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ECONOMIC UNCERTAINTY, (GEO)POLITICAL RISK, AND SUSTAINABLE DEVELOPMENT GOALS

Old wine in a new bottle: Applying the novel dynamic ARDL simulations approach to explore the impact of energy efficiency, financial development, economic growth, foreign direct investment, and urbanization on CO_2 emissions

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Abstract
Achieving carbon neutrality targets is crucial while considering the adverse impacts of carbon dioxide emissions (CE) on human life and the ecosystem. Therefore, its socioeconomic drivers have frequently been probed in the existing body of literature. Therefore, we investigate the impact of energy efficiency, FDI, financial development, urbanization, and economic growth on CE in Pakistan from 1975 to 2020. For this purpose, we apply the novel dynamic ARDL simulation approach to retrieve the short- and long-run estimates. The empirical results confirm that cointegration exists among the considered variables. Further, both the short- and long-run results reveal that energy efficiency impedes emissions, whereas urbanization, financial development, and FDI increase emissions. Considering the outcomes, there is a need to enhance energy efficiency in Pakistan. For this purpose, investment in technological advancements and innovations is required. Moreover, R&D in the energy sector should be promoted.

Keywords Financial Development · Urbanization · Foreign Direct Investment · CO_2 Emission · Energy Efficiency · Dynamic ARDL simulations

Introduction

Pakistan stands among the few countries in the world which are extremely affected by the heat wave and weather events (Kreft et al. 2017). The heat wave in the summer of 2015 was the cause of more than 1200 deaths in Karachi (i.e., a city in Pakistan) (Cheema 2015). The adverse change in climatic conditions leads to famines and floods, which result in the displacement of almost 10 million people in Pakistan and costs around $14 billion per year (Zhang et al. 2017). Among various greenhouse gasses, carbon dioxide emission (CE) is a major element, mainly responsible for global warming. The amount of CE has gradually been increasing in Pakistan, which adversely affects the climate conditions (Shahzad et al. 2017). Due to environmental degradation, the ozone layer is being affected which becomes a cause of various human diseases and glacier melting. Several socioeconomic factors exert a profound impact on CE (Shahbaz et al. 2013; Acharyya 2009).

Economic activities augment economic growth (EG) but also become a cause of environmental degradation

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(ED). Over the previous few decades, the attention of the world has shifted towards environment-friendly growth. However, this issue could not draw much attention from those policymakers who think that the environment is explicit to EG (Nasir and Rehman 2011). The increasing threat of climate change and global warming has called for more attention and discussion about the issues of the global environment. The higher temperature of the global average ocean and air, glacier melting, and rise in global sea level are some thoughtful indications of global warming (Saboori et al. 2012). CE has a vital contribution to overall greenhouse gas emissions as well as a major role in climate change and global warming (World Bank 2020). CE is the main culprit among all greenhouse gasses (GHG) emissions that cause global warming (Paul and Bhattacharya 2004; Baek 2016). The contribution of CE to the world's total GHG emissions was almost 67% in 2015 (World Bank 2020).

The financial sector is a driving force for EG but, on the other side, it also affects the ED. The impact of the financial sector on ED is ambiguous, depending on the maturity level of this sector. The financial development (FD) decreases the ED through the reallocation of financial resources for advanced technology and environment-friendly projects (Tamazian et al. 2009). On the other hand, a financial sector is said to be immature, if the sole motive of both the lender and investor is to maximize their profit without giving any attention to ED and such a financial sector becomes a cause of ED (Bello and Abimbola 2010).

Next, foreign direct investment (FDI) plays an important role in the process of economic development of the host countries via foreign capital, advanced technology, and skilled labor (Azam and Lukman 2010). FDI significantly increases the economic growth of Pakistan through knowledge spillovers, and capital accumulation decreases unemployment and also enhances the living standard of people. During the late 1980s and 1990s, the FDI inflow rapidly expanded in all regions of the world, energizing the extensive and argumentative discussion regarding the positive and negative impacts of FDI inflows. The advantages of FDI to the host country cover export promotion, transfer of capital and technology, and access to skilled labor and market (Acharyya 2009). But on the other side, FDI affects the ED. The pollution of developing countries would be reduced through FDI; by getting updated as well as environment-friendly equipment from developed economies (Al-mulali and Tang 2013).

Similarly, urbanization (URB) causes CE (Shahbaz et al. 2013; Anwar et al. 2021b). URB contributes to massive energy consumption, which results in high CE (Shahbaz et al. 2014). Further, URB propels investment in pollution-intensive sectors, which in turn upsurges CE (Brahmasrene and Lee 2017; Dogan and Turkekul 2016). One strand of literature supports this argument that URB has a positive influence on energy usage and CE (Poumanyvong and Kaneko 2010; Wang et al. 2016). On the contrary, another strand claims that URB has no significant influence on CE because energy consumption (EC) does not increase due to the majority of the population having a low level of income (Ali et al. 2016; Ozturk et al. 2010).

Parallel to this, energy efficiency (EEF) is a tool that can exert a positive impact on ED through increasing CE. It is worth noting that EEF is referred to as producing the given amount of output with a relatively low level of energy. Hence, improved EEF is one of the low-cost instruments to achieve carbon neutrality. Moreover, it also combats the issues of energy security and sluggish EG. There is a growing body of knowledge on the EEF-CE nexus (Ozturk 2010), nonetheless, empirical evidence in the case of Pakistan is still scant.

After considering all above discussion, the aim of this study is to explores the impression of energy efficiency, urbanization, financial development, foreign direct investment, and economic growth on carbon emission in Pakistan during 1975-2020. The contribution of present study in the existing literature is many folds. Firstly, this study is an earliest attempt to investigate the impact of energy efficiency on carbon emissions by incorporating the role of urbanization. It is worth noting that DARDL delineates the graphical explanation of the effect of shock in regressors on the predicted value of the dependent variable. This graphical analysis helps in future policy formulations related to sustainable development. No empirical evidence exists which employs the novel DARDL simulations approach to discern the impact of EEF, URB, FD, and FDI on CE. Thirdly, the previous theoretical and empirical studies for different countries on the relationship between EEF, URB, FDI, FD, and CE have presented inconclusive and mixed results. These studies present controversial views regarding the relationship among these variables. Keeping in view the policy importance of the process of EEF, URB, FDI, FD, and CE, there is a need to conduct a study by including these aforementioned variables in Pakistan for better policy formulation. Thus, the present study attempts to satisfy this need for building better environmental policy by investigating the impact of EEF, URB, FDI, FD, and EG on CE in the case of Pakistan.

Literature Review

This section discusses the prevailing studies which investigates the link between socioeconomic determinants of carbon emissions. For instance, Jalil and Feridun (2011) stated that FD decreases ED by decreasing emissions. Similarly, Frankel and Romer (1999) believed that FD attracts FDI, which becomes a cause of advanced research and technology and hence leads to low CE. Tamazian and Rao (2010) demonstrated that FD decreases ED by decreasing the volume of CE in countries where institutions are strong, and vice versa. On the contrary, the literature also concludes that the FD has an insignificant influence on ED (Dogan and Turkekul 2016). Shahbaz et al. (2013) argued that FD is a tool to impede emissions with the help of effective financial reforms. However, several research outlets reveal that there is an insignificant effect of FD on ED (see, for example, Ozturk and Acaravci 2013). The existing literature also reports that FD has a positive link with CE, which means that ED upsurges due to FD (Javid and Sharif 2016).

Next, Lau et al. (2014) explored the association between EG, FDI, and CE in Malaysia. To analyze the cointegration and direction of relation, they applied the ARDL approach. The short and long-term results confirmed the presence of the environmental Kuznets curve (EKC) hypothesis while FDI contributes to ED. The authors also found the two-way causal relations between emissions and EG, and between FDI and EG. Similarly, Tang and Tan (2015) investigated the link between FDI, energy, EG, and CE in Vietnam. To check the cointegration, they applied the Johansen cointegration technique. The long-run empirical findings revealed that the FDI plunges ED while consumption of energy and income enhance ED. Next, Wang et al. (2016) explored the association between URB, energy use, and CE for ASEAN countries. To test the cointegration among the variables the authors applied the FMOLS method. The empirical finding shows that URB and energy increase CE.

Likewise, there are several studies in the exisiting literature which has used similar variables such as, Ozturk and Bilgili (2015); Ozturk et al. (2016); Yang et al. (2023); Jahanger et al. (2023, 2023a, 2023e); Syed et al. (2019); Yang et al. (2023a); Ozturk and Acaravci (2010, 2013, 2011, 2016); Anser et al. (2021, 2021a, b, c); Jahanger et al. (2022); Jiang et al. (2022); Anwar and Malik (2021); Yu et al. (2023); Chang et al. (2019); Anwar et al. (2021a, 2021d), Bhowmik et al. (2021); Hashmi et al. (2022); Xu et al. (2023); Jahanger et al. (2023b, c, d); Esmaeili et al. (2023); Liu et al. (2022a, b); Cai et al. (2022); and Wen et al. (2022); Ozturk and Ullah (2022); Ozturk (2007, 2015, 2017, 2017a); Ozturk and Salah Uddin (2012); Ozturk and Al-Mulali (2015, 2015a). but the results of these studies are inconclusive and mixed. Such as, Dogan and Turkekul (2016) scrutinized the association among CE, energy, EG, URB, and FD in the USA. The empirical findings demonstrated that the major causes of CE in the USA are energy consumption and URB whereas the financial sector does not influence CE. Next, the existing literature reports EEF as a key instrument to curb CE at a relatively low cost. Xia et al. (2020) confirmed that, in the industrial sector, an increase in EEF leads to low levels of CE. Further, Li et al. (2022) presented that EEF has an asymmetric effect on CE. Similarly.

Data and Methodology

Data

This study investigates the influence of energy efficiency (GDP to energy consumption ratio), urbanization (ratio of urban population to total population), financial development (percentage share of GDP), foreign direct investment (percentage of GDP), and GDP (constant US dollar 2010) (Syed et al. 2022; Syed and Bouri 2022a, b; Farooq et al. 2021; Jiang et al. 2023; Anwar et al. 2023a, b; Salem et al. 2021; Anwar et al. 2023) on CE (CO_2 emission-kilo ton per capita) (Anwar et al. 2021b, c; Li et al. 2022; Liu et al. 2022c; Husnain et al. 2022; Bhowmik et al. 2023; Chien et al. 2021; Anwar et al. 2022; Sun et al. 2022; Wang et al. 2022; Jun et al. 2021; Habiba et al. 2022) during 1975-2020. The dependent variable is CE while all other indicators are independent variables. The data for all the indicators are collected from the World Development Indicators (World Bank 2020). The natural logarithm of the entire dataset is taken.

Model Specification

In the literature on environmental economics, the environmental Kuznets curve (EKC) and the STIRPAT[1] framework are the two eminent models that are being used to explore the socioeconomic drivers of CE. The STIRPAT model notes that CE mainly depends on affluence (EG), technology (EEF), and population (URB). Contrarily, the EKC framework notes that there exists an inverted U-shaped association between EG and CE. The present study augments the EKC framework into the STIRPAT model to formulate a comprehensive model that contains the characteristics of both the EKC and the STIRPAT model. Thus, our augmented STIRPAT model explores whether EEF, URB, FD, EG, and FDI impact CE.

[1] For detailed discussion on the STIRPAT model, see the study of Syed et al. (2022).

The model that we use is reported as follows:

$$CE = f(EG, EG2, EEF, FDI, FD, URB) \tag{1}$$

From Eq. (1), CE, EG, EG2, EEF, FDI, FD, and URB denote carbon dioxide emissions, per capita GDP, the square of per capita GDP, energy efficiency, foreign direct investment, financial development, and urbanization, respectively.

Methodology

There are different econometric techniques for investigating the dynamic association among the variables. Engle and Granger (1987), and Johansen and Juselius (1990) are generally applied to determine the presence of cointegration. These techniques require the same order of integration of variables for cointegration. The present study uses the ARDL bounds test put forward by Pesaran et al. (2001) to discern the cointegration among the considered variables. The ARDL approach has various advantages compared to other cointegration techniques. The ARDL approach could be applied regardless of whether the variables are stationary at the level (I (0)) or the first difference (I (1)) or the mix of both of them. It is better for a small sample size. It suggests a clear test for the presence of a distinctive cointegration vector, rather than assuming the existence of a vector. The selection of appropriate lag in the ARDL approach is suitable for the problem of endogeneity and serial correlation. ARDL technique provides better outcomes for a small sample in contrast to other cointegration techniques (Haug 2002).

The representation of Equation (1) in ARDL format is provided as follows:

$$\begin{aligned}\Delta CE_t = a_1 &+ \sum_{i=1}^{p} \beta_{1i}\Delta CE_{t-i} + \sum_{i=0}^{p} \beta_{2i}\Delta EEF_{t-i} \\ &+ \sum_{i=0}^{p} \beta_{3i}\Delta EG_{t-i} + \sum_{i=0}^{p} \beta_{4i}\Delta EG^2_{t-i} + \sum_{i=0}^{p} \beta_{5i}\Delta FDI_{t-i} \\ &+ \sum_{i=0}^{p} \beta_{6i}\Delta FD_{t-i} + \sum_{i=0}^{p} \beta_{7i}\Delta URB_{t-i} \\ &+ \beta_8 CE_{2t-1} + \beta_9 EEF_{t-i} + \beta_{10} EG_{t-i} + \beta_{11} EG^2_{t-i} \\ &+ \beta_{12} FDI_{t-i} + \beta_{13} FD_{t-i} + \beta_{14} URB_{t-i} + \varepsilon_t\end{aligned} \tag{2}$$

If, after the application of the first step, the cointegration is validated among the variables then the long- and short-term models can be estimated in the second step. The short- and long-term models are represented in equations (3) and (4), respectively.

$$\begin{aligned}\Delta CE_t = a_2 &+ \sum_{i=1}^{p} \gamma_{1i} CE_{t-i} + \sum_{i=0}^{p} \gamma_{2i} EEF_{t-i} + \sum_{i=0}^{p} \gamma_{3i} EG_{t-i} \\ &+ \sum_{i=0}^{p} \gamma_{4i} EG^2_{t-i} + \sum_{i=0}^{p} \gamma_{5i} FDI_{t-i} + \sum_{i=0}^{p} \gamma_{6i} FD_{t-i} \\ &+ \sum_{i=0}^{p} \gamma_{7i} URB_{t-i} + \varepsilon_t\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta CE_t = a_3 &+ \sum_{i=1}^{p} \beta_{1i}\Delta CE_{t-i} + \sum_{i=0}^{p} \beta_{2i}\Delta EEF_{t-i} \\ &+ \sum_{i=0}^{p} \beta_{3i}\Delta EG_{t-i} + \sum_{i=0}^{p} \beta_{4i}\Delta EG^2_{t-i} + \sum_{i=0}^{p} \beta_{5i}\Delta FDI_{t-i} \\ &+ \sum_{i=0}^{p} \beta_{6i}\Delta FD_{t-i} + \sum_{i=0}^{p} \beta_{7i}\Delta URB_{t-i} + \varphi ECT_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

Where the coefficient of error correction term (ECT) is denoted by ϕ. Next, ECT is explained as follows:

$$\begin{aligned}ECT = CE_t - a_2 &- \sum_{i=1}^{p} \gamma_{1i} CE_{t-i} - \sum_{i=0}^{p} \gamma_{2i} EEF_{t-i} \\ &- \sum_{i=0}^{p} \gamma_{3i} EG_{t-i} - \sum_{i=0}^{p} \gamma_{4i} EG^2_{t-i} - \sum_{i=0}^{p} \gamma_{5i} FDI_{t-i} \\ &- \sum_{i=0}^{p} \gamma_{6i} FD_{t-i} - \sum_{i=0}^{p} \gamma_{7i} URB_{t-i}\end{aligned} \tag{5}$$

It is worth reporting that the short- and long-term estimates can be retrieved through the ARDL approach, however, its complex dynamic structure/setting leads to certain issues during estimating and interpreting the parameters. On the independent side, the presence of multiple lags, their differences, and lag differences create a few complications in the ARDL estimation procedure. On top of this, the DARDL produces dynamic plots that depict the impact of positive and negative shocks in independent variables on the predicted value of the dependent variable. In this analysis, we apply 5000 simulations while estimating the novel DARDL model. While adopting the optimal lags, we use the AIC. Moreover, we also use several diagnostics to check the good fit of the model. It is worth noting that the equations of ARDL and DARDL are the same, while the estimation procedure is different in both of these approaches.

Results and Discussion

This section reports the empirical outcomes. Firstly, we report the preliminary statistics. Thereafter, we report the findings from the unit root tests. Next, we highlight the optimal lag selection criteria with the consort of the

Table 1 Descriptive Statistics

	CE	URB	EEF	FD	FDI	EG
Mean	86425.4	30.9506	411.71	23.810	0.77772	781.018
Median	81246.05	30.9527	425.53	24.213	0.54640	796.765
Maximum	171150.1	38.1949	539.955	29.786	3.66832	1142.75
Minimum	18929.05	24.5529	285.164	15.382	-0.06324	453.768
Std. Dev.	51256.22	3.92479	78.2389	3.5705	0.82229	205.976
Skewness	0.271229	0.03718	-0.1475	-0.621	2.11537	0.03690
Kurtosis	1.681365	1.94721	1.67076	3.0159	7.23269	1.87273
Jarque-Bera	3.727274	2.04213	3.3987	2.8252	65.6608	2.33967
Probability	0.155107	0.36021	0.18280	0.2435	0.00000	0.31041
Sum	3802721.	1361.82	18115.1	1047.9	34.2200	34364.8
Sum Sq.Dev.	1.13E+11	662.370	263217	548.19	29.0748	1824336
Observations	45	45	45	45	4T	

The dataset used in Table 1 is without logarithmic transformation

Table 2 Augmented Dickey-Fuller (ADF) Unit Root Test

Variables	ADF Test at Level		ADF Test at 1st Difference	
	Intercept	Probability value	Intercept	Probability value
CE	-3.197964**	0.0271	-3.036770**	0.0398
URB	-0.533713	0.8744	-6.095178***	0.0000
EEF	-1.029880	0.7341	-6.359726***	0.0000
FD	-1.112494	0.7024	-5.236169***	0.0001
FDI	-2.846397	0.0607	-7.793107***	0.0000
EG	-1.053327	0.7251	-5.031590***	0.0002

***, **, and * show level of significance at 10%, 5%, and 1% sig. level, respectively

ARDL bounds test. After that, we note the findings from the novel DARDL simulation.

The descriptive statistics are presented in Table 1. The mean value of CE is recorded as 86425.48 kilo ton per capita (kt/capita) while the maximum value of CE recorded in 2015 is 171150.1 kt/capita and 18929.05 kt/capita is the minimum value of CE that occurred in 1972. The mean values of URB, EEF, FD, FDI, and GDP are recorded as 30.95% of the total population, 411.70, 23.81% of GDP, 0.78% of GDP, and US$781.01 million respectively. The statistics describe that the skewness of EEF and FD are left-skewed while the skewness and kurtosis of all other variables are right-skewed.

Table 3 Phillips-Perron (PP) Unit Root Test

Variables	PP Test at Level		PP Test at 1st Difference	
	Intercept	Probability Value	Intercept	Probability value
CE	-3.036165*	0.0394	-6.598750	0.0000
URB	-0.473794	0.8864	-6.186536	0.0000
EEF	-1.058055	0.7236	-6.358800	0.0000
FD	-1.533206	0.5075	-5.215899	0.0001
FDI	-2.841027	0.0614	-7.666019	0.0000
EG	-1.419615	0.5639	-5.028581	0.0002

***, **, and * show level of significance at 10%, 5%, and 1% sig. level, respectively

The results from both the ADF and PP unit root tests are reported in Table 2 and Table 3, respectively. The findings show that CE is stationary at the level while EEF, EG, FD, FDI, and URB are stationary at their first difference. Since all selected variables are integrated either at I (0) or I (1), we can employ the ARDL models.

The outcomes from the ARDL bounds test are reported in Table 5. The outcome demonstrates that the calculated value of F-statistics is higher than the upper bounds critical value at 1%, which notes the existence of cointegration among the selected indicators.

The findings from the novel DARDL are delineated in Tale 6. Section-A contains the short-term results while the long-term findings are highlighted in section-B. Moreover, section-C reports the diagnostics. It is a point to note that all variables are statistically significant in the short- and long-run. This indicates that EG, URB, FD, FDI, and EEF have an impact on CE in Pakistan. The coefficient on EG and EG2 is >0 and <0, respectively. This confirms the validity of the EKC hypothesis across the short- and long-run. This outcome is backed

Table 4 Lag Length Selection

VAR Lag Order Selection Criteria						
Lag	LogL	FPE	LR	SC	HQ	AIC
0	200.4335	1.49e-13	NA	-9.3761	-9.5648	-9.6716
1	491.1844	8.70e-19	465.201	-19.3947*	-20.9043*	-21.759
2	550.8941	6.41e-19*	74.637*	-17.8614	-20.6917	-22.294*

The optimal lag length criteria are depicted in Table 4

Table 5 ARDL Bounds Test

ARDL Cointegration Test	Calculated value	Lag-order	Significance level	Bound Critical Value (Un-restricted intercept and trend)	
F-statistics	6.4226**	6		I(0)	I(1)
			1%	3.15	4.43
			5%	2.45	3.61
			10%	2.12	3.23

*** and ** denote significant levels at 5% and 1%

by the findings of Syed and Bouri (2022), claiming that the EKC exists in the US.

Next, EEF is statistically significant with a negative sign in the short- and long-run. Particularly, EEF is -0.09 and -0.79 in the short and long-term, respectively. This implies that a 1% upsurge in EEF impedes emissions by 0.09% and 0.79% in the short and long-run, respectively. The improved energy-efficient technologies lead to higher output with lower levels of energy consumption which in turn plunges emissions. Further, URB is 0.31 and 0.01, indicating that a 1% surge in URB escalates emissions by 0.31% and 0.01% in the short- and long-term, respectively. We confirm similar findings as reported by Liu et al. (2022c). It is a point to report that URB entails an enormous amount of energy, which eventually leads to a higher level of emissions.

Table 6 Results from the novel DARDL simulations model

Indicator	Coefficient	*p*-value
Section-A		
EG	0.73***	0.00
EG2	-0.09**	0.03
EEF	-0.45*	0.08
URB	0.31*	0.06
FD	0.01**	0.04
FDI	0.01**	0.03
Section-B		
EG	1.08***	0.00
EG2	-0.03**	0.02
EEF	-0.79***	0.00
URB	0.01*	0.05
FD	0.03***	0.00
FDI	0.01*	0.07
Section-C		
ECT	-0.59**	0.06
R-square (adjusted)	0.66	

***, **, and * show level of significance at 10%, 5%, and 1% sig. level, respectively

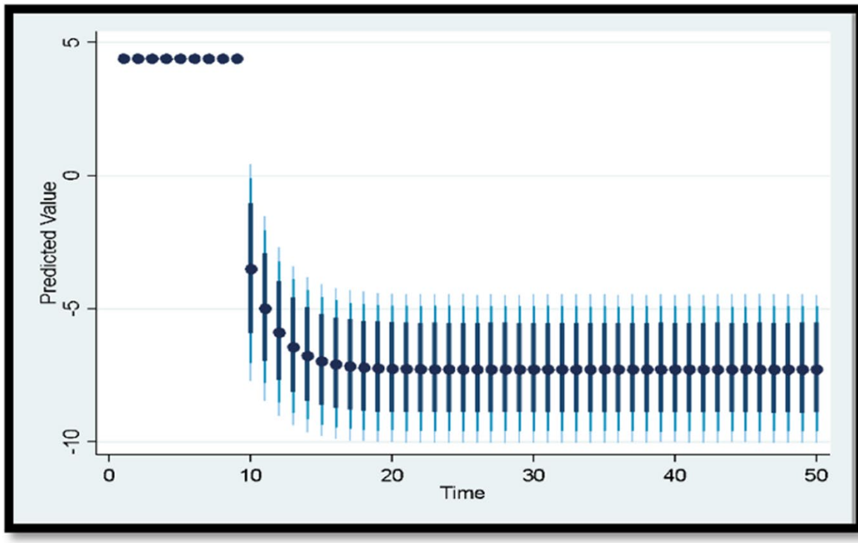
Next, FD is 0.01 and 0.03 during the short- and long-run, indicating that a 1% increase in FD enhances emissions by 0.01% and 0.03% in the short- and long-term, respectively. The reason could be the reality that FD improves the credit system and/or money regulation in the economy coupled with the ease of getting loans which in turn leads to economic growth at the cost of higher emissions. The findings related to FD are similar to the results of Jalil and Feridun (2011). Likewise, the FDI is 0.01 across the long- and short-term, delineating that a 0.01% upsurge in emissions is fostered by a 1% increase in FDI. The upsurge in industrial production due to higher levels of FDI could be one of the reasons behind an enormous volume of CE in Pakistan. Similar findings are reported by Chen and Wu (2017).

Finally, section-C notes the key diagnostics. The error correction term (ECT) is statistically significant with a negative sign, indicating that any deviation from the long-run equilibrium will be covered over time. Further, the adjusted R-square is 0.66, explaining that 66% variation in CE is explained by the selected independent variables (Tables 6).

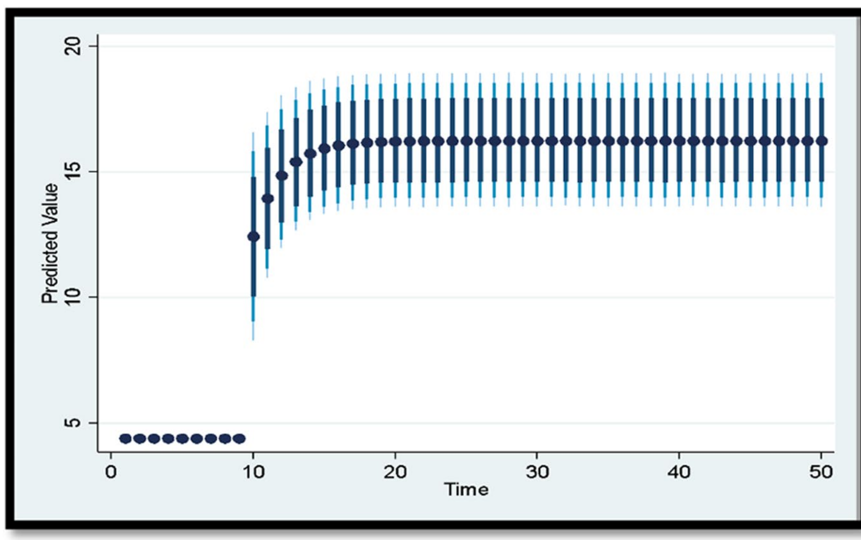
Next, we report dynamic plots in Fig. 1. The dynamic plots explain the impact of positive and negative shock in an independent variable on the predicted value of the dependent variable (i.e., CE in our case). Figures 1(a) and (b) report the impact of a positive and negative shock in EEF on the predicted value of CE, respectively. As can

Fig. 1 **a** A positive shock in EEF. **b** A negative shock in EEF. **c** A positive shock in EG. **d** A Negative shock in EG. **e** A positive shock in URB. **f** A negative shock in URB. **g** A positive shock in FD. **h** A Negative shock in FD. **i** A positive shock in FDI. **j** A negative shock in FDI

(a)



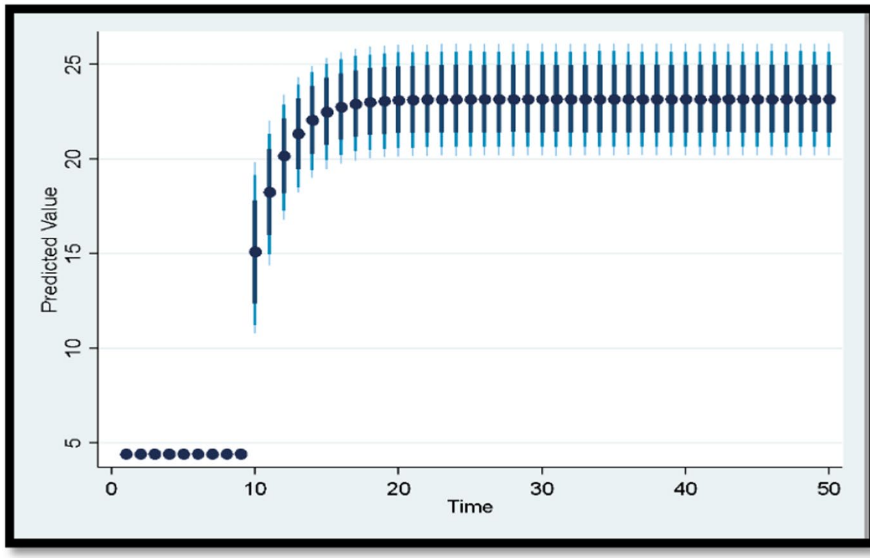
(b)



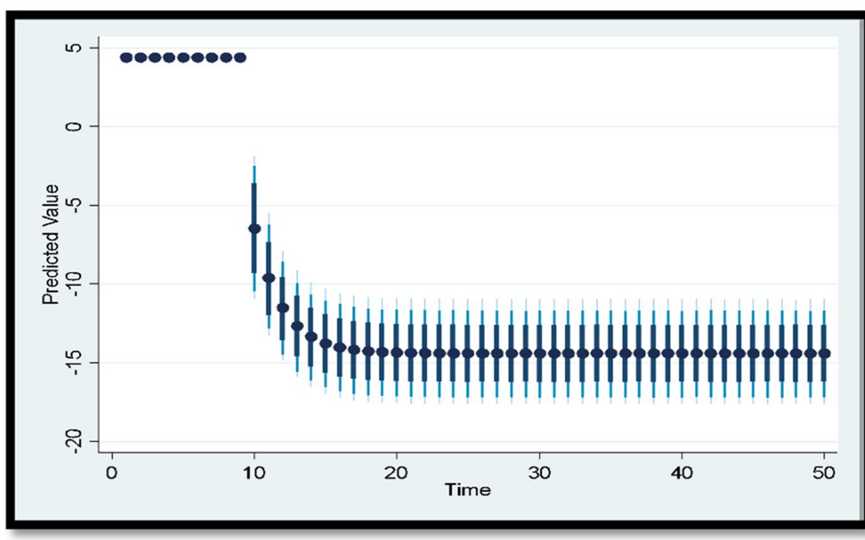
be seen that a positive shock in EEF plunges CE whereas a negative shock escalates it across the long- and short-run. Similarly, Figs. 1(c) and (d) note the impact of a positive and negative shock in EG, respectively. It can be delineated that a positive shock in EG enhances CE while a negative shock plunges CE in Pakistan. Likewise, Figs. 1(e) and (f) depict the impact of a positive and negative shock in URB. The dynamic plots reveal that a positive shock in URB upsurges the predicted value of CE whereas a negative shock curbs CE in both the long- and short-term. Next, Figs. 1(g) and (h) note the impact of a positive and negative shock in FD, respectively. We document that a positive shock in FD boosts CE whilst a negative shock plunges CE across the long- and short-run. Similar findings are reported in the case of FDI, which are depicted in Figs. 1(i) and (j).

Fig. 1 (continued)

(c)



(d)



Figures 2 and 3 depict the graphs of CUSUM and CUSUMsq proposed by Brown et al. (1975). These tests are useful to examine the correctness of the model specification. The null hypothesis will be accepted if the plots of both CUSUM and CUSUMsq are lies within the critical boundaries. The plot in Figs. 2 and 3 lies within the critical boundaries which confirm the reliability of the coefficient of regressors for the long-run which affects the environmental degradation in Pakistan.

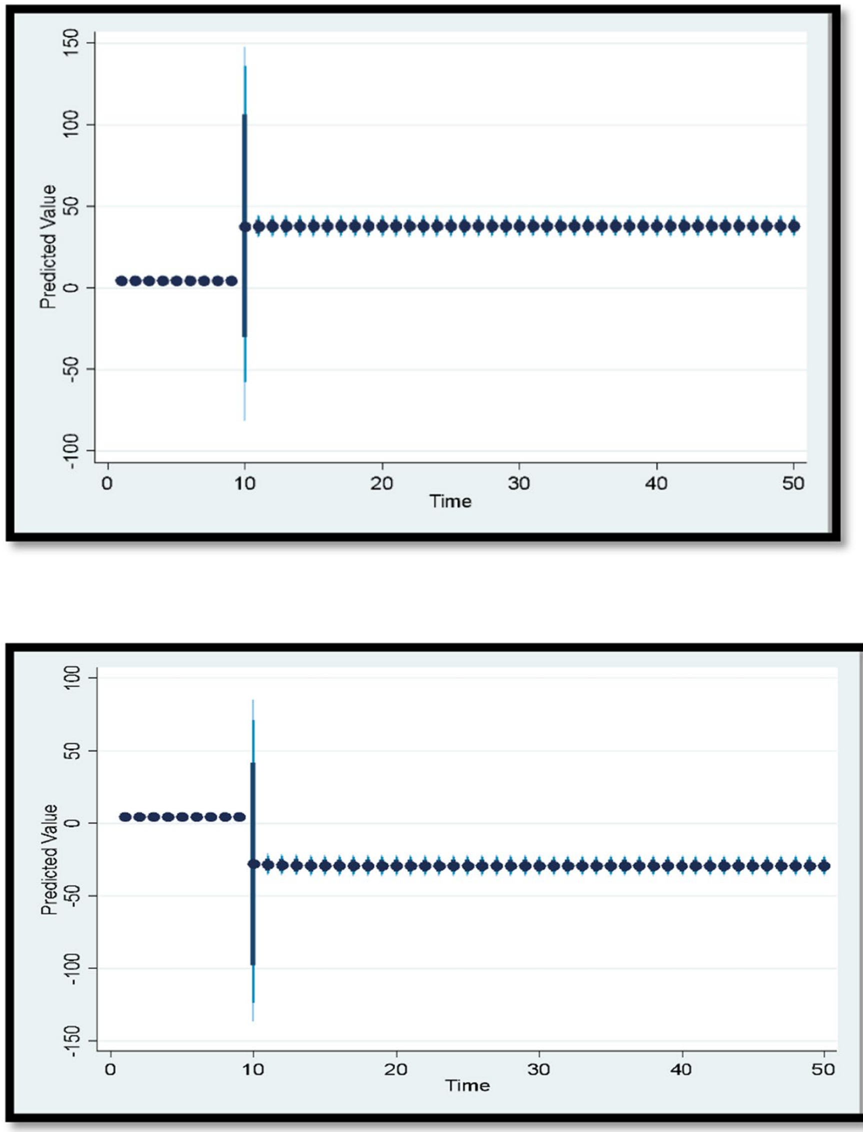
Conclusion and Policy Implications

From the last few decades, environmental degradation is considered as a serious issue for the entire world. CO_2 emissions (CE) are blamed to be a leading source of environmental degradation, therefore, researchers and policymakers are concerned about the factors that impact CE. Based on this, present study investigates the impression of energy efficiency (EEF), economic growth

Fig. 1 (continued)

(e)

(f)

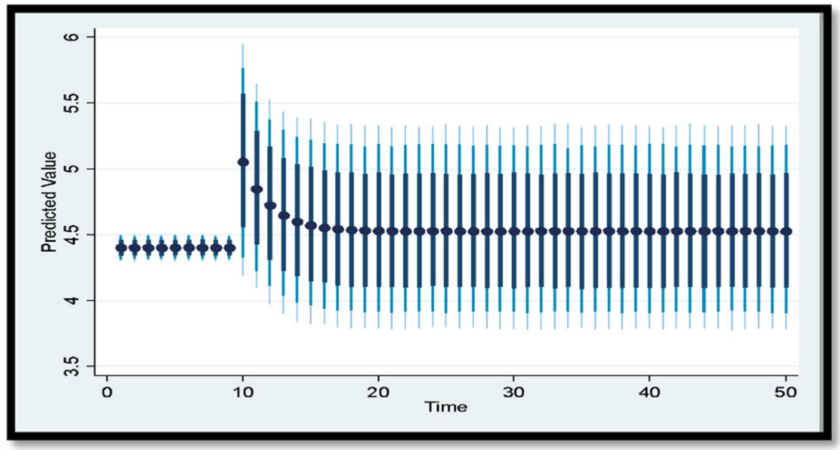


(EG), financial development (FD), FDI, and urbanization (URB) on CE in Pakistan by using time series data during 1975-2020. For this purpose, we use ARDL bounds test approach that confirms the cointegrating relationship among the studied variables. Next, empirical outcomes from the novel dynamic ARDL (DARDL) simulations approach validate the existence of the EKC hypothesis. In addition, EEF plunges CE in both the short- ad long-term. On the contrary, URB, FD, and FDI escalate CE in the long- and short-run.

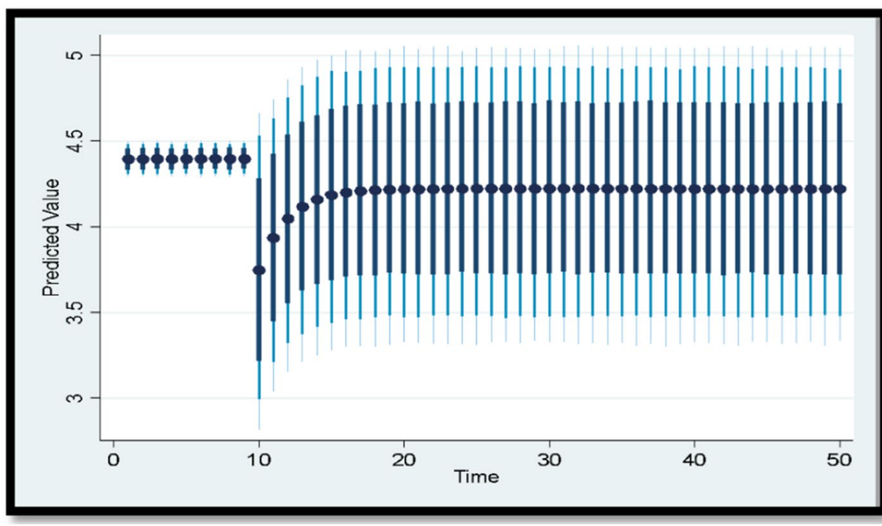
Based on the empirical findings, we purposes some policy implication for controlling and reducing the environmental pollution in Pakistan. Such as, the confirmation of the presence of EKC hypothesis in Pakistan economy suggests that economic growth is a helpful toll to reduce environmental pollution, therefore the policymakers should use measures (e.g., expansionary demand-side policies) to promote growth. The detrimental impacts of URB call for special attention from policymakers. In projects related to URB, there should be renewable energy adoption in

Fig. 1 (continued)

(g)



(h)

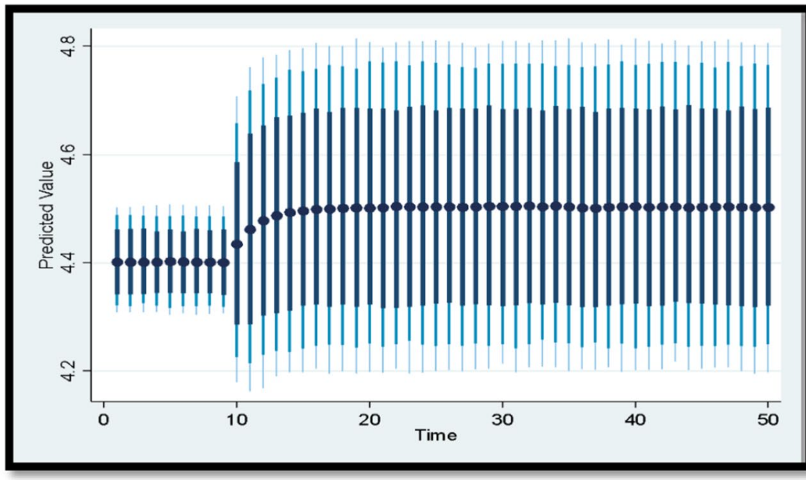


lieu of fossil fuel energy. Rural areas should be provided with facilities (e.g., education, health services, jobs, etc.) to impede migration, which in turn mitigate the pace of URB. Similarly, FDI should be diverted to green projects/businesses to improve environmental quality. For this, investment in green financial assets is inevitable. To curb the adverse impact of FD on the environment, reforms are imperative. Finally, there is a need to enhance EEF in Pakistan. For this purpose, investment in technological advancements and innovations is required. Moreover, R&D in the energy sector should be promoted.

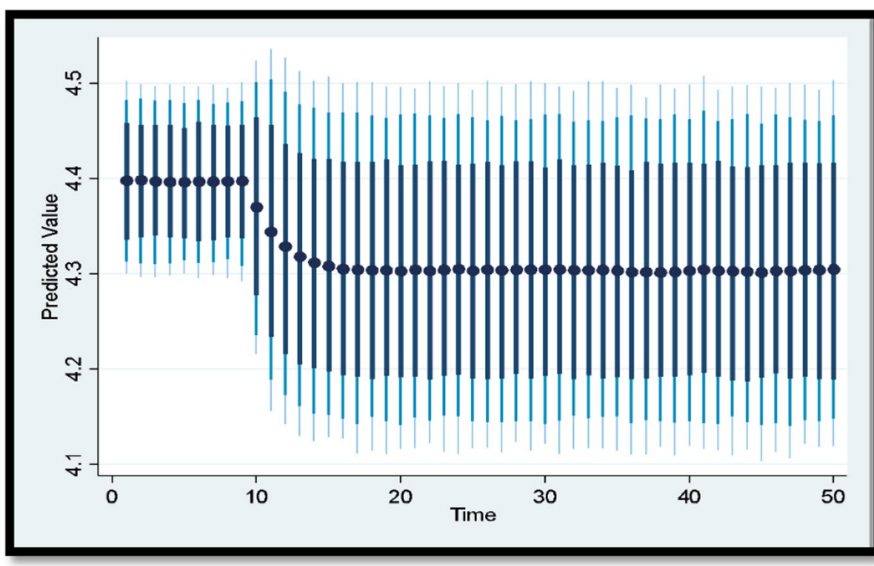
Finally, this study purposes some directions for future research. For instance, the researchers can discover the asymmetric affiliation using NARDL. Similarly, the researchers can also use QARDL for exploring the impact of considered variables on different quantiles of CE. In addition, the combined effect/interaction effect of EEF, FDI, and FD can also be investigated. Finally, the same research issue can be probed using consumption- and production-based CE. This study is based on the data of a single country, while it is better to do a panel data study of similar characteristics countries; so that many

Fig. 1 (continued)

(i)



(j)



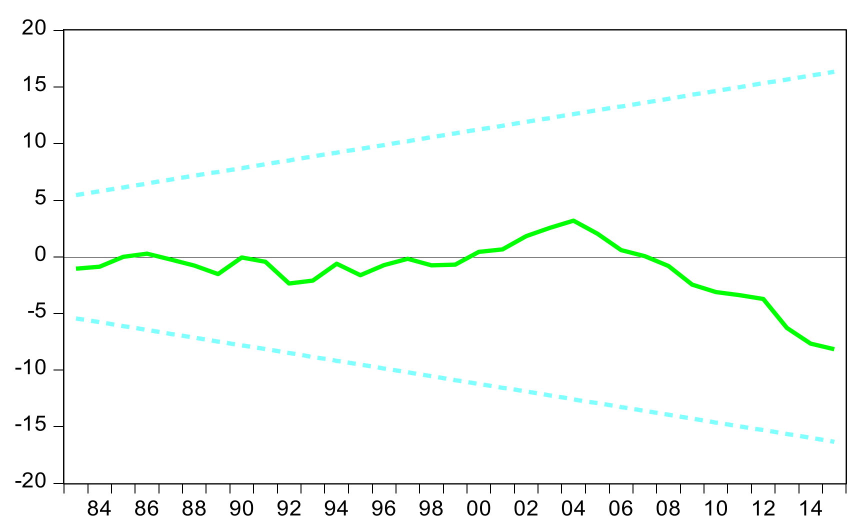
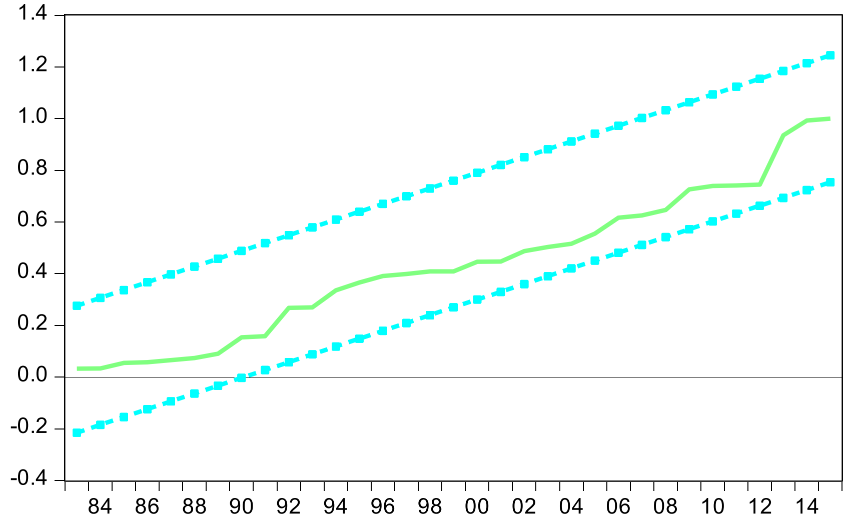


Fig. 2 CUSUM (5% Significance)

Fig. 3 CUSUM Square (5% Significance)



countries can get benefit from the policy implications instead of a single country.

Abbreviations *CE*: CO_2 Emissions; *FD*: Financial Development; *EEF*: Energy Efficiency; *FDI*: Foreign Direct Investment; *URB*: Urbanization; *EG*: Economic Growth

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Declarations

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Consent for Publication Not applicable.

Competing interests The authors declare that no competing interests.

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