



# Revealing the effectiveness of environmental policy stringency and environmental law on environmental performance: does asymmetry matter?

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## Abstract

Environmental stringency policy shocks and environmental tax have become fundamental policy tools for mitigating the degradation of the environment. The study explores the effects of environmental tax and environmental stringency policy shocks in the reduction of pollution emissions in China for the time 1993 to 2019. This study is a pioneer in assessing the simultaneous impact of these two policy instruments on pollution emissions in China. For empirical investigation, the study employed NARDL estimation techniques. The NARDL results show that positive shocks in environmental tax reduce N<sub>2</sub>O emissions by 0.03%, PM<sub>2.5</sub> emissions by 0.13%, CO<sub>2</sub> emissions by 0.18%, and GHGs emissions by 0.01%, however, negative shocks in environmental tax increase N<sub>2</sub>O emissions by 0.01%, PM<sub>2.5</sub> emissions by 0.07%, CO<sub>2</sub> emissions by 0.28%, GHGs emissions by 0.17% in the long run. The long-run results also show that positive shocks in environmental policy stringency reduced CO<sub>2</sub> emissions by 0.94%, GHGs emissions by 0.77%, while negative shocks in environmental policy stringency increased N<sub>2</sub>O emissions by 0.17%, PM<sub>2.5</sub> emissions by 0.50%, CO<sub>2</sub> emissions by 0.63%. The findings suggest vigorous policy implications.

**Keywords** Environmental regulation · Environmental stringency policies · Environmental pollution

## Introduction

Environmental degradation and the increasing ratio of greenhouse gas (GHG) emissions have become alarming threats to humanity as these factors crucially affect economic development and human health. Environmental pollution has become a universal issue. The United Nations (2020) warns

that these environmental crises are becoming persistent as the economies are not fulfilling the desired commitments regarding the reversal of environmental quality. The United Nations (2020) further highlighted that if the global world did not consider these issues seriously and failed to take appropriate steps, then the catastrophic impacts of environmental degradation will be worse than that of the COVID-19 pandemic. The economies are in the race of attaining fast economic development; in this regard, energy consumption is increasing at the cost of rising CO<sub>2</sub> emissions that cause global warming and environmental change. International energy agency (2019) reported that the energy sector is composed of 20% of GHG emissions and approximately 80% of carbon dioxide gas emissions. IEA (2020) reported that in 1990 the worldwide energy sector carbon emissions were 20,521 million tonnes, which reached 32,840 million tonnes in the year 2017.

The rise in carbon dioxide emissions is attached with numerous consequences for human health, economic development, and degradation of the environment (Dong et al. 2021; Yu et al. 2021; Majeed and Ozturk 2020). Regardless of the increase or decrease in carbon dioxide emissions in

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China, still, environmental change instigated by enlarged pollution emissions has irreversible and harmful impacts on human life and economic growth (Pan and Dong 2022a, b). Several empirical studies reveal that carbon dioxide emissions have a damaging impact on environmental quality (Tiba and Omri 2017; Shahbaz and Sinha 2019; Mardani et al. 2019; Aslam et al. 2021). The eminent warnings of climate change and global warming require appropriate energy policy to mitigate their adverse consequences. Recognition of these alarming warnings and market forces does not deliver elucidations of environmental issues (Pigou 1920). Most recently, environment stringency policy and environmental tax are attaining researchers' and environmentalists' attention to regain sustainability of the environment by mitigating carbon dioxide emissions.

The environmental policy stringency index is computed by OECD. The environmental policy stringency index is composed of market-based policies, non-market-based policies, and technology-based policies. Environmental policy stringency is important for environmental sustainability. Environmental tax is imposed on GHG emissions. The basic objective of the environmental tax is to take into account the externalities that are attached to climatic change. Without the environmental tax, individuals have to face a misleading set of prices. GHG emissions-related activities are relatively cheaper and usually, pollution emitters do not consider the emissions costs that other people have to bear including future generations. Due to environmental tax, pollution emitters have to face the complete consequences that emerged from carbon emissions. Environmental tax imposition is essential to make market outcomes optimal. Environmental tax enhances the competitiveness of low-carbon resources and renewable energy resources (Haites 2018). Environmental taxes can efficiently improve environmental quality in developed and developing economies (Ghaith and Epplin 2017; Babatunde et al. 2017).

The Chinese government passed the law of "Environmental Protection Tax" in 2016 to control environmental pollution. This law was effectively implemented on 1<sup>st</sup> January 2018. Along with environmental tax law, the government of China has also implemented a plan for green energy development to control the use of fossil fuels in the energy sector (Yu and Fang 2021). It is projected that by 2020, the clean energy consumption share will reach up to 15% of the total consumption of energy in China. As the industrialization process has intensified carbon emissions in China it has been ranked as the top energy-consuming economy around the world. The worldwide economies are putting pressure on China to control the CO<sub>2</sub> emissions level (Zhou et al. 2022). China is accounted for 30% production of the total global carbon emissions that are being generated from industrial processes and fossil fuel consumption (Jian et al. 2021). Additionally, changing

lifestyles and an upsurge in economic growth are also causing growth in CO<sub>2</sub> emissions in China. Another cause for intensification in CO<sub>2</sub> emissions is trade expansion that rapidly increased the level of energy consumption and carbon emissions in China (Lei et al. 2021). It is imperative to investigate whether environmental tax policies result in CO<sub>2</sub> emissions reduction while exerting a minimal effect on economic growth (Li 2019; Dong et al. 2021). Elkins and Baker (2001) argued that environmental tax partially and wholly modifies environmental issues by enhancing incentives for clean energy consumption. The literature found different types of environmental tax such as carbon tax, fuel tax, and energy tax to achieve the target of reducing environmental pollution (Tamura et al. 1999). Among them, the carbon tax is most important as it controls carbon emissions which are considered the most dominant source of GHG emissions (Scrimgeour et al. 2005). The impact of environmental tax, i.e., the carbon tax on carbon dioxide emissions has been investigated by many studies (see Jiang and Shao 2014; Chen et al. 2019). Some studies reveal that environmental tax can mitigate carbon emissions (Guo et al. 2014; Li 2019). While, others report that environmental taxes have a negligible effect on carbon emissions (Lin and Li 2011).

The promotion of green technology innovations in the energy sector and regulation of carbon emissions through the environmental tax act as major forces to change climatic policies on abatement of pollution emissions (Hashmi and Alam 2019). Regarding the regulation of pollution emissions and environmental policies, Wolde-Rufael and Mulat-Weldemeskel (2021) revealed that environmental policy stringency and air pollution tax are the fundamental instruments adopted by regulatory authorities to combat environmental change. In literature, little work is done on exploring the efficacy of these two instruments in reducing the level of carbon emissions (for instance, Wenbo and Yan 2018; Hashmi and Alam 2019; Albuлесcu et al. 2020). However, some studies have explored the role of environmental policy stringency in mitigating pollution emissions (see Wolde-Rufael and Mulat-Weldemeskel 2021; Wang et al. 2019). The existing studies are considering the symmetric impact of environmental policy stringency and environmental law on environmental quality. It is argued that a simple symmetric approach does not consider the improvement in econometric techniques such as these techniques fail to consider the impact of positive and negative shocks in variables. The asymmetric approach is capable of capturing the effects of these shocks. Yilanci and Aydin (2017) highlighted that existence of asymmetries in variables specifies that time-series responses are not the same for negative and positive shocks. Thus, our study is novel as it is capturing the asymmetric impact of environmental policy stringency and environmental law on environmental performance.

To the authors' knowledge, in literature, none of the empirical studies has tested the combined impact of environmental tax and environmental stringency policy on the reduction of carbon emissions. However, the studies have separately investigated the influence of environmental stringency policy or environmental tax on carbon emissions. For instance, the studies done by Ambec et al. (2013); Wang and Shen (2016); Cohen and Tubb (2018); and Wolde-Rufael and Mulat-Weldemeskel (2020) have explored the effect of environmental policy stringency on pollution emissions and the studies done by Freire-Gonzalez and Ho (2018), Aydin and Esen (2018), Timilsina (2018), and Shahzad (2020) have examined the impact of an environmental tax on carbon emissions. To fill this research gap, the current study aims to examine the role of environmental stringency policy and environmental tax in the mitigation of pollution emissions in China for time from 1993 to 2019. For instance, this study is a pioneer in examining the simultaneous role of environmental tax and environmental policy stringency on pollution emissions in the case of China. Another contribution is that the study investigates the symmetric and asymmetric impacts of the effectiveness of these two policy measures on the reduction of pollution emissions. The findings of this study will contribute to the provision of appropriate policy choices to achieve the environmental concerns of China's economy.

## Model and methods

Following the literature especially Wolde-Rufael and Mulat-Weldemeskel (2021) who carried out an alike analysis for emerging countries, we assume that China's environmental pollution emissions take the following forms:

$$EP_t = \omega_0 + \varphi_1 ER_t + \varphi_2 EPS_t + \varphi_3 GDP_t + \varphi_4 FDI_t + \varphi_5 REC_t + \varepsilon_t \quad (1)$$

Equation (1) signifies China's environmental pollution (EP) that depends on the environmental regulation (ER), environmental policy stringency (EPS), foreign direct investment (FDI), gross domestic product (GDP), and renewable energy consumption (REC). The study uses four different proxies to measure environmental pollution namely nitrous oxide emissions (N<sub>2</sub>O), PM<sub>2.5</sub> air pollution (PM<sub>2.5</sub>), CO<sub>2</sub> emissions (CO<sub>2</sub>), and greenhouse gas emissions (GHGs). Following the standard literature (Ullah et al. 2020; Hsu et al. 2021), we have used four different measures of environmental concerns. For establishing a relationship between environmental policy stringency, environmental law, and environmental performance log–log functional form is used. Based on the literature, our expected estimates of ER and EPS elasticities are negative in the environmental pollution model. Equation (1) provides

the long run estimates only; however, we are concerned with both short run and long run estimates. To that end, we need to reconsider the above equation in the error correction format as displayed below:

$$\begin{aligned} \Delta EP_t = & \omega_0 + \sum_{k=1}^n \beta_{1k} \Delta EP_{t-k} + \sum_{k=0}^n \beta_{2k} \Delta ER_{t-k} + \sum_{k=0}^n \beta_{3k} \Delta EPS_{t-k} \\ & + \sum_{k=1}^n \beta_{4k} \Delta GDP_{t-k} + \sum_{k=0}^n \beta_{5k} \Delta FDI_{t-k} + \sum_{k=0}^n \beta_{6k} \Delta REC_{t-k} \\ & + \omega_1 EP_{t-1} + \omega_2 ER_{t-1} + \omega_3 EPS_{t-1} + \omega_4 GDP_{t-1} + \omega_5 FDI_{t-1} \\ & + \omega_6 REC_{t-1} + \lambda ECM_{t-1} + \varepsilon_t \end{aligned} \quad (2)$$

Specification (2) has occupied the form of the linear ARDL of Pesaran et al. (2001). Once we estimate Eq. (2), we get both long-run with short-run estimates simultaneously. The estimates connected to the first-difference indicators ( $\Delta$ ) represent the short run estimates; whereas, the estimates connected to  $\omega_2$ – $\omega_6$  normalized on  $\omega_1$  are long run. The environmental policy stringency and environmental law have also short run negative effects on pollution emissions, we expect estimates of  $\beta_{2k}$  and  $\beta_{3k}$  to be positive. Short run negative effects translate into the long run in China. Various time-series cointegration methods have been introduced in the literature, but these methods contain several limitations (Johansen and Juselius 1990; Johansen 1988; Engle and Granger 1987). Moreover, the ARDL method is efficient in a small sample size. Another advantage is that pre-unit root testing is not a prerequisite for ARDL. This method provides robust estimates even as the variables are incorporated by distinct orders such as I(0) otherwise I(1). But we cannot include any variable, which is I(2). Moreover, the ARDL model offers efficient results in the presence of serial correlation and endogeneity problems. Equation (2) generally assumed that environmental regulation and environmental policy stringency changes have symmetric or linear effects on China's environmental pollution. Most of the macro-economic series move asymmetrically due to exposure to external shocks, and environmental policy stringency and environmental tax are no exception; hence, applying the asymmetric analysis is justified. This is one of the theoretical contributions in literature. This result can be valid for the EKC hypothesis. Shin et al. (2014) transform the above approach so that we can also examine the possibility of asymmetries, which contain positive changes in environmental regulation and environmental policy stringency as well as negative changes. The mathematical form of the partial sum procedure is presented below:

$$ER^+_t = \sum_{n=1}^t \Delta ER^+_t = \sum_{n=1}^t \max(ER^+_t, 0) \quad (3a)$$

$$ER^-_t = \sum_{n=1}^t \Delta ER^-_t = \sum_{n=1}^t \min(\Delta ER^-_t, 0) \tag{3b}$$

$$EPS^+_t = \sum_{n=1}^t \Delta EPS^+_t = \sum_{n=1}^t \max(\Delta EPS^+_t, 0) \tag{4a}$$

$$EPS^-_t = \sum_{n=1}^t \Delta EPS^-_t = \sum_{n=1}^t \min(\Delta EPS^-_t, 0) \tag{4b}$$

In Eqs. (3a) and (4a),  $ER^+$  and  $EPS^+$  represents the positive changes in the series, whereas Eqs. (3b) and (4b);  $ER^-$  and  $EPS^-$  represents the negative changes in the selected series. Next, we incorporate these partial sum variables in place of the original variables as shown below:

$$\begin{aligned} \Delta EP_t = & \omega_0 + \sum_{k=1}^n \delta_{1k} \Delta EP_{t-k} + \sum_{k=0}^n \delta_{2k} \Delta ER^+_{t-k} \\ & + \sum_{k=0}^n \delta_{3k} \Delta ER^-_{t-k} + \sum_{k=0}^n \delta_{4k} EPS^+_{t-k} \\ & + \sum_{k=0}^n \delta_{5k} \Delta EPS^-_{t-k} + \sum_{k=0}^n \beta_{6k} GDP_{t-k} \\ & + \sum_{k=0}^n \beta_{7k} FDI_{t-k} + \omega_1 EP_{t-1} \\ & + \omega_2 ER^+_{t-1} + \omega_3 ER^-_{t-1} \\ & + \omega_4 EPS^+_{t-1} + \omega_5 EPS^-_{t-1} \\ & + \omega_6 GDP_{t-1} + \omega_7 FDI_{t-1} \\ & + \omega_8 REC_{t-1} + \lambda ECM_{t-1} + \varepsilon_t \end{aligned} \tag{5}$$

The new Eq. (5) is known as the NARDL, which is proposed by Shin et al. (2014). This method is subject to the same econometric applications as Pesaran et al. (2001) proposed for the linear ARDL model. However, few asymmetric tests are to be applied to confirm the presence of asymmetry in the impacts of positive and negative components of ER and EPS. First, we see if the size of the estimate attached to  $\Delta ER^+$  ( $\Delta EPS^+$ ) at a particular lag is different from the size of the estimate attached to  $\Delta ER^-$  ( $EPS^-$ ) or not, and if they are different this is a sign of short asymmetry. Then, to

confirm the short run asymmetries, we nullified the null hypothesis of Wald-SR, i.e.,  $(\sum \delta_{2k} = \sum \delta_{3k}, \sum \delta_{4k} = \sum \delta_{5k})$ . Finally, the long asymmetries will confirm if we nullified the null hypothesis of Wald-LR i.e.  $(\frac{\omega_2}{-\omega_1} = \frac{\omega_3}{-\omega_1}, \frac{\omega_4}{-\omega_1} = \frac{\omega_5}{-\omega_1})$ .

**Data**

The purpose of the study is to investigate the effectiveness of air pollution tax and environmental policy stringency on the mitigation of pollution emissions in China. Pollution emissions is a dependent variable that is measured through four proxies such as nitrous oxide emissions, PM2.5 air pollution, and GHG emissions. Following the Hsu et al. (2021) and Cui et al. (2022), we have used four different measures of environmental concerns (i.e., CO<sub>2</sub> emission, N<sub>2</sub>O emissions, PM2.5, and GHG). Our focused independent variables are environmental regulations and environmental stringency policy. The control variables are GDP, FDI, and renewable energy consumption. In this study, nitrous oxide emission is measured in thousand metric tons of CO<sub>2</sub>. PM2.5 air pollution is taken as annual exposure in micrograms per cubic meter. CO<sub>2</sub> emissions is measured in kilotons. GHG emissions is equivalent to kilotons of carbon dioxide emissions. Environmental regulation is the environmental-related tax in percent of total tax revenue. The index of environmental policy stringency ranges from 0 to 6 where “0” is for no stringent policy and “6” is for the highest degree of stringency. The composition of the environmental policy stringency index consists of three sub-indices that are equally weighted. These include market-based policies, nonmarket-based policies, and technology-based policies. The environmental policy index ranges from 0 to 6 (where 0 is for no policy and 6 is for the most stringent policy). Gross domestic product is measured as GDP per capita at constant 2010 US\$. FDI is taken as net inflows in current US\$. Renewables and other consumption in quad Btu is used to measure renewable energy

**Table 1** Variables definitions and data sources

Variables	Abbreviations	Definitions	Data sources
Nitrous oxide emissions	N <sub>2</sub> O	Nitrous oxide emissions (thousand metric tons of CO <sub>2</sub> equivalent)	WDI
PM2.5 air pollution	PM2.5	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	WDI
CO <sub>2</sub> emissions	CO <sub>2</sub>	CO <sub>2</sub> emissions (kt)	WDI
Greenhouse gas emissions	GHGs	Total greenhouse gas emissions (kt of CO <sub>2</sub> equivalent)	WDI
Environmental policy stringency	EPS	Environmental policy stringency index ranges from 0 (not stringent) to 6 (highest degree of stringency)	OECD
Environmental regulation	ER	Environmentally related taxes, % total tax revenue	OECD
Gross domestic product	GDP	GDP per capita (constant 2010 US\$)	WDI
Foreign direct investment	FDI	Foreign direct investment, net inflows (BoP, current US\$)	WDI
Renewable energy consumption	REC	Renewables and other consumption (quad Btu)	IEA

**Table 2** Descriptive statistics

	Mean	Median	Maximum	Minimum	Std. dev	Skewness	Kurtosis	Jarque–Bera	Probability
N <sub>2</sub> O	12.99	12.99	13.23	12.66	0.163	-0.221	2.053	1.230	0.541
PM2.5	61.69	60.70	70.54	52.21	5.261	-0.160	2.176	0.879	0.644
CO <sub>2</sub>	15.59	15.69	16.27	14.87	0.505	-0.078	1.360	3.052	0.217
GHE	15.79	15.80	16.33	15.13	0.444	-0.135	1.367	3.082	0.214
EPS	1.085	0.850	2.160	0.520	0.613	0.651	1.759	3.638	0.162
ER	3.225	2.980	6.360	0.200	1.763	0.189	2.053	1.170	0.557
GDP	8.018	8.027	9.018	6.906	0.669	-0.059	1.653	2.058	0.357
FDI	0.723	0.740	0.797	0.580	0.057	-1.151	3.511	6.256	0.044
REC	5.720	3.615	16.39	1.327	4.782	0.929	2.487	4.177	0.124

consumption. The data on environmental stringency policy and environmental regulation is extracted from OECD, while data on other variables are taken from the World Bank. Variables definitions are reported in Table 1. In Table 2, the mean of N<sub>2</sub>O, PM2.5, CO<sub>2</sub>, GHE, EPS, ER, GDP, FDI, and REC are 12.99 metric tons, 61.69 µg per cubic meter, 15.59 kt, 15.79 kt, 1.085, 3.225%, 8.018 US\$, 0.723 US\$, and 5.720 quad Btu, respectively.

## Results and discussions

Before applying ARDL, we need to confirm whether the variables are stationary at I (0) or I (1) because we can't embrace the variables in our analysis that become stationary at the second difference. Thus, to know the stationarity of our variables, we apply two different unit root tests, one with a structural break and the other without a structural break. The Augmented Dickey-Fuller test is relatively more powerful and can be applied in the presence of a serial correlation issue. This method provides spurious and biased results due to the absence of information regarding the occurrence of structure breakpoints in the data series. The traditional unit root measures overlook the issue of a structural break. From the perspective of this insufficiency and the history

of oil price shocks, financial crises, and recessions, we captured the structural breakpoint by applying Zivot-Andrews (1992) test. However, for stationarity analysis, our study also applied Zivot-Andrews (1992) breakpoint test. For simplicity, we have used a single structural break unit root test. These tests are reported in Table 3, and we confirm that our variables have a mixed order of integration, hence, we can apply the ARDL model. Another thing we need to address is the imposition of a maximum number of lags; because our data is annual, we have used a maximum of two lags, and to select the appropriate number of lags, we used the Akaike Information Criterion (AIC).

This analysis has used four different proxies of environmental degradation in China, namely N<sub>2</sub>O, PM2.5, CO<sub>2</sub>, and GHGs. Tables 4, 5 and 6 provide the results of linear ARDL and nonlinear ARDL models, respectively. We start our discussion with the linear effects, and then later, we will discuss the asymmetric effects of our independent variables on environmental degradation.

In the long run, the estimated coefficients of ER are negatively significant in all four models, inferring that a 1% increase in the environmental regulations decreases the N<sub>2</sub>O, PM2.5, CO<sub>2</sub>, and GHGs emissions by 0.02%, 0.04%, 0.16%, and 0.07%, respectively. Similarly, the estimates of EPS are negatively significant in three out of four models

**Table 3** Unit root tests

	Unit root test without break			Unit root test with break				
	I(0)	I(1)	Decision	I(0)	Break date	I(1)	Break date	Decision
N <sub>2</sub> O	-1.752	-4.532***	I(1)	-2.656	2007	-7.326***	2015	I(1)
PM2.5	-1.452	-3.348**	I(1)	-3.159	2015	-12.03***	2011	I(1)
CO <sub>2</sub>	-0.532	-3.087**	I(1)	-4.562**	2002			I(0)
GHGs	-1.325	-2.654*	I(1)	-5.895***	2003			I(0)
ER	-1.632	-3.658**	I(1)	-2.899	2015	-11.23***	2013	I(1)
EPS	-0.356	-3.898***	I(1)	-3.565	2010	-5.589***	2012	I(1)
GDP	-0.654	-2.745*	I(1)	-6.389***				I(0)
FDI	-2.754*		I(0)	-3.589	2003	-7.565***	2009	I(1)
REC	-1.032	-2.678*	I(1)	-2.688	2012	-7.321***	2008	I(1)

**Table 4** Short and long run estimates of ARDL

Variable	N <sub>2</sub> O		PM2.5		CO <sub>2</sub>		GHGs	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short run								
D(ER)	-0.030***	3.107	-0.025	0.962	-0.054*	1.682	-0.027*	1.890
D(ER(-1))			-0.020	1.238	-0.037	1.359		
D(EPS)	0.001	0.009	0.029	1.013	0.045	0.591	0.038	1.249
D(EPS(-1))			0.053	1.418	-0.114	1.171		
D(GDP)	0.498*	1.824	0.321*	1.759	0.034	1.029	0.640***	3.511
D(GDP(-1))	0.924***	3.223	0.559	1.437	3.296***	3.052	0.998*	1.935
D(FDI)	-0.258**	2.565	-0.316**	2.375	-0.528	1.265	-0.171	1.100
D(FDI(-1))	-0.331***	2.724			-0.601	1.357		
D(REC)	0.029***	3.018	0.059***	3.844	0.084**	2.529	0.018*	1.720
Long run								
ER	-0.021*	1.864	-0.047**	2.234	-0.164***	2.961	-0.079***	2.957
EPS	-0.100***	2.631	-0.003	0.052	-0.340**	2.519	-0.222***	3.624
GDP	0.009	0.071	0.146	1.144	0.570	1.138	0.213	1.109
FDI	-0.038	0.111	-0.320**	2.034	-1.188*	1.918	-0.294***	2.115
REC	-0.016*	1.688	-0.001	0.023	-0.112***	2.703	-0.031*	1.746
C	12.73***	19.14	4.789***	5.597	17.39***	6.200	13.31***	10.76
Diagnostics								
F-test	10.52***		5.521***		2.012		3.898*	
ECM(-1)	-0.771***	4.684	-0.787***	3.041	-0.753***	4.463	-0.580***	4.735
LM	1.023		0.987		0.654		2.898*	
BP	1.456		0.935		0.456		0.502	
RSSET	1.365		1.998		0.987		1.623	
CUSUM	S		S		S		S	
CUSUM-sq	S		US		S		S	

\*\*\**p* < 0.01; \*\**p* < 0.05; and \**p* < 0

**Table 5** BDS test

Dimension	ER				EPS			
	BDS Stat	Std. Error	z-Stat	Prob	BDS Stat	Std. Error	z-Stat	Prob
2	0.175***	0.009	18.85	0.000	0.151***	0.011	13.47	0.000
3	0.291***	0.015	19.34	0.000	0.242***	0.018	13.33	0.000
4	0.360***	0.018	19.60	0.000	0.284***	0.022	12.93	0.000
5	0.396***	0.020	20.26	0.000	0.305***	0.023	13.12	0.000
6	0.409***	0.019	21.16	0.000	0.267***	0.023	11.71	0.000

\*\*\**p* < 0.01; \*\**p* < 0.05; and \**p* < 0

except for the PM2.5 model. In the context of elasticity, we noted that a 1% rise in the EPS decreases the N<sub>2</sub>O, CO<sub>2</sub>, and GHGs emissions by 0.10%, 0.34%, and 0.22%, respectively. The general meaning of our findings is that more environment-related regulations and stringency in environmental policy improve environmental quality in China. Previous studies such as Castellanos and Boersma (2012) and Yirong (2022) also confirmed the positive impact of policy stringency in mitigating GHG emissions. Haites (2018) found the negative impact of environmental taxes on GHG emissions.

Environmental regulations and taxes are considered the most vital organs of any policy to mitigate environmental pollution (Wolde-Rufael and Mulat-Weldemeskel 2021). Government can impose different taxes to protect the environment, such as fuel, energy, and carbon taxes. The most effective is the carbon tax, as it can control the massive inflow of carbon into the atmosphere (Guo et al. 2014; Li et al. 2018). China is an emerging economy that relies heavily on energy consumption to maintain the pace of economic growth. China’s energy mix is dominated by coal and other non-renewable sources, and more than 80% of

**Table 6** Short and long run estimates of NARDL

Variable	N <sub>2</sub> O		PM2.5		CO <sub>2</sub>		GHGs	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short run								
D(ER_POS)	-0.068***	3.550	-0.110***	2.987	-0.033	0.178	-0.019	0.071
D(ER_POS(-1))	0.020	0.611	-0.290	1.611			0.318*	1.679
D(ER_NEG)	-0.072***	12.70	-0.091***	2.816	-0.248***	3.815	-0.079	0.852
D(ER_NEG(-1))	-0.015***	12.19	0.127**	2.286	-0.036***	2.859	0.009	0.722
D(EPS_POS)	-0.055***	2.860	-0.168**	2.232	-0.096*	1.681	-0.147	0.996
D(EPS_POS(-1))	0.183***	7.983					-0.149	0.787
D(EPS_NEG(-2))	-0.033***	3.204						
D(EPS_NEG)	-0.074***	11.39	-0.048	0.528	-0.244***	4.069	-0.045	0.587
D(EPS_NEG(-1))			-0.235	1.035			0.059	0.816
D(GDP)	0.018	0.353	0.670**	2.124	0.898	1.397	0.840	1.528
D(GDP(-1))	1.064***	8.351	0.610**	2.513	4.838***	11.36	0.704	1.110
D(FDI)	0.313***	15.53	0.139**	2.326	0.581***	4.091	0.253*	1.794
D(FDI(-1))	-0.252***	10.99			-0.325**	2.358	0.240**	1.977
D(REC)	0.050***	10.76	0.052***	3.218	0.176***	7.249	0.014	0.316
D(REC(-1))	-0.018***	6.860	0.040**	2.004	0.067*	1.936	0.043	1.106
Long run								
ER_POS	-0.030**	2.454	-0.134***	3.138	-0.187*	1.923	-0.018*	1.776
ER_NEG	-0.010***	3.908	-0.072***	8.790	-0.288***	10.96	-0.170***	5.150
EPS_POS	-0.022	1.155	-0.011	0.786	-0.944***	10.28	-0.772***	2.725
EPS_NEG	-0.179***	12.60	-0.503***	9.325	-0.636***	3.845	-0.365	1.147
GDP	0.272***	4.123	0.784***	3.646	0.867	0.840	0.631	0.561
FDI	-0.188***	4.808	-0.106*	1.682	1.044**	2.712	-0.566	1.285
REC	-0.017***	3.470	-0.011	1.369	-0.041**	1.994	-0.057*	1.861
C	10.96***	25.04	-1.406	0.972	19.99***	2.897	10.928	1.403
Diagnostics								
F-test	14.03***		8.235***		7.566***		9.564***	
ECM(-1)	-0.470	5.541	0.511*	1.718	-0.574***	4.833	-0.669*	1.954
LM	0.987		0.198		0.356		0.987	
BP	1.032		0.789		0.689		0.356	
RESET	0.321		2.145		1.452		0.564	
CUSUM	S		S		S		S	
CUSUM-sq	S		S		S		S	
Wald-ER-LR	5.654***		3.215*		5.987***		8.615***	
Wald-ER-SR	2.689		3.658*		0.023		1.023	
Wald-EPS-LR	2.989*		3.878**		5.125		3.789*	
Wald-EPS-SR	0.987		4.288**		4.023		0.397	

\*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; and \* $p < 0$

its energy needs are fulfilled by coal, liquid fuel, and natural gas. As a result, China has become the largest emitter of carbon into the atmosphere. Therefore, the pressure on China to reduce the flow of carbon emissions is mounting from all corners. In 2016, the Chinese government passed an environmental protection tax that became fully effective on Jan 01, 2018. Moreover, the government also focused on replacing non-renewable energy sources with renewable ones. In this regard, the government planned to increase the installed capacity of renewable energy sources to 15% by

the end of the year 2020. All these factors may contribute to lowering the environmental pollution in China, and our results indicate the same thing. One thing that is noticeable in our results is that EPS is insignificant in the PM2.5 model, which is not consistent with the previous literature (Chen et al. 2014; Lurmann et al. 2015). The implied reason could be that PM2.5 is a mixture of sulfate, ammonium salt, nitrate, elemental carbon, organic compound, etc., and human activities are not the only cause behind these emissions; instead, PM2.5 is a by-product of various complex

physical and chemical phenomenon's (Bell et al. 2007; Xing et al. 2016).

Among control variables, GDP appeared to be insignificant in all models. The insignificant relationship between GDP and CO<sub>2</sub> emissions can be justified by the following reasons. In recent years, the economic structure of China has converged towards green growth and it is under the transition process. Thus, the true impact of GDP has become neutralized in China. However, FDI and REC have negative and significant in most models, suggesting that these factors improve China's environmental quality.

From Table 4, we gather that the estimated coefficients of D(ER) are significant and negative in three out of four models, except the PM2.5 in which the estimate is negative but insignificant. Conversely, the forecasted values of D(EPS) are insignificant in all four models. The estimates of D(GDP) and D(REC) are positively significant in most of the models; whereas, the estimated coefficients of D(FDI) are negatively significant. Now we turn our attention to the long run linear estimates. Few diagnostics are also reported in Table 4. Among them, the most important are cointegration tests, i.e., *F*-test and ECM<sub>t-1</sub>. A bulk of standard literature is considered both tests as diagnostics (see, Bahmani-Oskooee et al. 2020; Ullah et al. 2021; Usman et al. 2021). Relying on these tests, we can say that our long-run outcomes are cointegrated, meaning they are valid. Then, we performed Lagrange Multiplier (LM), Ramsey RESET, and Breusch Pagan (BP) tests to check the serial correlation, misspecification, and heteroscedasticity. The results infer that our models are free from serious issues, while CUSUM and CUSUM-sq tests confirm the stability of our models.

Now, we discuss the results of asymmetric estimates, which are reported in Table 6. However, before discussing the asymmetric results, we use the BDS test to justify the NARDL model application. Table 5 shows the results of the BDS test, which confirm that our main variables are nonlinear. Hence, we can apply the NARDL model.

In the long run, the estimated coefficients of ER\_POS are significant and negative in all four models inferring that a 1% rise in ER reduces the N<sub>2</sub>O emissions by 0.03%, PM2.5 emissions by 0.13%, CO<sub>2</sub> emissions by 0.18%, GHGs emissions by 0.01%. Similarly, the estimated coefficients of ER\_NEG are negatively significant in all four models implying that a 1% decline in the ER increases the N<sub>2</sub>O emissions by 0.01%, PM2.5 emissions by 0.07%, CO<sub>2</sub> emissions by 0.28%, and GHGs emissions by 0.17%. However, the estimated coefficients of EPS\_POS are insignificant in N<sub>2</sub>O and PM2.5 models and positively significant in the remaining two models. On the other side, the estimated coefficients of EPS\_NEG are negatively significant in three out of four models. In general, our findings imply that a positive change in ER and EPS improves the environmental quality in China,

while a negative change in ER and EPS hurts the environmental quality in China. These findings complement the results of our linear models; however, the asymmetric model provides us with an opportunity to measure the impact of the negative shocks in ER and EPS on the environmental quality in China. Nevertheless, the estimates of both negative and positive change are significantly different, confirming the asymmetric effects of negative and positive changes in ER and EPS on the environmental quality in China.

Our findings are supported by Wolde-Rufael and Mulat-Weldemeskel (2021), who reported that environmental policy stringency brings a reduction in CO<sub>2</sub> emissions. Ahmed (2020) and Sezgin et al. (2021) reported a similar association between environmental policy stringency and CO<sub>2</sub> emissions. Strict environmental-related policies and regulations mainly focused on clean energy, environmental tax, and environmental proficiency policies. The environmental policy stringency mechanism is based on regulations and rules that raise the cost of pollution-generating agents. Thus, businesses and firms adopt precautionary measures that control pollution emissions. Correspondingly, the consumption of those products that generate pollution also declines. Positive shocks in environmental policy stringency provide favor impacts on the environment. In this regard, the Porter hypothesis reveals that environmental policy stringency promotes eco-friendly technologies and improves environmental and economic performance (Porter and Van der Linde 1995).

Our findings are backed by Hashmi and Alam (2019) and Zhang et al. (2020). These studies confirmed that environmental regulation contributes significantly to achieving the objective of environmental quality. Environmental regulation intends to control the negative impact of externalities on environmental and economic activities. The literature claims that energy-intensive firms have to adopt less pollution-generating sources of production under strict environmental regulations (Pei et al. 2020). In contrast, economies with fragile environmental regulations become highly polluted (Zhang et al. 2022). This finding is in line with the prior studies (see Albulescu et al. 2019; Hashmi and Alam 2019; Zhang et al. 2020).

The asymmetric D(ER) estimates are significantly negative in all four models in the short run. The asymmetric estimates of D(EPS) are significantly negative in three of four models. The negative sign with positive shock suggests that a rise in ER and EPS improves the environmental quality. In contrast, the negative sign with negative shock implies that a decline in ER and EPS worsens the environmental quality. Seeing the behavior of asymmetric estimates, we can confirm that pollution emissions respond asymmetrically to the negative and positive shocks, and the asymmetric effects are also confirmed via a significant estimate of Wald-ER-LR and Wald-EPS-LR reported in Table 6. The rest of the variables and diagnostics have the same inference as already



clarified in the linear model; hence, they don't need any further elaboration.

## Conclusion and implications

As there is a dearth of literature that investigates the simultaneous impact of environmental tax and environmental policy stringency on the mitigation of pollution emissions, hence, this study considers this vacuum for China for time 1993 to 2019. The study takes into account several measures of pollution emissions such as Nitrous oxide emissions, PM<sub>2.5</sub> air pollution, CO<sub>2</sub> emissions, and greenhouse gas emissions. The study extracted symmetric and asymmetric effects of these two policy instruments on pollution emissions by adopting ARDL and NARDL techniques. The empirical findings of both techniques confirm that these two policy instruments are significant and negatively associated with pollution emissions suggesting that environmental tax and environmental policy stringency are the effective policy measures that play an important role in the mitigation of environmental pollution. As it is obvious from this study that environmental regulation and environmental stringency policy lead to a decrease in pollution emissions revealing that the climatic enactment of an economy could be associated with its air pollution tax-related policies and to its environmental stringency policies indicating their vital role in negative externalities of environment. In this regard, the policy implication is that reforming environmental regulations and rules more stringently and accumulating air pollution taxes can be two active policy measures for combating and controlling pollution emissions.

These two policy measures are not enough to control the detrimental impacts of pollution emissions, that's why, our study incorporated the role of some other variables which exert direct influence on pollution emissions such as GDP per capita, FDI, and renewable energy consumption. The study reports the positive impact of economic development on pollution emissions suggesting that government should adopt such reforms that lead to green growth and protection of the environment. Mitigation of pollution emissions while retaining high levels of green development should be a fundamental administrative principle towards maintainable growth for the economy. The government of China should maintain a balance between protecting the quality of environment and promoting green growth. The study found that renewable energy demand leads to decrease in emissions, in this regard; the goal of the authority should enhance the efficiency of energy that contributes to the improvement of environmental quality.

The finding of a negative association between environment tax and pollution emissions, and a negative link between renewable energy consumption and pollution emissions, recommends that the most suitable way of reducing pollution emissions is to enhance clean energy consumption and minimize the consumption of dirty energy. The authority should create incentives for energy users in case of consumption of more environmentally friendly goods and services. The study also highlights the role of foreign capital in determining the effectiveness of environmental tax and environmental policy stringency in the reduction of pollution emissions. The study suggests that the country should receive foreign direct investment from such sources that encourages innovative renewables and green technologies that may help in promoting sustained development of energy and a good quality environment. So far, pollution emission is a worldwide problem and it requires a worldwide solution. Hence, the Chinese government should involve itself in global cooperation to play its role in the mitigation of pollution emissions.

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**Data availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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