets (1955), Grossman and Krueger (1991) initiates empirical investigation on environmental degradation by incorporating the relationship between income and environmental mitigation which led to the formulation of the environmental Kuznets curve (EKC) hypothesis. The hypothesis denotes that real income degrades the environmental quality initially, but when the threshold of income is overtaken, the environmental mitigation has augmented subsequently. Therefore, the nexus between income-environmental quality will be seen by a standard inverted U-shaped EKC. Therefore, many kinds of research have examined the linkage between income-environmental degradation, but the financial development and environmental quality relationship are few treated in the last decade. Theoretically, financial development has improved environmental quality in 46 sub-Saharan African countries during the period 2000–2015. The result of empirical estimation by a generalized method of moment (GMM) denotes that financial development moderates energy use to increase dioxide carbon emissions (Acheampong 2019). Similarly, Sadorsky (2010) examined the linkage between financial development and energy use in emerging economies between the period 1990–2006. The financial development variable is measured by stock market capitalization and stock market turnover. Therefore, the empirical findings by a generalized method of moment (GMM) estimation show a positive and statistically causality linkage between financial development and energy use. Tamazian et al. (2009) have...
developed a contribution between financial development and environmental quality in BRIC countries, by introducing both variables, economic growth and financial development, to examine the environmental quality over the period 1992–2004. The empirical estimations show that financial liberalization and environmental quality are measured to promote environmental degradation. Al-Mulali et al. (2015) tested the relationship between financial development and environmental mitigation in 129 countries between 1980 and 2011. The Granger causality test shows that environmental quality has a negative impact on carbon dioxide emissions. Paramati et al. (2017) inspected the relationship between environmental quality in G-20 countries over the period 1993–2012 and show that Foreign Direct Investment (FDI) and the stock market with political globalization have a negative impact on carbon dioxide emissions.

The STIRPAT methodology has been broadly applied to evaluate the driving factors of environmental quality, but many researchers have used the STIRPAT models and specify different econometric estimates on different scopes and scales by added and dropped purely traditional variables. Khan et al. (2018) examined the linkage nexus between financial development and carbon dioxide emissions in Asian countries (Bangladesh, India, and Pakistan) using a STIRPAT model during the period 1980–2014 by introducing income inequality and energy use. The FMOLS methodology shows that financial development has a negative and significant impact on environmental degradation. In addition, Usman and Hammar (2020) tested the dynamic linkage between financial development and environmental mitigation by incorporating technological innovations in Asia Pacific Economic Cooperation (APEC) countries over the period 1990–2017. The Westerland cointegration test confirms the long-run association between financial development and environmental quality. Wang et al. (2021) found that financial development by a STIRPAT model improves environmental quality in 198 countries over the period 1990–2018 by introducing ecological footprint. Lin et al. (2017) examined the relationship between financial development and carbon dioxide emissions in non-high and middle-income countries over the period 1991–2013 by incorporating nine variables of the IPAT model. The prostate STIRPAT model shows that financial development decreases environmental degradation in non-high-income countries, but increases environmental mitigation in middle-income countries. Zhang et al. (2016) added the environmental protection technology by a dummy variable into the STIRPAT model in China over the period 2003–2010 to examine the environmental mitigation. Likewise, Zhao et al. (2014) added a water footprint variable on the STIRPAT model on the Chinese agricultural sector over the period 1990 to 2009. The empirical estimation denotes that water footprint has a significant and positive impact on environmental quality. Ren et al. (2018) introduced an environmental settlement in 30 China districts over the period 2000–2013 for the STIRPAT model and decomposed this variable into three types. The empirical findings denote that environmental regulation has no significant impact on China’s ecosystems improvement. Lin et al. (2016) have added agriculture and industrial economic development variables to examine the validity of the environmental Kuznets curve in Africa. The FMOLS approach denotes that the EKC is not valid and both variables, energy structure and energy intensity, have only a significant and positive impact on carbon dioxide emissions. Nosheen et al. (2020) introduced energy use and urbanization on the STIRPAT to explain the effect of financial development on dioxide carbon emissions in Asian and African regions during the period 1995–20018. The FMOLS and DOLS methods explain that financial development has a negative and significant impact on carbon dioxide emissions in both countries used. Nwani (2021) incorporates government consumption expenditure variable with the STIRPAT model in Venezuela to examine the linkage between financial development and carbon dioxide emissions. The linear ARDL testing approach shows that positive shock in financial development denotes a positive impact on environmental quality. Ahmad et al. (2021) incorporated healthcare expenditures variable into the STIRPAT model to examine the dynamic linkage between used variables and environmental quality in 27 Chinese provinces over the period 1990–2018. The empirical estimation by a STIRPAT model demonstrates that a bidirectional causality links between healthcare expenditures and carbon dioxide emissions. Munir and Ameer (2021) incorporated standard variables such as urbanization, trade, economic growth, and technology in the STIRPAT approach in emerging economies between 1975 and 2018. The panel cointegration relationship shows that the U-shaped environmental Kuznets curve is validated. Therefore, this research upholds that supplementary variables used in the STIRPAT model should not be arbitrarily added, but should be relevant for any specification. Guided by Martinez-Zarzoso and Maruotti (2011), we measure the technology variable by the share of the industrial sector in a gross domestic product which is performed by the industry, value added (% of GDP). The technology effects of financial development are expressed by the composite effects of technology and financial development and an additional variable to extend the STIRPAT approach.

Data and methodology

Data

This record explores the dynamic relationship between real GDP, environmental quality, financial development,
technology, population, and the technology effects of financial development in the Kingdom of Saudi Arabia from 1990 to 2016 that joint real GDP per capita (constant 2010 US$), carbon dioxide emissions (CE) quantified in metric tons per capita, financial development (FD) measured by domestic credit to the private sector by banks (% of GDP); regarding the technology, there is no consensus on the ideal measure. The literature review of many studies has used either trade openness, foreign direct investment, or energy intensity. Guided by Martinez-Zarzoso and Maruotti (2011), we measure the technology variable by the share of the industrial sector in a gross domestic product which is performed by the industry, value added (% of GDP). The technology effect of financial development is expressed by the composite effect of technology and financial development. All variables are selected from the database of the World Bank (WDI 2018). Logarithmic dealing has been applied from all variables.

As mentioned, Pairwise Granger causality tests were used to perform the short-run causal links between financial development and environmental quality. The time plot of carbon dioxide emissions, financial development, real GDP, technology, population, and the technology effect of financial development are represented in Fig. 1.

### Methodology

Many researchers have employed the IPAT model to examine the effect of economic growth on environmental quality, but this model has a purview in the econometric model testing hypothesis (Hubacek et al. 2011). Therefore, with the modification of Dietz and Rosa (1997) by using the IPAT model, the STIRPAT model was developed and it can solve the problem of heteroscedasticity and nonlinearity of the models. The STIRPAT model has often been used in inquiring the potency of human spunk on an environmental shape.

The objective of this study is to estimate the existence of relationship between the financial development and the environmental degradation in Saudi Arabia. We use the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology model), which is a multivariate non-linear model and can be expanded to incorporate extra factors, and can be used to check the hypotheses on an empirical way.

The model can be written as follows:

$$ I_t = \alpha_0 P^{\alpha_1} A^{\alpha_2} T^{\alpha_3} \varepsilon_t $$  \hspace{1cm} (1)

This model takes the linear form after taking logarithms:

$$ \ln I_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln A_t + \alpha_3 \ln T_t + \varepsilon_t $$  \hspace{1cm} (2)

where \( I \) is the dependent variable and it represents the environmental quality (dioxide carbon emissions), and the independent variables are as follows: Total population \( P \), Affluence \( A \) measured by GDP per capita (constant 2010 US$), and Technology \( T \) measured by the technology variable by the share of the industrial sector in a gross domestic product which is performed by the industry, value added (% of GDP), guided by Martinez-Zarzoso and Maruotti (2011). The residual series \( (\varepsilon_t) \) and \( \alpha_0 \) are constant; \( \alpha_1, \alpha_2, \alpha_3, \alpha_4, \) and \( \alpha_5 \) are the coefficient of these variables, respectively.

We apply this model in Saudi Arabia, and the variables are derived from the data in KSA over the period 1970–2016. The time series methods are used to analyze the variables with the autoregressive dynamic lagged (ARDL) model used for the empirical inquest. For three reasons, we apply the stationarity test for these variables and the cointegration test must be applied for a long run equilibrium relationship analysis to confirm the existence of long-run cointegration. Therefore, the established STIRPAT model is given as follows:

$$ \ln I_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln A_t + \alpha_3 \ln T_t $$

$$ + \alpha_4 \ln FD_t + \alpha_5 \ln (T*FD)_t + \varepsilon_t $$ \hspace{1cm} (3)

where \( I \) represents the environmental quality. The factor \( A \) is the affluence measured by GDP per capita (constant 2010 US$). The factor \( T \) represents the technology measured by the share of the industrial sector in a gross domestic product which is performed by the industry, value added (% of GDP) in KSA. FD refers to the financial development measured by domestic credit to the private sector by banks (% of GDP). The composite effect \((T*FD)\) by the technology and financial development in KSA is the proxy of the technology effect of financial development. The residual series \( (\varepsilon_t) \) and \( \alpha_0 \) are constant; \( \alpha_1, \alpha_2, \alpha_3, \alpha_4, \) and \( \alpha_5 \) are the coefficient of selected variables, respectively.

### The ARDL bounds cointegration tests

This research explores the relationship between environmental quality, financial development, affluence, population, technology, and the technology effects of financial development. The autoregressive dynamic lagged (ARDL) model is used to investigate whether the long and short run exists between variables of all models based on the log-linear specification of model in Eq. (3). The strength of the linear autoregressive dynamic (ARDL) lagged model to tender trustworthy estimation in small and large samples in order to variables are I(0) an I(1) order of integration, in so far as none of used variables in different models is I(2).

Allowing Pesaran et al. (2001) methodology to survey the dynamic short and long-run association between the environmental quality (CE), financial development (FD), affluence (A), population (P), technology (T), and the effects of technology (T*FD), based on the log-linear specification in Eq. (3).
by the different models (Eq. 4, Eq. 5, Eq. 6), the ARDL is defined as follows:

\[ \Delta CE_t = \alpha_1 CE_{t-1} + \alpha_2 GDP_{t-1} + \alpha_3 POP_{t-1} + \alpha_4 T_{t-1} + \alpha_5 FD_{t-1} + \alpha_6 (T^{*}FD)_{t-1} + \sum_{i=0}^{p} \alpha_7 \Delta CE_{t-i} + \sum_{i=0}^{p} \alpha_8 \Delta GDP_{t-i} + \sum_{i=0}^{p} \alpha_9 \Delta POP_{t-i} + \sum_{i=0}^{p} \alpha_{10} \Delta T_{t-i} + \sum_{i=0}^{p} \alpha_{11} \Delta FD_{t-i} + \sum_{i=0}^{p} \alpha_{12} \Delta (T^{*}FD)_{t-i} + \varepsilon_t \]  

In Eq. 4, CE is the environmental quality, GDP is the economic growth, POP is the human capital, T is technology, FD is financial development, and (T*FD) is the effect of technology. Therefore, the coefficient terms in level \((\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6)\) reflect long-run dynamics, while coefficient terms in the first difference \((\alpha_7, \alpha_8, \alpha_9, \alpha_{10}, \alpha_{11}, \alpha_{12})\) reflect short-run effects. In addition, \(\varepsilon_t\) denotes the error term and \(\Delta\) signifies the first difference operator. The choice of lagged variable \((p)\) is determined according to the Akaike Information Criterion (AIC) or Schwarz Bayesian criterion (S.B.C). Using a Wald test, the presence of cointegration relationship for models is tested by the following:

\[
\begin{align*}
H_0 : & \quad \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0 \quad \text{(absence of long run relationship)} \\
H_1 : & \quad \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq \alpha_6 \neq 0 \quad \text{(presence of long run relationship)}
\end{align*}
\]

The null hypothesis suggests no cointegrating relationship between carbon dioxide emissions and independent variables. The decision to accept or reject the null hypothesis is determined by the Wald test statistic.
hypostasis is based on the calculated F-statistics with Narayan’s (2005) critical value.

\[ \Delta CE_t = \beta_1 CE_{t-1} + \beta_2 GDP_{t-1} + \beta_3 POP_{t-1} + \beta_4 T_{t-1} \\
+ \beta_5 FD_{t-1} + \sum_{i=0}^{p} \beta_6 \Delta CE_{t-i} + \sum_{i=0}^{p} \beta_7 \Delta GDP_{t-i} \\
+ \sum_{i=0}^{p} \beta_8 \Delta POP_{t-i} + \sum_{i=0}^{p} \beta_9 \Delta T_{t-i} \\
+ \sum_{i=0}^{p} \beta_{10} \Delta FD_{t-i} + \epsilon_t (5) \]

In Eq. 5, CE is the environmental quality, GDP is the economic growth, POP is the human capital, T is technology, and FD is financial development. Therefore, the coefficient terms in level \((\beta_1, \beta_2, \beta_3, \beta_4, \beta_5)\) reflect long-run dynamics, while coefficient terms in the first difference \((\beta_6, \beta_7, \beta_8, \beta_9, \beta_{10})\) reflect short-run effects. In addition, \( \epsilon_t \) denotes the error term and \( \Delta \) signifies the first difference operator. The choice of lagged variable \((p)\) is determined according to the Akaike Information Criterion (AIC) or Schwarz Bayesian criterion (S.B.C). Using a Wald test, the presence of cointegration relationship for models is tested as follows:

\[
\begin{align*}
H_0 &: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0 \text{ (absence of long run relationship)} \\
H_1 &: \beta_i \neq \beta_j \neq \beta_k \neq 0 \neq \beta_l \neq 0 \text{ (presence of long run relationship)}
\end{align*}
\]

The null hypothesis suggests no cointegrating relationship between carbon dioxide emissions and independent variables. The decision to accept or reject the null hypothesis is based on the calculated F-statistics with Narayan’s (2005) critical value.

In addition, bounds cointegration tests must be inspected for all models (4, 5, and 6) prior proceeding to the autoregressive dynamic lagged model assessment. The presence of long-run cointegration between variables is tested by the null hypothesis: \(H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0\) against the alternative hypothesis \(H_1 : \alpha_i \neq \alpha_j \neq \alpha_k \neq \alpha_l \neq \alpha_m \neq 0\) for model (4), \(H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0\) against the alternative hypothesis \(H_1 : \beta_i \neq \beta_j \neq \beta_k \neq \beta_l \neq \beta_m \neq 0\), for model (5), and \(H_0 : \omega_1 = \omega_2 = \omega_3 = \omega_4 = 0\) against the alternative hypothesis \(H_1 : \omega_i \neq \omega_j \neq \omega_k \neq \omega_l \neq \omega_m \neq 0\) for model (6). Furthermore, if the calculated F statistic passes through the upper critical value of the bound cointegration test of Narayan (2005), the null hypothesis is rejected. In addition, if the calculated F statistic is under the critical value of the limit bounds cointegration test of Narayan (2005), the null hypothesis of no cointegration is accepted. Finally, if the calculated F statistic is under the superior and inferior limit critical value of the bounds cointegration test of Narayan (2005), the null hypothesis of no cointegration relationship is inconclusive. After estimation results of the log-linear model by the STIRPAT methodology, the diagnostic tests are implemented to uphold the approval results. Furthermore, the heteroskedasticity test of Breusch–Pagan–Godfrey is used to inspect for heteroscedasticity, and the Breusch–Godfrey Serial Correlation LM Test is used to detect the autocorrelation.

**Unit root test**

To verify the integration order for the component of the STIRPAT model, the involvement of any order, if integration I (2) must be removed, and the claim of the linear ARDL are restricted in the variable, integrated I (1), so the ARDL bounds testing approach to long-run cointegration is verified. In this document, we check the stationarity of the STIRPAT model by the Ng–Perron unit root test.

The results of unit root tests of all variables, mentioned in Table 1, are stationary at levels and in the first difference, so integrated into order one I (1), so the log-linear by the STIRPAT model can be used as an ARDL model.

**The bound-testing approach**

In compliance with the results of the cointegration relationship of variables by the log-linear models (STIRPAT) and choose the lag length by the Akaike information criteria (AIC) after appointed the results of the Ng–Perron unit root test.
Lütkepohl (2006) peaked up that the AIC criteria supply an efficient result in track down dynamic relationships. The bounds testing approach for model (1), model (2), and model (3) are introduced in Table 2. The calculated F-statistics of Wald tests of all models are well overhead the upper bound limit of Pesaran et al. (2001) or Narayan (2005) tables at 5% level of significance, so the null hypothesis of no cointegration is rejected, meaning that environmental quality, affluence, population, financial development, technology, and the effect of technology are cointegrated in the long run association in Saudi Arabia. The results of Table 2 confirmed the long run association between all used variables, because the critical values of cointegration of Narayan (2005) (case III: unrestricted intercept and no trend, K=5) are respectively 2.848 and 4.160.

**Empirical results**

Saudi Arabia maintains such a stable financial development a lot on fossil fuel energy that could cause substantial CO$_2$ emissions. This study may help the Saudi Arabia to control its carbon dioxide emissions in the future and to alleviate global warming. Furthermore, the Saudi government attempts not only implementing such an innovation-oriented development strategy encouraging the innovative firms but also accelerating the development of the service industry that helps achieving the goal of economic growth as well as reducing environmental degradation, and encouraging investors to move toward green industry. In order to resolve the dilemma between financial development and carbon emissions, it is necessary for the Saudi policy makers to devote significant efforts to ensure that alternative energy can compete with fossil fuel in the future (Table 3).

Table 4 predicts the short and long-run assessment results founded on the ARDL models. The coefficient of financial development indicates that a 1% rise in financial development decreases CO$_2$ emissions by 0.24% in model 1. This outcome implies that financial development upgrades the environmental quality in Saudi Arabia. The increasing of carbon dioxide emissions that are due to the domestic credit to the private

### Table 1

Descriptive statistics of variables

|           | (T*FD) | T   | POP | FD   | GDP | CE   |
|-----------|--------|-----|-----|------|-----|------|
| Mean      | 11.31150 | 4.09375 | 16.57168 | 2.840544 | 9.997948 | 2.674032 |
| Median    | 11.68339 | 4.007697 | 16.69264 | 3.068460 | 9.879154 | 2.667106 |
| Maximum   | 15.34178 | 4.420175 | 17.29498 | 4.062415 | 10.57521 | 3.015645 |
| Minimum   | 4.472612 | 3.632853 | 15.57962 | 1.011817 | 9.661109 | 2.048999 |
| Std. Dev. | 3.160148 | 0.187255 | 0.506397 | 0.819337 | 0.275661 | 0.201143 |
| Skewness  | −0.438375 | −0.109205 | −0.461489 | −0.631328 | 0.150278 | −0.682754 |
| Kurtosis  | 2.082704 | 2.259696 | 2.038134 | 2.232115 | 2.665236 | 3.494100 |
| Jarque–Bera | 0.206681 | 0.558031 | 0.175511 | 0.117387 | 0.011738 | 0.127173 |
| Sum       | 531.6407 | 188.4406 | 778.8689 | 133.5055 | 469.9036 | 125.6795 |
| Sum Sq. Dev. | 459.3806 | 1.612960 | 11.79612 | 30.88041 | 3.495504 | 1.861100 |

Source: Author computation from the World Development Indicators (WDI) database

### Table 2

Results of Ng–Perron unit root test

| Variables | (T*FD) | T   | POP | FD   | GDP | CE   |
|-----------|--------|-----|-----|------|-----|------|
| CE        | −2.80159 | −1.02637 | 0.36635 | 8.27537 | −12.9014 | −2.40336 | 0.18629 | 2.41652 |
| FD        | 0.65934  | 0.47545  | 0.72110  | 37.0282  | −4.71629  | −1.51377  | 0.32097  | 5.24148 |
| GDP       | −7.79206 | −1.97289 | 0.25319  | 3.14779  | −8.06002  | −1.98702  | 0.24653  | 3.11697 |
| Pop       | 1.37093  | 1.96829  | 1.43573  | 146.577  | −8.86518  | −2.02032  | 0.22789  | 3.08693 |
| T         | −8.24250 | −1.92230 | 0.23322  | 3.37334  | −19.7950  | −3.11830  | 0.15753  | 1.33615 |
| T*FD      | −0.01686 | −0.01069 | 0.63395  | 26.4511  | −2.30782  | −1.06650  | 0.46212  | 10.5622 |

The critical values are −8.10, −1.98, 0.233, and 3.17 for the MZa, MZt, MSB, and MPT tests, respectively. The null hypothesis of Ng–Perron tests is the non-stationarity. The null hypothesis is rejected if the statistic is lower than critical values. Spectral GLS-detrended AR based on AIC criterion (Ng and Perron 2001)

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sector by banks on industry sector in Saudi Arabia is not amazing because the country’s economy is strongly reliant on the oil sector. So, the energy consumption used by the financial sector issued from fossil fuels to spread industrial spunk. In addition, the domestic credit to the private sector by banks was used for investment in the oil sector.

The coefficient of technology variable is positive and statistically significant, that indicates that a 1% increase in technology increases CO2 emissions by 0.20% in the long run. That denotes that the technology used in the financial sector is outmoded which leads to deteriorating environmental quality. In addition, the Foreign Direct Investment (FDI) by foreign investors adopt this method based on the classical methods of production and inexpensive technology to reduce their inceptive costs. These conservative processes need more energy consumption and eventually release more ejections of

| Table 3 Results of bounds cointegration tests |
|-----------------------------------------------|
| Test statistic | Value | Signif. | I (0) | I (1) |
|----------------|-------|---------|-------|-------|
| F-statistic (model 1) | 3.44032** | 10% | 1.81 | 2.93 |
| F-statistic (model 2) | 4.62114** | 5% | 2.14 | 3.34 |
| F-statistic (model 3) | 3.01322*** | 1% | 2.82 | 4.21 |

*indicates 5% level of significance; ** indicates 10% level of significance (Narayan 2005)

| Table 4 Linear ARDL estimation and diagnostic checks (CE dependent variable) |
|-------------------------------|-----------------|-----------------|-----------------|
| Variable | Model 1: CE=f(GDP, POP, FD, T, T*FD) | Model 2: CE=f(GDP, POP, FD, T) | Model 3: CE=f(GDP, POP, FD) |
|-----------------|-----------------|-----------------|-----------------|
| Short-run estimates | | | |
| FD | – | – | 0.251335*** | 0.0133 | – | – |
| FD (−1) | −2.575865** | 0.0025 | – | – | 0.195176** | 0.0688 |
| GDP | 0.721212*** | 0.0013 | 0.306279** | 0.0424 | – | – |
| GDP (−1) | – | – | – | – | 0.218853* | 0.1356 |
| POP | – | – | −0.171472* | 0.0633 | – | – |
| POP (−1) | 0.226632* | 0.1204 | – | – | −0.107634 | 0.2703 |
| T | – | – | 0.152203 | 0.2554 | – | – |
| T (−1) | −2.155576** | 0.0021 | – | – | – | – |
| T(FD) (−1) | 0.671561*** | 0.0008 | – | – | – | – |
| Δ (CE (−1)) | 0.369872*** | 0.0410 | 0.097545 | 0.4883 | – | – |
| Δ (CE (−2)) | 0.452210*** | 0.0107 | – | – | – | – |
| Δ (CE (−3)) | 0.291324*** | 0.0596 | – | – | – | – |
| Δ (FD) | −1.177294 | 0.2256 | – | – | 0.183917* | 0.1263 |
| Δ (GDP) | – | – | – | – | 0.776174*** | 0.0007 |
| Δ (POP) | 4.592368** | 0.0169 | – | – | 3.108432* | 0.1114 |
| Δ (T) | −1.229905 | 0.1682 | – | – | – | – |
| Δ (T(FD)) | 0.252419 | 0.2339 | – | – | – | – |
| Long-run estimates | | | |
| FD | −0.2491966*** | 0.0030 | 0.439170*** | 0.0068 | −0.0398*** | 0.0398 |
| GDP | 0.697722*** | 0.0003 | 0.535176*** | 0.0328 | 0.0993* | 0.0993 |
| POP | 0.219251 | 0.1280 | −0.299622** | 0.0623 | 0.2495 | 0.2495 |
| T | 0.2085367*** | 0.0018 | 0.265952 | 0.2583 | – | – |
| (T*FD) | 0.649688*** | 0.0007 | – | – | – | – |
| ECT (−1) | −1.033668*** | 0.0000 | −0.572294*** | 0.0001 | −0.397532*** | 0.0011 |
| Diagnostic test | F-statistic | Prob. | F-Statistic | Prob. | F-statistic | Prob. |
| RESET test | 0.018582 | 0.8927 | 1.296018 | 0.2625 | 0.772075 | 0.3851 |
| Normality test | 3.019854 | 0.220926 | 0.53617 | 0.758200 | 0.092994 | 0.954567 |
| LM test | 2.046008 | 0.1521 | 0.054609 | 0.9496 | 0.054303 | 0.9472 |
| Heteroskedasticity test | 0.958103 | 0.5290 | 2.436431 | 0.0322 | 2.396436 | 0.0456 |

*indicates 1% level of significance; ** indicates 5% level of significance; *** indicates 10% level of significance (Pesaran et al. 2001)
dioxide carbon emissions into the environment more than the modern technology used.

The elasticity of affluence in all models is positive and statistically significant, indicating that affluence in Saudi Arabia increases environmental quality. Therefore, a 1% increase in affluence increases dioxide carbon emissions between 0.53 and 0.69%. This finding suggests that a rise in affluence damages the environmental quality in KSA (Nasir et al. (2020)). The unfavorable effect of affluence in KSA implies that the production in goods and services led to mitigating poor environmental quality by increasing energy consumption.

The coefficient of the composite effect of technology and financial development is positive and statistically significant, that a 1% increase in technology effect of financial development in KSA led to an increase in environmental quality by 0.64%. Therefore, our findings affirmed the presence of an unfortunate technology effect of financial development in KSA, and denote that technology is a supplement of financial development and stimulate environmental quality.

Table 3 presents the F-statistic value bounds cointegration tests of models 1, 2, and 3 (3.44032, 4.62114, and 3.01322). The latest values are higher than the upper critical value of bounds tests of Narayan (2005) table. Thus, the STIRPAT methodology denotes the long-term cointegration between environmental quality and affluence, technology, population, and technology, and the effect of technology variables is confirmed. In addition, the lagged error correction term ECT (−1) of the three models (−1.033668, −0.572294, and −0.397532) are negative and statistically significant, confirming the long-run association in the STIRPAT models and are adjusted by 1.033%, 0.57%, and 0.39%, respectively. The fixed optimal lag length in models 1, 2, and 3 of the first differences of the STIRPAT methodology is fixed by the Akaike information criterion (AIC) and the Schwarz information criterion (SIC).

Therefore, all three estimation models combine diagnostic tests, such as the Breusch–Godfrey serial correlation LM test, normality tests, and heteroskedasticity test of Breusch–Pagan–Godfrey and the stability tests such us Ramsey RESET test and CUSUM test and CUSUM of squares test (Brown et al. 1975). Thus, all tests indicate that no problems of serial correlation and heteroskedasticity affecting residuals are observed. In addition, Figs. 2, 3, and 4 exposes that CUSUM and CUSUMSQ tests are stable. Thus, the three graphs validated that all used models were confident and stable since all models bring down within the critical value of bounds test at a 5% significance level.

**Pairwise Granger causality tests**

Bounds cointegration long-run relationship techniques denote the relationship between the dependent and the used explicative variables by the STIRPAT approach. However, it is substantial for policymakers to be aware of the direction of the short-run causal linkage between used variables in the STIRPAT model. To this explanation, we use a causality ascertain by Dumitrescu and Hurlin (2012) to establish the causal linkage between variables. The null hypothesis of the analysis states that there was no Granger causality under the alternative hypothesis. Therefore, in Table 5, there was no linear causal relationship between environmental quality and the explicative variables (affluence, technology, population, financial development, and technology effect). In contrast, there exists a linear Granger causality among the carbon dioxide emissions and the independent variables (affluence, technology, population, financial development, and technology effect) as proposed by the alternative hypothesis.

In Saudi Arabia’s status, we establish no bidirectional causality between environmental quality and technology; instead, we looked at economic growth Granger, cause environmental quality. In addition, a unidirectional causality was seen running from environmental quality to financial development. Similarly, the relationship between affluence and financial development in KSA is unidirectional. Therefore, the
environmental degradation causes technology effects at a 1% level of significance, but the affluence causes technology effects at a 5% level significance. However, if we tested the causal relationship between technology, financial development, and the technology effects of financial development, there was no significant causality that existed from financial development and technology to the effects of technology. Considering the variable population, we find a short-run unidirectional link from affluence to the population at a 1% level of significance, but the opposite direction is unobservable. In addition, the short-term causal relationship between technology and population is bidirectional.

**Conclusions and policy implications**

Advance environmental mitigation is key respect in the 2015 sustainable development schedule by the United Nations. Following this project, practically, the majority of countries in the world are intensifying pains to reinforce the goodness of their environment such as Saudi Arabia. Financial development has been highlighted in many researchers to be a practice force of environmental degradation (Tamazian et al. 2009). This motivates this paper to reexamine the nexus relationship between financial development and environmental mitigation in the Saudi Arabia over the period 1970–2016 and the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) with an Autoregressive Distributed Lag (ARDL) model used for the empirical inquest. We also examine the technology effect of financial development on dioxide carbon emissions. In addition, we establish the pairwise causal linkage between financial development and environmental degradation.

This study finds the following results. First, financial development in Saudi Arabia is negatively related with dioxide carbon emissions, denoting that financial development upgrades the environmental quality. Second, the composite effects of both variables’ financial development and technology (technology effects of financial development) are positive and statistically significant in model 1. Thus, the technology effects of financial development are a noxious to the environmental mitigation. The increasing of dioxide carbon emissions that are due to the domestic credit to the private sector by banks on the industry sector in Saudi Arabia is not amazing because the country’s economy is strongly reliant on the oil sector. Therefore, our findings affirmed the presence of an unfortunate technology effect of financial development in KSA, and denote that technology is a supplement of financial development and

**Fig. 3** CUSUM and CUSUMQ from the CE model 2 (CE=f (GDP, POP, FD, T)) (Brown et al. 1975)

**Fig. 4** CUSUM and CUSUMQ from the CE model 3 (CE=f (GDP, POP, FD)) (Brown et al. 1975)
Table 5  Pairwise Granger causality tests

| Null hypothesis                  | F-statistic | Prob. |
|----------------------------------|-------------|-------|
| FD does not Granger cause CE     | 0.58801     | 0.5602|
| CE does not Granger cause FD     | 6.20171     | 0.0045***|
| GDP does not Granger cause CE    | 0.03948     | 0.8434|
| CE does not Granger cause GDP    | 5.73066     | 0.0211**|
| POP does not Granger cause CE    | 1.29041     | 0.2864|
| CE does not Granger cause POP    | 1.40110     | 0.2582|
| T does not Granger cause CE      | 0.38812     | 0.6809|
| CE does not Granger cause T      | 1.63598     | 0.2075|
| T*FD does not Granger cause CE   | 1.41809     | 0.2541|
| CE does not Granger cause T*FD   | 5.89996     | 0.0057***|
| GDP does not Granger cause T*FD  | 5.74770     | 0.0064***|
| FD does not Granger cause GDP    | 0.72492     | 0.4906|
| POP does not Granger cause FD    | 11.0528     | 0.0002***|
| FD does not Granger cause POP    | 2.81443     | 0.0718*|
| T does not Granger cause FD      | 0.98659     | 0.3817|
| FD does not Granger cause T      | 1.04101     | 0.3625|
| T*FD does not Granger cause FD   | 0.80630     | 0.4536|
| FD does not Granger cause T*FD   | 0.16123     | 0.8517|
| POP does not Granger cause GDP   | 3.18497     | 0.0521**|
| GDP does not Granger cause POP   | 11.0625     | 0.0001***|
| T does not Granger cause GDP     | 0.20955     | 0.8118|
| GDP does not Granger cause T     | 2.37481     | 0.1060*|
| T*FD does not Granger cause GDP  | 0.71277     | 0.4964|
| GDP does not Granger cause T*FD  | 3.82686     | 0.0301**|
| T does not Granger cause POP     | 13.8417     | 3.E–05***|
| POP does not Granger cause T     | 2.42345     | 0.1015*|
| T*FD does not Granger cause POP  | 0.08550     | 0.9182|
| POP does not Granger cause T*FD  | 12.2812     | 7.E–05***|
| T*FD does not Granger cause T    | 0.89739     | 0.4157|
| T does not Granger cause T*FD    | 0.25002     | 0.7800|

Note: * and ** significant value at 1% denote significant value at 5% and 10%, respectively (Dumitrescu and Hurlin 2012)

stimulate environmental quality. Third, our research indicates that affluence, population, and technology are positively allied to environmental quality in KSA. Therefore, the environmental quality reaches to be lower, with a higher technology level, greater affluence, and more renewable energy consumptions. Finally, a unidirectional causality was seen running from environmental quality to financial development.

Policymakers in Saudi Arabia should upgrade green financial development which can contribute to emission mitigation. Therefore, we allocate fiscal and taxation action to encourage private financial institutions to invest in green energy. In addition, regarding the result of the technical effects of financial development on environmental quality, policymakers in Saudi Arabia are invited to increase per-capita financial investment in renewable energy over the estimated threshold to reach the desired effects on reducing environmental degradation and it would be vital to protect the financial development sector by providing the private sector more funds to develop research in clean energy use and reduce carbon dioxide emissions.

Furthermore, the KSA attempts not only implementing such an innovation-oriented development strategy to encourage innovative firms but also accelerating the development of the service industry that helps to achieve the goal of economic growth as well as reducing environmental degradation, and encouraging investors to move toward the green industry. In order to resolve the dilemma between financial development and carbon emissions, it is necessary for the Saudi policymakers to devote significant efforts to ensure that alternative energy can compete with fossil fuel in the future with the regular technology effects of financial development.

Author contribution Abduussalam Aljadani designed the study, studied the concepts or design, dealt with data collection, and performed the calculations so as to write the manuscript.

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