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# The role of economic policy uncertainty in the energy-environment nexus for China: Evidence from the novel dynamic simulations method

Azka Amin [a], Eyup Dogan [b,c,*]

[a] Faculty of Business Administration, Iqra University, Karachi, Pakistan
[b] Finance and Economics, University of Sharjah, United Arab Emirates
[c] Department of Economics, Abdullah Gül University, Turkey

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ABSTRACT

Even though a great number of researches have explored the determinants of carbon emissions, the impact of economic policy uncertainty (EPU) on the environment has not been fully investigated in the energy-environment literature. Since recent studies show a strong relationship between the external environment and uncertainty, the present study for the first time in the literature aims to explore the function of EPU in the energy-environment nexus for China by using the novel bounds testing with dynamic simulations. The empirical results indicate that increases in the real income and energy intensity contribute to environmental pollution while increases in renewable energy lower the level of emissions. Besides, an increase in EPU causes an increase in the volume of carbon emissions. As EPU increases, the government's attention to implement environmental protection policies decreases, and the execution of the environment-related strategies is likely directed in an expected way. The empirical findings suggest that the government should establish consistency in economic and environmental policies to mitigate environmental pollution and thus to reach environmental sustainability.

## 1. Introduction

Climate change has become one of the world's major problems which may have an adverse impact on sustainable economic performance of countries (Ding et al., 2020). Over the last few decades, greenhouse gas emissions; mainly, carbon dioxide emissions have caused global warming which leads to a change in the climate across the globe. Thus, it is important to identify and understand the factors that increase and decrease the level of emissions. Many studies in the literature have already confirmed the existence of the relationship between income and carbon emissions (Ali et al., 2020; Dogan and Inglesi-Lotz, 2020; Bilgili et al., 2016). Furthermore, according to the World Energy Outlook published by the International Energy Agency, IEA (2019), a high record of 33.1 Gt carbon emissions was reached and increased by 1.7% in 2018 mainly due to higher energy consumption. Likewise, researchers have also found energy consumption (i.e., renewable energy, non-renewable energy, and total energy consumption) impacts environmental pollution (Anwar et al., 2021; Gkisakis et al., 2020; Suwanmanee et al., 2020).

Economic policy uncertainty (EPU) is defined as the uncertainty associated with public policies, especially fiscal and monetary policies that affect an economy's environment in which business entities operate (Pirgaip and Dinçergök, 2020). All over the world, political and economic instability occurred due to global uncertainties that have an adverse impact on economic activities (Blattman and Miguel, 2010; Guidolin and La Ferrara, 2010). For example, the second Gulf war in 2003 caused huge economic uncertainty in international markets (Rigobon and Sack, 2005). Recently, COVID-19 has created a lot of uncertainty around the globe (Altig et al., 2020; Baker et al., 2020). The business environment is generally affected by EPU, which ultimately affects business decisions. EPU may affect the environment in addition to its economic impacts. For instance, EPU motivates manufacturers to adopt environment unfriendly production methods resulting in higher $CO_2$ emissions. EPU may affect investment and consumption expenditures, thereby influencing $CO_2$ emissions. Furthermore, reduction in renewable energy sources as well as R&D because of higher EPU may cause a stimulation in $CO_2$ emissions. This shows as the environment associates with production processes of business entities, EPU may potentially affect carbon emissions (Al-Thaqeb and Algharabali, 2019). Jiang et al. (2019) pointed out the impact of EPU on $CO_2$ emissions through direct sustainable government policies that may stimulate or impede environmental quality.

EPU may have an effect on consumption, which leads to decreased

* Corresponding author. Finance and Economics, University of Sharjah, United Arab Emirates.
*E-mail addresses:* azka.amin@iqra.edu.pk (A. Amin), edogan@sharjah.ac.ae (E. Dogan).

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$CO_2$ emissions. The weak public and financial sector policies in a highly uncertain economic environments leads to a plunge in $CO_2$ emissions due to reduced consumption expenditures (Aastveit et al., 2017). In order to make up for low turn-over caused by EPU, manufacturers use cheap energy sources for production purpose. Thus, as the revenues of such industries rise, they employ environment friendly production methods which in turn lead to reduce $CO_2$ emissions. Despite the importance of EPU for a sustainable environment, there are only a few studies available in the literature that analyzes the impact of EPU on environmental pollution. This is the first attempt to study the environment-EPU nexus for China, a prominent country among the developing countries of the world. The existing studies regarding EPU-environment nexus are for G-7 countries (Pirgaip and Dincergok, 2020); the USA (Danish et al., 2020; Jiang et al., 2019; Wang et al., 2020), and resource rich economies (Adams et al., 2020). Pirgaip and Dinçergök (2020) examined the relationship between EPU, energy consumption and $CO_2$ emissions for G-7 countries from 1998 to 2018. Their overall findings suggest that such policies should be introduced which endorse reducing energy consumption and $CO_2$ emissions or to use alternative energy sources in G-7 countries in order to help ~~to~~ alleviate the impact of EPU in such countries. Wang et al. (2020) investigated the impact of income, energy prices, and EPU on $CO_2$ emissions for the United States over the period of 1960–2016 by utilizing the autoregressive-distributed lag (ARDL) approach. They found that EPU positively affects $CO_2$ emissions in the long run. They suggested carbon emissions in the USA can be reduced by implementing stable and transparent policies. By employing a novel parametric causality test, the study Jiang et al. (2019) found that $CO_2$ emissions are affected by EPU when a rise in the level of emissions occurs in a higher or lower growth period. Using Panel Pooled Mean Group ARDL, Adams et al. (2020) investigated the relationship between EPU, energy consumption, and $CO_2$ emissions for resource-rich countries. They found a significant relationship between EPU and CO2 emissions in the long run. Furthermore, their findings show energy consumption and economic growth may stimulate environmental pollution.

Given the above-mentioned discussions and explanations, this study aims to investigate the impact of EPU on carbon emissions in the energy-income-environment nexus under the STIRPAT framework for China by applying the novel dynamic ARDL simulations on the data from 1980 to 2016. To the best of our knowledge, this is the first attempt to analyze the environment-EPU nexus for China. Besides, from a view of empirical estimation, this study contributes to the thin body of literature that applies the above-mentioned novel econometric approach proposed by Jordan and Philips (2018). Therefore, the empirical findings from this study are supposed to exploit robust and reliable policy suggestions. This research is focused on China since this country became the world's leading economy with US$14.4 trillion GDP in 2019 according to the World Bank. China is the largest carbon dioxide emitter, accounting for nearly 30% of global greenhouse gas emissions (Adams et al., 2020). During 1978–2018, China's $CO_2$ emissions rapidly increased from 1.37 Gt to 9.64 Gt $CO_2$, an average annual increase of 5%, and a 6 times overall increase in energy-related emissions (Zheng et al., 2019). Currently, China is implementing several economic policy reforms related to policy uncertainty shocks; thus, EPU may have important implications on the frequency of China's macroeconomic business cycles (Huang and Luk, 2019).

Our results reveal increasing $CO_2$ emissions is accompanied by higher economic policy uncertainty in China. The unstable factors in environmental policies may stimulate $CO_2$ emissions in a country. In order to plunge $CO_2$ emissions, there is a need to establish stable economic and environmental policies which may lead to contribute green and clean energy sources. Furthermore, GDP and energy intensity enhance environmental pollution. If energy intensity is decreased, it would contribute to achieve sustainable development goals and to fulfill basic human needs. In addition, the consumption of green and clean energy may decrease environmental degradation. Thus, policymakers should promote consistency in environmental and economic policies to achieve a friendly environment in China. The consumption of renewable energy is an effective way to mitigate environmental degradation which can lead to promote sustainable development in China. The remainder of the paper is organized as follows. Section 2 presents the literature review. Section 3 discusses data, model, and methodology while results and discussions are presented in section 4. The last section concludes the study with policy recommendations.

## 2. Literature review

A considerable number of studies analyzed the driving factors of $CO_2$ emissions, as from the last few decades climate change has become a serious issue across the globe. For instance, in the economic growth-$CO_2$ emissions nexus, the environmental Kuznets curve (EKC), an inverted U-shaped curve that shows the relationship between income and environmental degradation, has been extensively used by many researchers (see, Murshed et al., 2020; Shahbaz et al., 2020a; Nasir et al., 2019; Aslan et al., 2018; Shahbaz et al., 2018; Apergis and Ozturk, 2015; Narayan and Narayan, 2010). For instance, by employing panel spatial techniques, Murshed et al. (2020) examined the authenticity of EKC hypothesis for 12 OPEC member countries over the period 1992–2015. Their results confirm the validity of EKC hypothesis as evidenced by its inverted U-shaped relationship between economic growth and carbon emissions. Further, Shahbaz et al. (2020a) investigated the relationship between economic growth, R&D expenditures, financial development, and energy consumption with $CO_2$ emissions in the UK over the period 1870–2017. They found an inverted U-shaped relationship between economic growth and CO2 emissions which demonstrates the validity of EKC hypothesis with a U-shaped relationship found between financial development and carbon emissions. Aslan et al. (2018) examined the authenticity of EKC hypothesis by identifying the relationship between economic growth and carbon emissions for United States during 1966–2013. They found an increasing trend in economic growth from 1982 to 1996 and a decreasing trend during 1996–2013, which confirms the existence of EKC hypothesis in the United States. In the energy consumption-$CO_2$ emissions nexus, Adedoyin et al. (2020); and Zhang and Lin (2012) found energy consumption (renewable and non-renewable) a key factor to stimulate environmental degradation. Parallel to these studies, several other researchers, for instance, Alola et al. (2019); Baloch et al. (2019); Dogan and Seker (2016); Dogan and Ozturk (2017); Zaidi et al. (2018) concluded that renewable energy consumption alleviates $CO_2$ emissions, while non-renewable energy consumption contributes to stimulate $CO_2$ emissions. In addition, Amuakwa-Mensah and Adom (2017) explored the relationship between quality of the institution, forest, energy intensity, globalization and the environment for sub-Saharan Africa by utilizing the GMM technique. They found a positive and significant relationship between energy intensity and CO2 emissions in SSA.

In addition to the above-mentioned factors, several other researchers explored economic and non-economic determinants of CO2 emissions, for instance, natural resources (Shahbaz et al., 2020b; Bekun et al., 2019; Danish et al., 2019b; Joshua and Bekun, 2020); financial development (Amin et al., 2020; Abbasi and Riaz, 2016; Al-Mulali et al., 2015a, b); foreign direct investment (Nguyen et al., 2021; Peng et al., 2016; Zhang and Zhou, 2016; Chandran and Tang, 2013; Pao and Tsai, 2011); trade (Farhani and Ozturk, 2015; Shahbaz et al., 2013); globalization and urbanization Destek (2020); Sadorsky (2014); Shahbaz et al., (2017); population (Begum et al., 2015; Mohsin et al., 2019); and economic policies (fiscal and monetary policy) (Ullah et al., 2020). None of these studies examined the role of economic policy uncertainty (EPU), a key macroeconomic factor that influences $CO_2$ emissions.

Abel and Eberly presented the option theory in 1993 in which they stated that it is possible to manage investment opportunities as the capital of an economic organization where the investment is irreversible. It is recommended in signal transmission theory presented by

Connelly et al. (2011), that in case of increasing carbon exposure, the pressure on investor's environmental problems can be decreased. In the light of the above-described theories, as a reflection of macroeconomic factors, EPU affects the business environment, which in turn affects the decision-making of economic entities. While on the other hand, $CO_2$ emission is closely related to the production decisions of economic entities. This implies that as $CO_2$ emissions relate to business decisions; consequently, EPU may have an effect on $CO_2$ emissions as well.

Yu et al. (2021) examined the impact of EPU on Chinese manufacturing firm's $CO_2$ emission intensity. Their results reported that EPU has a positive and significant on Chinese firm's $CO_2$ emission intensity. They further identified that the Chinese manufacturing firms prefer to utilize cheap fossil fuels to cope with the growth of EPU. By employing the novel parametric test of Granger causality, the study of Jiang et al. (2019) found the relationship between EPU and $CO_2$ emissions for the United States. Their findings revealed that $CO_2$ emissions arise by EPU when the rise in $CO_2$ emissions occurs in a higher or lower growth period. Danish et al. (2020) concluded that EPU increases energy consumption, which surges $CO_2$ emissions in the USA. Pirgaip and Dinçergök (2020) also reported that EPU increases $CO_2$ emissions in the G7 countries. Recently, Adams et al. (2020) employed the world uncertainty index (WUI), as a proxy for EPU, and explored the relationship between EPU and $CO_2$ emissions in countries with high geopolitical risk. The study revealed that EPU (measured by WUI) escalates $CO_2$ emissions. Similarly, Wang et al. (2020) found that EPU increases the $CO_2$ emissions in the USA. In contrast, Anser et al. (2021) explored the relationship between EPU (measured by the world uncertainty index, WUI) and $CO_2$ emissions for the top ten carbon emitter countries by using the PMG-ARDL approach. They found that increasing WUI mitigates $CO_2$ emissions. Their findings suggested that the top ten carbon emitter countries must promote renewable energy, innovation, and environment-friendly technology policies. Similarly, Adedoyin and Zakari (2020) concluded that EPU decreases $CO_2$ emissions in the short run, whereas it escalates them in the long run. In order to reveal the potential specific drivers of $CO_2$ emissions, studies on the determinants of carbon emissions are increasing significantly. The most widely used model to answer this problem is the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. The STIRPAT model is presumed to be linear, which is easy to interpret and estimate (Wang et al., 2017). Previously, several studies used the STIRPAT model to analyze the impact of various factors on $CO_2$ emissions. For instance, Nasir et al. (2021) employed the STIRPAT model to find out the relationship between trade openness, industrialization, economic growth, energy consumption, and $CO_2$ emissions for Australia. Pham et al. (2020) investigated the long-run and short-run impact of energy, economic and sociological determinants on environmental degradation for 28 European countries by utilizing the STIRPAT model. York et al. (2003) investigated the relationship between population and carbon emissions by using the STIRPAT model. Wang et al. (2013) examined the impact of economic level, technology, population, urbanization, industrialization, service level, trade, and energy structure on $CO_2$ emissions in China from 1980 to 2010 by employing the extended STIRPAT model. While Zhang and Lin (2012) explored the impact of urbanization on energy consumption by applying the STIRPAT model for China. By using the STIRPAT model, Yeh and Liao (2017) explored the relationship between population, economic growth, and $CO_2$ emissions for developing countries. Parallel to these studies, none of the studies available identify the role of economic policy uncertainty in the energy-environment nexus by using the STIRPAT model.

Given the above discussion, it can be concluded that the relationship between EPU and $CO_2$ emissions has not been yet investigated for China. Moreover, none of the studies employed the STIRPAT model. Thus, our study contributed to the existing literature by exploring the impact of EPU on $CO_2$ emissions in the energy-environment nexus for China with the STIRPAT framework.

## 3. Model, data and econometric methodology

### 3.1. Model and data

This study investigates the role of energy, income, and environment nexus to policy-induced uncertainty for China from 1980 to 2016. It is noteworthy that this study uses the most up-to-date available data for China as of January 2021. Based on the well-known population, affluence, and technology-STIRPAT-theory framework (Wang et al., 2013; Ghazali and Ali, 2019; Chen et al., 2021), we propose the following model:

$$CO2_t = \beta_1 + \beta_2 GDP_t + \beta_3 EI_t + \beta_4 ES_t + \beta_5 POP_t + \beta_6 EPU_t + \mu$$

where $CO_2$ emission is an environmental indicator; EI is the energy intensity; GDP is gross domestic product in constant US$ 2010; ES is the energy structure; EPU is the index of China's economic policy uncertainty developed by Baker et al. (2016), and POP is the population of the country. The description is reported in Table 1.

The descriptive statistics of the analyzed indicators are reported in Table 2. The results of descriptive statistics show positive values of all the variables. The summary statistics contains minimum, maximum, mean, median, and standard deviation. These variations seem sufficient for further empirical estimation.

### 3.2. Econometric methodology

Pesaran et al. (2001) proposed an autoregressive distributed lag (ARDL) model which provides effective and reliable estimates; however, several new techniques have been developed which ~~to~~ improve the robustness of the model. In order to easily understand and interpret ARDL estimates, Jordan and Philips (2018) developed the dynamic ARDL simulations method which is the state-of-the-art type of ARDL due to (Pesaran et al., 2001). While the implementation of the ARDL model is convenient, its dynamic form accepts first differences and multiple lags of both independent and dependent variables (Jordan and Philips, 2018). The Dynamic ARDL method eliminates the complexity of the existing ARDL method in order to explore the long and short-run relationship between independent and dependent variables. The dynamic ARDL automatically stimulates, estimates and predicts the graphs to find out the impact of independent variables on the dependent variable while the other indicators in the equation stay unchanged. Conversely, the (Pesaran et al., 2001) ARDL model can only estimate the long-run and short-run relationships among variables. For the dynamic ARDL approach, the variables should be stationary at the first difference I(I) as well as cointegration should exist between all indicators (Sarkodie et al., 2019; Jordan and Philips, 2018). This method applies 5000 simulations

**Table 1**
Variables description.

| Abbrv. | Indicator name | Measurement scale | Source |
|---|---|---|---|
| $CO_2$ | Carbon dioxide emissions | Metric tons | WDI |
| GDP | Gross Domestic Product | Constant 2010$ | WDI |
| EI | Energy intensity | How efficiently the economy uses energy to produce every dollar of GDP | EIA |
| ES | Energy structure | The share of renewable energy consumption in total energy | EIA |
| POP | Population | Total population | WDI |
| EPU | Economic policy uncertainty | Measuring policy uncertainty raises potential concerns related to newspaper reliability, accuracy, bias, and consistency. | Economic Policy Uncertainty |

WDI: Word Development Indicators (https://databank.worldbank.org/).
EIA (https://www.eia.gov/international/data/world).
EPU (https://www.policyuncertainty.com/).

**Table 2**
Descriptive statistics.

| Variable | Obs | Mean | Median | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| $\ln CO_2$ | 37 | 15.166 | 15.041 | 0.630 | 14.188 | 16.147 |
| lnGDP | 37 | 28.257 | 28.279 | 1.027 | 26.554 | 29.885 |
| lnEI | 37 | 2.537 | 2.346 | 0.401 | 1.984 | 3.328 |
| lnES | 37 | 1.662 | 1.596 | 0.313 | 1.131 | 2.439 |
| lnPOP | 37 | 20.912 | 20.940 | 0.104 | 20.704 | 21.044 |
| lnEPU | 37 | 4.439 | 4.559 | 0.442 | 3.571 | 5.467 |

of the vector of parameters by utilizing multivariate normal distribution. The equational form of dynamic ARDL approach based on dynamic simulation is presented as:

$$\Delta(\mathrm{y})_{\mathrm{t}} = \alpha_0 + \delta(\mathrm{Y})_{\mathrm{t-1}} + \delta_1(\mathrm{x}_1)_{\mathrm{t-1}} + \ldots + \delta_{\mathrm{k}}(\mathrm{x}_{\mathrm{k}})_{\mathrm{t-1}} + \sum_{\mathrm{i=1}}^{\mathrm{p}} \alpha_{\mathrm{i}}\Delta(\mathrm{y})_{\mathrm{t-1}} + \sum_{\mathrm{j=0}}^{\mathrm{q_i}} \beta_{\mathrm{ij}}\Delta(\mathrm{x}_1)_{\mathrm{t-j}} + \ldots + \sum_{\mathrm{j=0}}^{\mathrm{q_k}} \beta_{\mathrm{kj}}\Delta(\mathrm{x}_{\mathrm{k}})_{\mathrm{t-j}} + \varepsilon_{\mathrm{t}} \quad (1)$$

In Eq. (1), y shows the variation in the dependent variable; $\alpha_0$ is the intercept; t-1 is the maximum p-value of the independent variable; $q_k$ is the number of lags; Δ indicates the 1st difference operator; t is the time period and ε is the error term. The null hypothesis of no cointegration ($H_0$: $\delta_0 + \delta_1 + \ldots + \delta_k = 0$) is checked against the alternative hypothesis ($H_1$: $\delta_0 + \delta_1 + \ldots + \delta_k \neq 0$). If calculated F-value is greater than the critical value, the null hypothesis of no co-integration is rejected.

### 4.2. Cointegration test

To check the existence of long run relationship between variables, this study utilizes the ARDL bound test by using the critical values of Kripfganz and Schneider (2018). The Kripfganz and Schneider (2018) approach is more efficient if the variables are integrated at level I(0) or at first difference I(1), as similar in this study. Moreover, the calculated values of F-test and *t*-test are greater than the upper bounds for all statistical significance level. As $CO_2$ emissions is a function of the real income, energy intensity, energy structure, population and EPU; so there exists a long run equilibrium relationship between $CO_2$ emissions and all independent variables as shown in Table 4.

### 4.3. Dynamic ARDL simulations

The ARDL model with dynamic simulations proposed by Jordan and Philips (2018) is utilized in this study, which overcomes complexities in the already existing model in order to investigate the long run and short run estimations of determinants on $CO_2$ emissions. The results of dynamic ARDL simulations are illustrated in Table 5. The coefficients of GDP and energy intensity indicate a statistically significant and positive relationship with the level of emissions at 1% level of significance. This shows that a 1% increase in economic growth and energy intensity leads to increased $CO_2$ emissions by 0.63% and 0.92%, respectively. The results indicate that economic growth and energy intensity increase $CO_2$ emissions which harms the environment both in the long and short-run.

$$\Delta\ \ln(CO_2)_t = \alpha_0\ \ln(CO_2)_{t-1} + \beta_1\Delta\ \ln(GDP)_t + \vartheta_1\Delta\ \ln(GDP)_{t-1} + \beta_2\Delta\ \ln(EI)_t + \vartheta_2\Delta\ \ln(EI)_{t-1} + \beta_3\Delta\ \ln(ES)_t + \vartheta_3\Delta\ \ln(ES)_{t-1} + \beta_4\Delta\ \ln(POP)_t + \vartheta_4\Delta\ \ln(POP)_{t-1} + \beta_5\Delta\ \ln(EPU)_t + \vartheta_5\Delta\ \ln(EPU)_{t-1} \quad (2)$$

This study employs the dynamic ARDL approach based on dynamic simulations which has recently been employed in the literature by Danish et al. (2020), Danish and Ulucak (2019a), Khan et al. (2019), and Sarkodie et al. (2019).

## 4. Results and discussion

### 4.1. Unit root test

Before applying dynamic simulations of the ARDL method, it is essential to check the stationarity of all variables, that is, the dependent variable must be I(1), and the regressors should be I(0) or I(1). This study applies DF-GLS and Phillip-Perron (PP) unit root tests to test the stationarity among variables. The results of unit root tests in Table 3 confirm the stationarity of all variables at first difference.

**Table 3**
Unit root test results.

| | DF-GLS | | Phillips-Perron | |
|---|---|---|---|---|
| | Level | First difference | Level | First difference |
| $\ln CO_2$ | −2.24 | −2.92* | −1.91 | −3.60** |
| lnGDP | −2.55 | −3.53** | −2.16 | −3.49* |
| lnEI | −1.42 | −3.37** | −1.47 | −4.07** |
| lnES | −1.24 | −3.91*** | −1.05 | −7.36*** |
| lnPOP | −4.75*** | −3.416** | −0.72 | −4.73*** |
| lnEPU | −2.39 | −5.30*** | −3.12 | −6.51*** |

**Note:** *, **, *** represent 10%, 5% and 1% level of significance, respectively.

If energy intensity remains constant, economic growth leads to increase energy demand, thereby increasing $CO_2$ emissions. In contrast, energy efficiency increases if there is a decrease in energy intensity, which in turn decreases $CO_2$ emissions. Our results are similar to Dogan and Inglesi-Lotz (2020), Poumanyvong and Kaneko (2010), and Zhang and Zhou (2016) which found economic growth and energy intensity increase China's $CO_2$ emissions.

With respect to the coefficient of energy structure (ES), it is identified that increases in the share of renewable energy consumption in the total energy mix negatively affects $CO_2$ emissions in China. The elasticity of $CO_2$ emissions with respect to energy structure implies that a 1% increase in the share of renewable energy consumption in total energy reduces $CO_2$ emissions by 0.013% in the long run. It is identified that in China with increasing concern over health and environmental costs of $CO_2$ emissions, renewable energy has to turn out to be an effective alternative to fossil fuels (for instance petroleum, coal and gas). The consumption of renewable energy mitigates $CO_2$ emissions and environmental degradation, thus will lead to promote sustainable development in China. These findings are consistent with other studies (Anwar et al., 2021; Bekun et al., 2019; Sarkodie and Adams, 2018; Danish et al., 2017; Ito, 2017; Al-Mulali et al., 2015a,b). The coefficient of the population shows a positive and significant effect on environmental degradation. This implies that a 1% rise in population boosts the level of emissions by 2.045% in the long run. The results are consistent with Chen et al. (2021); Anwar et al. (2020) and Pham et al. (2020) ~~that~~ who pointed out that increasing population results in increasing carbon emissions. Moreover, they argue that over the last few decades, the growing population leads to increased transportation and industrial sector activity which are detrimental to environmental quality.

The coefficient of EPU shows the significantly positive impact on

**Table 4**
Bounds test cointegration using the approach by Kripfganz and Schneider's (2018).

| | Calculated Statistics | p-value | | 10% | | 5% | | 1% | |
|---|---|---|---|---|---|---|---|---|---|
| | | I(0) | I(1) | I(1) | I(0) | I(1) | I(0) | I(1) | I(0) |
| **F-test** | 5.919** | 0.002 | 0.014 | 2.559 | 3.834 | 3.107 | 4.56 | 4.441 | 6.316 |
| ***t*-test** | −4.116* | 0.004 | 0.066 | −2.546 | −3.850 | −2.911 | −4.291 | −3.665 | −5.199 |

**Note:** *, ** represent 10% and 5% level of significance, respectively.

**Table 5**
Results for dynamic ARDL simulations.

| Regressor | Coeff. | Prob. |
|---|---|---|
| $\ln GDP_{t-1}$ | 0.630*** | 0.001 |
| $\Delta \ln GDP_t$ | 1.016*** | 0.001 |
| $\ln EI_{t-1}$ | 0.920*** | 0.000 |
| $\Delta \ln EI_t$ | 0.626*** | 0.000 |
| $\ln ES_{t-1}$ | −0.013 | 0.872 |
| $\Delta \ln ES_t$ | −0.094 | 0.342 |
| $\ln POP_{t-1}$ | 2.045** | 0.017 |
| $\Delta \ln POP_t$ | 0.566 | 0.925 |
| $\ln EPU_{t-1}$ | 0.037 | 0.138 |
| $\Delta \ln EPU_t$ | 0.041** | 0.038 |
| Constant | −50.79*** | 0.005 |
| Simulation# | 5000 | |
| $R^2$ | 0.757 | |
| F-stat | 6.800*** | 0.000 |
| **Diagnostic tests** | | |
| Breusch-Godfrey LM (Autocorrelation) | 1.40 | 0.266 |
| Breusch-Pagan (Heteroscedasticity) | 0.45 | 0.504 |
| Skewness & Kurtosis (Normality) | 0.52 | 0.770 |

**Note:** ** and *** represent 5% and 1% level of significance, respectively.

environmental pollution which demonstrates how increasing $CO_2$ emissions is accompanied by higher economic policy uncertainty in China. The unstable factors in environmental policies usually contribute to stimulate $CO_2$ emissions in an economy. The reasons behind the positive impact of EPU on $CO_2$ emissions are; economic policy uncertainty encourages producers to use those production methods which are environmentally harmful, thereby contributing to increased $CO_2$ emissions. Because of higher EPU, a reduction in the use of renewable energy and R&D may contribute to enhance $CO_2$ emissions.

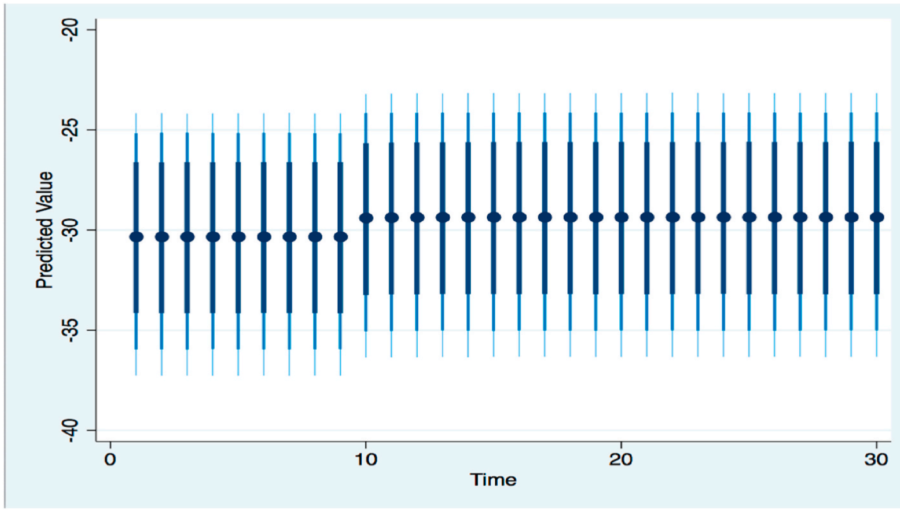
This demonstrates as the environment is linked with the manufacturing process of the corporate sector, accordingly, EPU contributes to stimulate $CO_2$ emissions. Pastor and Veronesi (2013, 2012) theoretically proved that higher economic policy uncertainty may cause macroeconomic instability in a country. The sign of EPU is in line with the previous literature on the EPU-environment nexus (Danish et al., 2020; Pirgaip and Dincergok, 2020; Adams et al., 2020). Furthermore, the increasing income of individuals may cause increases in $CO_2$ emissions. For instance, due to an increase in income people usually enhance traveling which may lead to enhanced $CO_2$ emissions. Moreover, as EPU decreases, the government's attention to implement environmental protection policies increases, and the execution of these environment-related strategies will be directed in a positive way.

The results of different diagnostic tests are reported in Table 5. We apply diagnostic tests to check the consistency of the econometric model. The results of the Breusch-Godfrey LM test show the absence of serial correlation in the model. The results of Breusch-Pagan indicate that no heteroscedasticity was found in the model. The skewness and kurtosis are applied to check the normality of the dataset. The results confirm the existence of normal distribution under the null hypothesis. To check the robustness of the results in Table 5, the same method is applied on per capita values, which are posted in Table A in Appendix. Fig. 1a and b plot the negative and positive shocks of EPU in carbon emissions, supporting incremental effect of uncertainty on the level of emissions in China. In other words, they show a 1% increase and a 1% decrease in EPU and its effect on $CO_2$ emissions. The dots specify average prediction value, whereas the dark blue to light blue line specifies 75, 90, and 95% confidence interval, respectively.

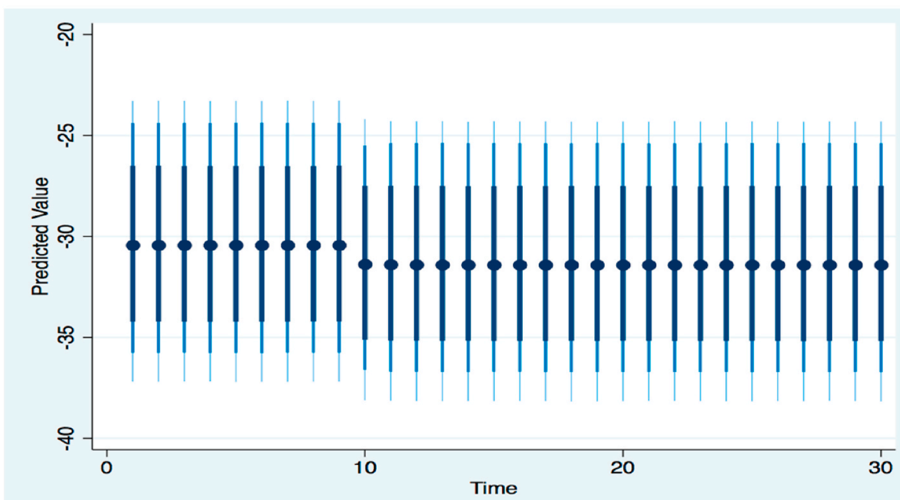
## 5. Conclusion and policy recommendations

In recent decades, climate change has become a serious problem that may lead to deteriorated sustainable development throughout the world. Over the past few decades, $CO_2$ emissions have significantly contributed to global warming which ultimately leads to a change in the climate across the globe. Therefore, it is important to examine those factors which significantly contribute to enhance $CO_2$ emissions. The present study investigates the role of economic policy uncertainty in relation to the energy-income-environment nexus to investigate the association among $CO_2$ emissions, energy intensity, real income, energy structure, population, and EPU under the STIRPAT framework for China over the period 1980–2016. For empirical analysis, this study utilized an up-to-date time series approach; namely, ARDL with dynamic simulations proposed by Jordan and Philips (2018) which overcomes complexities in the already existing model in order to investigate the long run and short run estimations of determinants on $CO_2$ emissions. This method applies 5000 simulations of the vector of parameters by utilizing multivariate normal distribution. The empirical findings highlight that EPU has a positive economic effect on $CO_2$ emissions which demonstrates increasing $CO_2$ emissions is accompanied by higher economic policy uncertainty in China. The establishment of stable economic and environmental policies contributes to green and clean energy, thus mitigating environmental pollution. Moreover, GDP and energy intensity leads to increased environmental pollution. The use of renewable energy (energy structure) mitigates $CO_2$ emissions and environmental degradation which will lead to promote sustainable development in China.

The empirical results of this study suggest some important policy implications. It is clear from the findings of this study that energy intensity increases $CO_2$ emissions in China which signifies inefficient energy use. If energy intensity is reduced, it would effectively lead to achieve sustainable development goals and to fulfill basic human needs. The energy sector can decarbonize through energy innovation which can be done through R&D expenditures. This should ultimately help decrease energy intensity and thus result in a lowered volume of emissions. In addition, the consumption of green energy can lessen environmental degradation, which would promote China's sustainable economic development. Therefore, it is better for China to improve the efficiency of coal utilization, explore value-added products of non-renewable energy sources (for example coal cooking, coal power generation, and coal gasification), and utilization of more renewable energy sources. In order to maintain a sustainable environment and energy efficiency, policymakers encourage spending on research and development. To maintain environmental quality and to establish environment-friendly environments, policymakers should establish consistency in economic and environmental policies. Environmental pollution can be controlled by decreasing energy intensity, economic policy uncertainty, and considering technological innovation measures such as spending on, subsidies from the government, and tax incentives. Furthermore, the empirical results demonstrate that EPU stimulates environmental pollution. EPU is considered an important source for government regulation from the practical implication perspective. It is recommended for the government to promote transparent and consistent policies, as




a




b

**Fig. 1.** a. (+1%) changes in predicted EPU on $CO_2$ emissions. b. (−1%) changes in predicted EPU on $CO_2$ emissions.

the establishment of such policies stimulates investors to invest in clean energy which would definitely help to mitigate environmental pollution.

This study has certain limitations. It mainly focused on policy uncertainty to understand the changes in carbon emissions using the STIRPAT model in China. Future research may focus on globalization and geopolitical risk in shaping the relationships of selected variables with $CO_2$ emissions. Further, future studies may use other models such the EKC. Last, this study explored linear relationship between the analyzed variables whereas future studies can explore asymmetric relationships.

### Credit author statement

Eyup Dogan: Supervision, Model, Methodology, Writings; Azka Amin: Introduction, Empirical Results, Conclusion.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.112865.

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