Sustainable environment, energy and finance in China: Evidence from dynamic modelling using carbon emissions and ecological footprints

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TITLE: Sustainable environment, energy and finance in China: Evidence from dynamic modelling using carbon emissions and ecological footprints

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27 **Highlights:**

- 28 • Robust results explained that sustainable finance place a lucrative cause to preserve the
29 environment
- 30 • A novel Dynamic Autoregressive Distributed Lag technique is applied
- 31 • For this study, annual data is collected for China over 1970-2017
- 32 • In the long run, sustainable economic factors show a positive impact on carbon emissions
33 whereas economic growth, energy consumption, and exports improve the ecosystem
- 34 • On contrary, in the short run, urbanization supports the environment while economic
35 development, energy use, and exports exert a positive impact on the environment

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Sustainable environment, energy and finance in China: Evidence from dynamic modelling using carbon emissions and ecological footprints

Abstract

This study investigates sustainable finance along with sustainable economic factors on both carbon emissions and ecological footprints in China. A novel Dynamic Autoregressive Distributed Lag technique is applied, results revealed sustainable finance exerts positive/negative influence on carbon emissions in the long- and short-run, respectively. Results are robust with ecological footprints that sustainable finance placed a lucrative cause to preserve the environment. Sustainable economic factors show a positive impact on carbon emissions in the long run, while economic growth, energy consumption, and exports improve environmental quality. Conversely, in the short run, urbanization supports the environment while economic development, energy use, and exports exert a positive impact. In addition, this study suggests useful policy implications for the stakeholders.

Keywords: Sustainable environment, energy and finance, market capitalization, Carbon/CO₂ emissions, ecological footprints, DARDL, China.

1. Introduction

Environmental degradation is a foremost challenge for both developed and developing economies across the world. In particular, the crucial question facing businesses, environmental activists, academics, governments, managers, policy-makers and regulators is how to cut greenhouse gases (GHG)/carbon/ CO₂ emissions and ecological footprints (sustainable environment/energy), while generating wealth (sustainable finance) for society. Answering this crucial policy question and

preserving the environment is arguably the most demanding task for the current human generation (Collins and Zheng 2015; Bekun et al., 2019a 2019b).

Environmental degradation is triggered by a flood, fire, and the most prominently, GHG emissions. These events can disrupt the natural resources, infrastructure, agricultural land, and the most importantly, human lives. Within the context of the obligations imposed by the Paris Agreement in 2015, these have major implications, especially in emerging economies. Meanwhile, China as the largest emerging economy is the leading energy consumer and the first CO₂ emitter in the world (Lahiani 2020). For example, China's carbon emissions have increased from 0.94 in 1970 to 7.18 metric tons per capita in 2016, which represents almost seven times in growth terms over the same period (World Bank 2018). In this regard, it is essential to sustain economic and financial growth, whilst maintaining a sustainable environment by curtailing CO₂/GHG emissions. In this study, we contend that the answer to the questions mentioned above is committing to sustainable finance through managing stock market capitalization. The purpose of this study, therefore, is to investigate the influence of sustainable finance (market capitalization) and economy on environmental degradation with the help of carbon emissions and ecological footprints over 38 years in China. In addition, other sustainable economic factors, such as energy use, economic growth, exports, non-renewable energy use, and urbanization are taken as extra predictors in this research.

Apart from carbon emissions, ecological footprints have been proposed by Rees (1992) as a cumulative factor for environmental quality (Charfeddine 2017; Fakher 2019; Destek and Sinha 2020). Moreover, it is indicated that these were the consequences of financial and non-financial activities (Nathaniel and Khan 2020). Generally, the ecological footprint shows a part of the water

and land, which is claimed to be used by the operators to manufacture products for consumption and to produce waste continually (Wackernagel and Rees 1997). Similarly, China is considered the leading country in ecological footprints in the world (Ulucak and Lin 2017). Sustainable finance i.e., market capitalization is a decent indicator of the size of firms and is corroborated by the finance literature. It contains additional elements for which the balance sheet is silent, such as company reputation, growth, and management expertise (Adom et al. 2020). Bougatef (2017) claimed that market capitalization is a way through which profitability can be enhanced. Fig 1 represents the line graphs of CO₂ emissions (metric tons per capita) and ecological consumption per capita (total) in China from 1970 to 2017. It is evident from both graphs that environmental degradation is progressively increasing that making China the world largest CO₂ emitter country in the world. The point emanated from the figure that environmental pollution is continually increasing and need to be declined for a healthier future.

To the best of our understanding, this research is unique to explore the role of sustainable finance by examining the effect of market capitalization on the environment through CO₂ emissions and ecological footprints. Thus, based on the review of prior research related to financial indicators and the environment, this study contributes to environmental finance literature in a number of ways. *First and foremost*, a plethora of research in Environmental Kuznets Curve EKC perspective has been done on environmental degradation with financial development (Nosheen et al. 2019; Lahiani 2020; Rahman et al. 2020), economic growth (Lau et al. 2014; Acquaye et al. 2017; Dogan et al. 2019; Khan et al. 2019; Lahiani 2020), energy consumption (Bölük and Mert 2014; Wang et al. 2016a; Bhattacharya et al. 2017; Sarkodie and Strezov 2019), non-renewable energy consumption (Bhattacharya et al. 2017; Dogan et al. 2019; Sarkodie and Strezov 2019) and urbanization (Zhang and Lin 2012; Erdoğan 2013), but the literature is silent to uncover the

sustainable finance considering the rapid increases in the market capitalization of listed companies in emerging economies.

[INSERT FIGURE 1]

Fig 2 indicates the ecological footprints consumption per person for China from 1960 to 2017. The value of ecological footprints consumption global hectares per person was initially favourable in 1960 and it became adverse in 1969. The value of ecological footprints consumption increased and reached from 1 to 2 global hectares per person in 33 years. Then, it increased exponentially and crossed the next unit in just six years. Therefore, ecological footprint consumption in China continues to grow. The reason behind this is twofold. Firstly, China is the largest populated country globally, and this massive population demands more natural resources. Secondly, China is the largest manufacture and exporter globally.

To the best of our understanding, this research is unique to explore the role of sustainable finance by examining the effect of market capitalization on the environment through CO₂ emissions and ecological footprints. Thus, based on the review of prior research related to financial indicators and the environment, this study contributes to environmental finance literature in a number of ways. *First and foremost*, a plethora of research in Environmental Kuznets Curve EKC perspective has been done on environmental degradation with financial development (Nosheen et al. 2019; Lahiani 2020; Rahman et al. 2020), economic growth (Lau et al. 2014; Acquaye et al. 2017; Dogan et al. 2019; Khan et al. 2019; Lahiani 2020), energy consumption (Bölük and Mert 2014; Wang et al. 2016a; Bhattacharya et al. 2017; Sarkodie and Strezov 2019), non-renewable energy consumption (Bhattacharya et al. 2017; Dogan et al. 2019; Sarkodie and Strezov 2019) and urbanization (Zhang and Lin 2012; Erdoğan 2013), but the literature is silent to uncover the

sustainable finance considering the rapid increases in the market capitalization of listed companies in emerging economies.

[INSERT FIGURE 2]

Secondly, the existing research enormously utilized autoregressive distributive lag (ARDL) (Pesaran et al. 1999; Pesaran et al. 2001), Non-linear ARDL (NARDL) (Shin et al. 2014) and Quantile ARDL (QARDL) (Cho et al. 2015), while in this study we have applied novel Dynamic ARDL (DARDL) simulations to consider the effects of long and short run association of among the variables that we investigate. DARDL model is robust to automatically plot positive and negative simulations (Jordan and Philips 2018). *Thirdly*, the study is exclusive in examining the influence of sustainable finance using market capitalization and sustainable economic factors with energy consumption, economic growth, urbanization, and exports on GHG emissions to validate EKC and additionally, ecological footprints in order to obtain robust results. *Lastly*, this research contributes to the Chinese Economy perspective, which is the leading manufacturer globally and hence, exporting products around the globe. It necessarily seeks to consume traditional energy sources based on fossil fuels (Lahiani 2020). In doing so, this study investigates the relationships among sustainable environment, finance and energy by applying dynamic modelling using carbon omission and ecological footprints.

The remainder of the study is structured as follows. Section 2 presents the literature review, while Section 3 outlines the methodology. Furthermore, Section 4 reports and interprets the findings whilst Section 5 concludes the paper including outlining the policy implications.

2. Literature review

Countries' economic performance depends on energy, but the excessive usage of traditional sources of energy may result in global warming (Apergis and García 2019). Energy use and the environment have a significant relationship, and the results suggested that more use of nonrenewable energy plays a key role in the deterioration of the environment (Katircioğlu and Taşpınar 2017; Baloch et al. 2019). In addition, the excessive use of traditional energy leads to environmental and ecological degradation in both developing and developed nations (Ahmed et al. 2020). Zhang et al. (2017) reported that utilization of sustainable energy improves environmental conditions, whereas non-renewable energy consumption deteriorates the environment. Renewable energy and energy efficiency play their role in mitigating the GHG emissions in BRICS countries (Akram et al., 2020). Economic complexity and non-renewable energy consumption cause detriment to the ecological footprints (Shahzad et al. 2021).

Literature shows a positive influence of sustainable economic factors such as economic growth on GHG emissions in developing economies. For instance, Nazir et al. (2018) examined that per capita income is positively significant with carbon emissions in Kyoto Annex countries. As the economic growth of an economy increases, environmental pollution also increases (Katircioğlu and Taşpınar 2017; Dogan et al. 2019; Rahman et al. 2002). The relationship between carbon emissions and economic growth was analyzed using the NARDL model in China. The examined results of asymmetric relationship showed that positive and negative change in GDP brings significantly positive and negative impacts on the environment, respectively (Lahiani 2020). In addition, Fareed et al. (2018) analyzed the association between tourism, economic growth, and terrorism. The results showed statistically significant and asymmetric behaviour. The impact of

non-renewable energy and economic growth is positive on ecological footprints. Non-sustainable economic growth holds a significant direct effect on the surge in ecological footprints (Sharif et al. 2020).

Zhang et al. (2017) reported that renewable and non-renewable energy use with carbon emissions. The outcomes are evident that sustainable energy impedes environmental degradation, whereas non-sustainable energy consumption deteriorates the environment. The relationship among renewable energy use, GDP, and carbon emissions are asymmetric in both the long and short-run in Saudi Arabia (Toumi and Toumi 2019). Similarly, the outcomes of non-sustainable energy consumption and economic growth embrace a statistically significant impact on ecological footprints (Sharif et al., 2020). Dogan et al. (2019) examined the influence of non-renewable energy use on CO₂ emissions, while Sharif et al. (2020) on ecological footprint, and both the studies revealed that the consumption of non-sustainable energy leads to the degradation of the environment.

Hashmi et al. (2020) studied the influence of urbanization on CO₂ emissions. They found that urban agglomeration has a direct and significant effect on environmental degradation in the top ten urban agglomerated countries. Urbanization holds a positively significant impact on the ecological footprints (Godil et al. 2021). Similarly, Sadorsky (2010) reported that urbanization has a significant positive effect on CO₂ emissions in panel data of emerging economics. The association of urbanization and carbon emissions is significant, leading to the deterioration of the environment (Pata 2018; Dogan et al. 2019).

Mahmood et al. (2019) analyzed the nonlinear or asymmetric impact of trade on carbon emissions. The results have shown that the immediate change in trade significantly augments CO₂ emissions,

while the negative change improves the environment. In addition, there is a nonlinear impression of FDI and trade on CO₂ emissions in Turkey (Haug and Ucal 2019). Godil et al. 2021 analyzed the influence of financial development and transportation on ecological footprints using Quantile ARDL. The outcomes of the study revealed that both transportation and financial development present reasons to preserve the environment. In the above-mentioned literature, it is evident that a lot of work has been done to explore the sustainable environment (CO₂ emissions or ecological footprints) with financial indicators (financial development and economic growth) and non-financial indicators (transportation, energy consumption, and urbanization). In contrast, the literature is silent to uncover the impact of sustainable finance on the environment.

3. Methodology

For this study, annual data is collected for China over 1970-2017. The description of the variables is presented in Table 1. Moreover, data for carbon dioxide emissions (CO₂), economic growth (GDP), energy use (EC), exports of products (EXP), the market capitalization of listed companies (MCAP), and urban population (URB) is collected from World Bank (World Development Indicators). In contrast, data of ecological footprints (EF) and non-renewable energy (NREC) are gathered from Global Footprint Network (GFPN) and BP Statistics, respectively.

For the selection of variables, this research follows the prior studies. The relationship of GDP (Katircioğlu and Taşpinar 2017; Pata 2018; Lahiani 2020), energy consumption (Katircioğlu and Taşpinar 2017; Nosheen et al. 2019), non-renewable energy consumption (Dogan et al. 2019), urbanization (Dogan et al. 2019), and trade (Nosheen et al. 2019) is examined with greenhouse gases emissions. Similarly, financial development results and carbon emissions are enormously analyzed (Pata 2018; Eren et al. 2019; Rahman et al. 2020).

In line with existing literature, the variables such as market capitalization, exports, economic growth, energy use, and urbanization are selected to examine their impact on the sustainable environment in China for 48 years, taking from 1970 to 2017. The model of this study is presented as follows.

$$(\text{CO2})_t = \beta_0 + \beta_1 \text{MCAP}_t + \beta_2 \text{GDP}_t + \beta_3 \text{EC}_t + \beta_4 \text{NREC}_t + \beta_5 \text{URB}_t + \beta_6 \text{EXP}_t + \varepsilon_t \quad (1)$$

Along with carbon emissions, this study also considered the ecological footprints as another proxy for the environment. Sharif et al. (2020) examined the influence of GDP and energy consumption (renewable and non-renewable) on ecological footprints, while Godil et al. (2021) explored urbanization, transport, and financial development with ecological footprints. Hence, the second model for this study can be as follow.

$$(\text{EF})_t = \beta_0 + \beta_1 \text{MCAP}_t + \beta_2 \text{GDP}_t + \beta_3 \text{EC}_t + \beta_4 \text{NREC}_t + \beta_5 \text{URB}_t + \beta_6 \text{EXP}_t + \varepsilon_t \quad (2)$$

3.1 ARDL bound testing

ARDL bounds test results are utilized to demonstrate the long-run association among the study variables, and the value of f-statistics indicate the long-run relationship. If the f-value is higher than the upper limit at a 5% significance level, then long-term co-integration among variables is assumed (Pesaran et al. 2001). But, if the f-value is smaller than the lower critical limit, then the long-run relationship is absent. If the f-value lies between the lower and upper limit, co-integration is considered un-decidable. The following hypothesis is assumed for checking long-run relationships among variables.

[INSERT TABLE 1]

$$H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = 0 \quad (3)$$

The bounds testing approach equation is presented below.

$$\begin{aligned} \Delta \text{CO2}_t = & \alpha_0 + \delta_1 \text{CO2}_{t-i} + \delta_2 \text{MCAP}_{t-i} + \delta_3 \text{GDP}_{t-i} + \delta_4 \text{EC}_{t-i} + \delta_5 \text{NREC}_{t-i} + \delta_6 \text{URB}_{t-i} \\ & + \delta_7 \text{EXP}_{t-i} + \sum_{i=1}^r \beta_1 \text{MCAP}_{t-i} + \sum_{i=1}^r \beta_2 \text{GDP}_{t-i} + \sum_{i=1}^r \beta_3 \text{EC}_{t-i} + \sum_{i=1}^r \beta_4 \text{NREC}_{t-i} \\ & + \sum_{i=1}^r \beta_5 \text{URB}_{t-i} + \sum_{i=1}^r \beta_6 \text{EXP}_{t-i} + \varepsilon_t \end{aligned} \quad (4)$$

In the equation mentioned above, Δ shows change operator while $t-i$ indicates optimal lag selection based on SBIC and HQIC as shown in Table 4. δ_1 to δ_7 and β_1 to β_6 are coefficients that will be estimated. In addition to CO_2 emissions, ecological footprints are also examined with predictor variables to robust the results. Following is the bound testing approach equation for ecological footprints.

$$\begin{aligned} \Delta \text{EF}_t = & \alpha_0 + \delta_1 \text{EF}_{t-i} + \delta_2 \text{MCAP}_{t-i} + \delta_3 \text{GDP}_{t-i} + \delta_4 \text{EC}_{t-i} + \delta_5 \text{NREC}_{t-i} + \delta_6 \text{URB}_{t-i} \\ & + \delta_7 \text{EXP}_{t-i} + \sum_{i=1}^r \beta_1 \text{MCAP}_{t-i} + \sum_{i=1}^r \beta_2 \text{GDP}_{t-i} + \sum_{i=1}^r \beta_3 \text{EC}_{t-i} + \sum_{i=1}^r \beta_4 \text{NREC}_{t-i} \\ & + \sum_{i=1}^r \beta_5 \text{URB}_{t-i} + \sum_{i=1}^r \beta_6 \text{EXP}_{t-i} + \varepsilon_t \end{aligned} \quad (5)$$

3.2 Dynamic ARDL simulations

ARDL model was proposed by (Pesaran et al. 1999; Pesaran et al. 2001). It presents numerous benefits over other co-integration techniques (Duasa 2007). First of all, ARDL can be applied with different lag lengths of the variables as some model demands identical lags (Engle and Granger 1987; Johansen and Juselius 1990). Secondly, this model can be utilized if the data is stationary at

I (0) or I (1) or a combination of both orders. Lastly, the ARDL model is favourable when the sample size is small (Narayan 2004).

After developing the ARDL technique, Shin et al. (2014) introduced the NARDL model to satisfy the asymmetric effects among variables. Later on, Cho et al. (2015) enhanced this model and presented the QARDL technique. In addition, Jordan and Philips (2018) proposed Dynamic ARDL with dynamic simulations to consider the effects of the long and short-run association of variables. This newly developed model is competent enough to plot positive and negative simulations automatically. Hence, the following models of this study are proposed for a sustainable environment using dynamic ARDL.

$$\begin{aligned}\Delta\text{CO2}_t = & \varphi_0 + \theta_0\text{CO2}_{t-1} + \beta_1\Delta\text{MCAP}_t + \theta_1\text{MCAP}_{t-1} + \beta_2\Delta\text{GDP}_t + \theta_2\text{GDP}_{t-1} + \beta_3\Delta\text{EC}_t \\ & + \theta_3\text{EC}_{t-1} + \beta_4\Delta\text{NREC}_t + \theta_4\text{NREC}_{t-1} + \beta_5\Delta\text{URB}_t + \theta_5\text{URB}_{t-1} + \beta_6\Delta\text{EXP}_t \\ & + \theta_6\text{EXP}_{t-1} + \text{YECT}_{t-1} + \varepsilon_t\end{aligned}\quad (6)$$

$$\begin{aligned}\Delta\text{EF}_t = & \varphi_0 + \theta_0\text{CO2}_{t-1} + \beta_1\Delta\text{MCAP}_t + \theta_1\text{MCAP}_{t-1} + \beta_2\Delta\text{GDP}_t + \theta_2\text{GDP}_{t-1} + \beta_3\Delta\text{EC}_t \\ & + \theta_3\text{EC}_{t-1} + \beta_4\Delta\text{NREC}_t + \theta_4\text{NREC}_{t-1} + \beta_5\Delta\text{URB}_t + \theta_5\text{URB}_{t-1} + \beta_6\Delta\text{EXP}_t \\ & + \theta_6\text{EXP}_{t-1} + \text{YECT}_{t-1} + \varepsilon_t\end{aligned}\quad (7)$$

4. Results and discussion

Table 2 displays the descriptive statistics of all the variables of this study. Variables have positive mean values, and it is shown that economic growth has the highest mean of 3.0440, followed by energy consumption, 2.9640. Similarly, GDP is more volatile than the rest of the given variables. On the other hand, ecological footprints and urbanization have a minimum standard deviation. GDP has a larger range value, which is 1.5070. Skewness values show that almost all the variables

are moderately skewed because given values lie between 0 - 0.5. Kurtosis values are less than 3, and hence, kurtosis has a somewhat thin tail.

Table 3 reveals the unit root tests of study variables using ADF and ZA (Zivot and Andrews 2002) tests. In addition, the structural break is found by using the ZA unit root test, as shown in the table. These tests represent that variables are non-stationary at I (0), whereas all of them become stationary at first difference. Hence, both the unit root tests reject the null hypothesis when applied at I (1), representing the accomplishment of the condition for ARDL (Pesaran et al. 1999; Pesaran et al. 2001). Table 4 shows lag selection indication based on Vector Auto-Regressive (VAR) model (Khan et al. 2019). It presents the results of LR, FPE, AIC, SBIC, and HQIC criteria. As per the SBIC and HQIC, the first lag is appropriate, while AIC indicates that the second lag is satisfactory. Hence, for the model selection, SBIC and HQIC are used with lag one.

[INSERT TABLE 2]

Table 5 describes the ARDL bounds testing outcomes to demonstrate the long-term relationship among variables. F-statistics value is 20.9330 and is greater than the upper limit at 1% *p*-value (Pesaran et al. 2001). The model has sufficient evidence to accept the alternative hypothesis representing that the variables of this study embrace long-run cointegration and equilibrium. Moreover, the error correction term (ECT) is negative and significant in Table 6 corroborates the cointegration (Kanjilal and Ghosh 2013).

Table 6 displays the results of dynamic ARDL simulations. The model outcomes indicate that market capitalization has a significant association with carbon emissions for both the long and short-run. China represents a 4 to 5% contribution of market capitalization (percentage of GDP)

towards the environment. The relationship indicates that market capitalization behaves negatively and positively in the short and long-run. This is because China is an emerging economy, and an increase in market capitalization helps to save the environment. Then, in the long run, this impact becomes adverse and shifts to negative due to more investment and consumption of traditional sources of energy. Hence, China is leading in energy consumption and is the biggest carbon emitter country across the world (Lahiani 2020).

[INSERT TABLE 3]

[INSERT TABLE 4]

The outcome of short-run economic growth shows the positive and insignificant influence on CO₂ emissions in China. The 1% increase in GDP influences to increase of 0.26% in environmental degradation per year. The positive effect of GDP on carbon emission shows that currently, China falls at the first stage of EKC and is moving towards industrial richness. On the other hand, in the long run, economic growth shows a negative impact on CO₂ emission in China because there will be a threshold point when CO₂ emissions would start to decline even though GDP per capita is increasing (Grossman and Krueger 1991). These outcomes are consistent with the literature, which explains that economic growth might lead to environmental degradation (Sharma 2011; Acquaye et al. 2017; Pata 2018; Dogan et al. 2019; Lahiani 2020).

The results of dynamic ARDL simulations report a direct and significant association between energy use and carbon emissions in the short run. China is an emerging economy and the largest producer of manufactured goods in the world. Hence, an increase of 1% in energy use pollutes the environment by 0.51% due to more traditional energy sources in the short run. On the other hand,

this relationship shifts and becomes negatively insignificant in the long run. The coefficient is also decreased from 0.51 to 0.28 in the long run, which indicates that China tends towards more renewable energy use (Shahbaz et al. 2013; Wang et al. 2016a; Bhattacharya et al. 2017; Sarkodie and Strezov 2019). It is indicated that emerging countries of the world are impatient for economic growth. These economies use traditional ways of energy sources based on fossil fuels and hence, causing the quality of the environment (Khan et al. 2019).

[INSERT TABLE 5]

The results of Table 6 show that between non-renewable energy use and GHG emissions, there exists a significantly positive and negative association in the short and long-run, respectively, in China. This is due to the long-lasting effect of non-renewable energy use on the environment. Findings of urbanization represent insignificant relation with carbon emissions. This relationship is direct in the long-run whereas inverse in the long-run. The coefficient shows that urbanization is more robust in the long-run than in the long-run in China. Wang et al. (2016b) studied the association of energy use and urbanization with CO₂ emissions, and the outcomes of the study presented that urbanization is a key indicator of environmental degradation. There exists a direct impact of urbanization on GHG emissions (Zhang and Lin 2012; Erdoğan 2013). The outcomes of urbanization are similar to (Pata 2018; Dogan et al. 2019) but opposite to (Khan et al. 2019).

The results of dynamic ARDL simulations state a positive and significant relationship between exports and carbon emissions in the short-run. China is one of the leading manufacturers and exporter countries in the world. An increase of 1% in exports adds to environmental degradation by 0.06% in the short run. Whereas in the long run, this relationship is negatively insignificant. An increase of 1% in exports leads to reducing GHG emissions by 0.003%. Trade has a bidirectional

relationship with CO₂ emissions (Mirza and Kanwal 2017; Chandia et al. 2018). In addition, developed countries shift their CO₂ emissions-related technologies to emerging economies (Khan et al., 2019).

ECT is negatively significant (-0.1991), which states the speed of adjustment parameter aftershock. ECT narrates that in one year, the rate of adjustment to the preceding equilibrium exists almost - 20%. R-squared value presents that the independent variables of the study explained 88% variation in CO₂ emissions. For the ECT algorithm, this study utilized 5000 simulations for the variables vector as recommended (Sarkodie et al., 2019). The P-value of the overall model is significant at a 1% level. Root mean square error (RMSE) and F-statistics values of the model are also favourable, which are 0.0091 and 19.24, respectively.

Table 7 shows the outcomes of dynamic ARDL simulations for sustainable environment taking ecological footprint as a dependent variable. This indicates that market capitalization has an insignificant relationship with ecological footprints for both the long and short-run. The 1% increase in market capitalization saves the environment by 0.01%. Sharif et al. (2020) presented a direct association of economic growth, while Godil et al. (2021) explored the negative relationship of financial development with ecological footprints. In the short-run, economic growth outcomes show a significant association with ecological footprints in China. The 1% increase in GDP affects 0.38% of natural resources. In the long-run, economic growth shows a negative influence on ecological footprints similar to (Sharif et al. 2020), while financial development leads to ignoring the environment (Godil et al., 2021).

Moreover, the results show a significantly positive association between energy consumption and ecological footprints in the short-run. An increase of 1% in energy consumption influences the

expansion of environmental degradation by about 0.75%. On the other hand, this relationship is negatively insignificant in the long-run. Sharif et al. (2020) examined the negatively significant relationship between the environment and renewable energy consumption. In addition, it is found that emerging countries of the world look keen to use traditional ways of energy production based on fossil fuels, irrespective of the environment, to fulfil their energy demand (Khan et al., 2019).

[INSERT TABLE 6]

The results of Table 7 display that between non-renewable energy consumption and ecological footprints, there is an insignificantly negative and positive association in the short and long-run, respectively. An escalation in non-renewable energy use leads to polluting the environment (Bhattacharya et al., 2017). Non-renewable energy consumption shows a positively significant effect on natural resources (Sharif et al. 2020). The results of urbanization represent insignificant relation between environmental degradation and urbanization. This affiliation is direct in the short-run whereas inverse in the long-run. The coefficients show that the influence of urbanization is stronger in the long-run in China. Similarly, the results of dynamic ARDL simulations show that there exists a positive and insignificant connection between exports and ecological footprints. The 1% increase in exports causes to spoil the environment by 0.01% in the short-run while and 0.04% in the long-run. There is a bidirectional relationship between trade and environmental degradation (Shahzad et al., 2017; Chandia et al., 2018).

Besides, ECT is negatively significant (-0.7561). In this model, ECT narrates that the speed of adjustment to the preceding equilibrium is almost 76% in one year. R-squared value presents that the independent variables explain -76% variation in ecological footprints. The P-value of the overall model is significant at 1%. F-statistics and RMSE values are 8.31 and 0.0071, respectively.

4.1 *Graphs of dynamic ARDL simulations*

Fig. 3 presents positive and negative 10% change in market capitalization and its impact on carbon emissions in China for 1970-2017. A 10% increase in market capitalization saves the environment in a shorter period but deteriorates in the long-run, on the opposite, the decrease in urbanization assets a negative influence on environmental quality. Fig. 4 shows positive and negative 10% change in economic growth and its impact on carbon emissions in China for 1970-2017. The 10% rise in GDP has positive and negative effects on carbon emissions in the long and short-run, respectively whilst decrease in GDP helps to save the environment in China.

[INSERT TABLE 7]

[INSERT FIGURE 3]

[INSERT FIGURE 4]

Fig. 5 reports positive and negative 10% change in energy use and its impact on carbon emissions. Escalation in energy consumption makes the environment deteriorate both in the long and short-run. But, a 10% decrease in energy use helps to support the environment. Fig. 6 shows positive and negative 10% change in non-renewable energy use and its impact on carbon emission in China for 1970-2017. It is shown that the rise in non-renewable energy use has a direct influence on carbon emissions in the short-run. Still, an inverse impact in the long-run as non-renewable sources save the environment. Moreover, a 10% decrease in non-renewable energy use supports the environment.

[INSERT FIGURE 5]

408 **[INSERT FIGURE 6]**

409 Fig. 7 shows positive and negative 10% change in urbanization and its impact on carbon emissions
410 in China. The rise in urbanization has a positive influence on carbon emissions. On the other hand,
411 a 10% decrease in urbanization helps to minimize environmental degradation in the short-run than
412 in the long-run. Fig. 8 reports positive and negative 10% change in exports of products and its
413 impact on carbon emissions in China over 1970-2017. A rise in exports has a direct effect on
414 carbon dioxide emissions. In contrast, a 10% decrease in exports has an opposite influence on
415 carbon emissions.

416 **[INSERT FIGURE 7]**

417 **[INSERT FIGURE 8]**

418 Fig 9 indicates CUSUM (cumulative sum) and CUSUM squares graphs at a 5% significance level.
419 These two graphs are utilized to know the reliability of the coefficient. Both the graphs represent
420 the upper and lower boundary lines, and between these limits, residual values are shown. These
421 residual values are between the boundaries and prove that the examined DARDL model is stable
422 and reliable at a 5% significance level.

423 **[INSERT FIGURE 9]**

424 **5. Conclusion**

425 This study has sought to extend the extant literature on sustainable environmental, energy and
426 finance by applying a dynamic model to evaluate the effects of sustainable finance and other
427 economic factors on the environment in China using annual data from 1970 to 2017. The main

findings are as follows. First, the results indicate that the study's variables are stationary at the first order that leads to long-run cointegration and equilibrium. Second, empirical outcomes of this study show that the novel measure of sustainable finance (market capitalization) exerts a negative and positive influence on carbon emissions in the short- and long-run, respectively. Similarly, these results in the short-run are robust with ecological footprints through which it is evident that sustainable finance placed a reasonable cause to preserve the environment. In the long-run, on the contrary, sustainable finance leads to observable degradation of the environment. This might be due to the more use of non-renewable energy production sources in China. In the long run, other sustainable economic factors, such as urbanization capture a positive impact on CO₂ emissions, while economic growth, energy use, and exports are worthy indicators to improve environmental quality. Finally, these results have adverse effects in the short-run. Urbanization negatively impacts the environment, while economic growth, energy consumption, and exports have a positive impact on CO₂ emissions in China.

Firstly, our findings will be of interest to investors, especially Chinese investors as they are required to attain an optimal level of sustainable finance in order to achieve sustainable economic growth. *Second*, since economic growth has a negative influence on GHG emissions, in the long-run, it seems appropriate to work towards increasing GDP so that maximum economic growth along with a sustainable environment can be accomplished in order to fulfil the target of net-zero CO₂ emissions by 2060. *Third*, in the short-run, energy consumption adds to pollute the environment by emitting more carbon emissions in China. It is pertinent, therefore, to replace the conventional energy production techniques with renewable and sustainable energy consumption methods. Hence, policymakers in China, as well as other leading CO₂ emitters' economies, can accomplish sustainable economic growth by providing subsidies on low carbon-emitting

technologies and the availability of smart energy-efficient methods by imposing a ban on the use of fossil fuels in order to improve the community's lifestyle. Future research can be applied with the same set of variables in other leading GHG emitter countries following China, especially in the Asian region or with additional sustainable factors to further explore sustainable growth by persevering the environment.

Ethical Approval

Manuscript does not report on or involve the use of any animal or human data etc.

Consent to Participate

Authors have agreed for authorship, read and approved the manuscript, and given consent for submission of the manuscript.

Consent to Publish

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The data will be provided upon a reasonable request to the corresponding author.

Authors Contributions

Rizwan Ali: Introduction, Writing results and discussion and Conclusion.

Mubeen Abdur Rehman: Abstract, Introduction and Literature Review.

Ramiz ur Rehman: Data analysis, Writing results and discussion, Methodology.

Collins G Ntim: Conceptualization, Data curation, Conclusion.

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649

Figures

Figure 1

Representing the CO₂emissions and ecological footprints in China

Figure 2

Ecological Footprints in China over 1960-2017.

Figure 3

Market capitalization and carbon dioxide emissions. The paired graphs represent $\pm 10\%$ change in market capitalization and its impact on environmental degradation. Dots display ordinary forecasts, whereas the blue lines indicate a 95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 4

Economic growth and carbon dioxide emissions. The paired graphs represent $\pm 10\%$ change in growth (GDP per capita) and its impact on environmental degradation. Dots display ordinary forecasts, whereas the blue lines indicate a 95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 5

Energy use and carbon dioxide emissions. The paired graphs represent $\pm 10\%$ change in energy use and its impact on environmental degradation. Dots display ordinary forecasts, whereas the blue lines indicate a 95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 6

The above-shown graphs represent $\pm 10\%$ in non-renewable energy consumption and its impact on carbon emissions. The Dots display an average forecast while the dark blue line indicates 95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 7

Urbanization and carbon dioxide emissions. The paired graphs represent $\pm 10\%$ change in urbanization and its impact on environmental degradation. Dots display ordinary forecasts, whereas the blue lines indicate 95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 8

Exports and carbon dioxide emissions. The paired graphs represent $\pm 10\%$ change in exports and its impact on environmental degradation. Dots display ordinary forecasts, whereas the blue lines indicate

95% confidence interval, which decreases to 90% and 75% confidence interval as the line becomes thin in two stages.

Figure 9

CUSUM and CUSUM square graphs indicate a 5% significance level. Upper and lower dotted lines represent the upper and lower limits of stability.

Supplementary Files

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