

Zhongguo's Transition to Carbon Neutrality: Unveiling the Econometric Significance of Fossil Fuel in China's Pursuit of Carbon Emission Mitigation (1992-2019)

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Abstract:

This study investigating the links between fossil fuel imports, renewable energy use, and greenhouse gas emissions in China from 1992-2019 employs the ARDL approach and Error Correction Model to examine the dynamics and estimate relationships between these variables over time. The findings offer insights into fossil fuels, renewables, and emissions interacting as China pursues climate change mitigation and carbon neutrality goals. The study highlights need for improved energy efficiency, low-carbon technologies, and international cooperation. Optimizing its energy mix enables China to mitigate environmental impact and meet neutrality targets. However, economic, social, technological, and lifestyle challenges must be addressed. Overcoming these demonstrates China's commitment to global climate action and leadership in fighting climate change.

Keywords: Climate Change, Greenhouse-Gas Emissions, Fossil Fuel Imports, Renewable Energy Consumption, Carbon Neutrality, ARDL Approach, ECM Model.

Jel Classification Codes: C53 · O13 · Q40 · Q53 · Q54 · Q58

1. Introduction

Climate change and recent geopolitical tensions have heightened concerns about the security of energy supplies and the environmental impacts associated with energy production and consumption. Therefore, many countries are currently proposing strong energy replacement policies and radical conservation measures. In this context, the prospects for success of these policies must be assessed, including the expected effects on economic growth. (Goldemberg & Lucon, 2010)

Despite the emergence of the Bourgeois literature on the relationship between energy consumption and economic growth, consensus remains elusive. Some possible reasons for the lack of any consensus in this area are using different datasets, alternative econometric methodologies, and different characteristics of different countries.

As an overview of the development of climate mitigation policy in China. The first national climate change plan was released in 2007, and it set a target of reducing carbon intensity (carbon emissions per unit of GDP) by 40% by 2020. In 2014, China announced that it would peak its carbon emissions by 2030 (Zhang Z. , 2015).

An international Climate Change Conference (COP21) was held in 2015 and resulted in an agreement to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels; increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas (GHG) emissions development in a manner that does not loom up food industry; and confirming consistent pecuniary flows with a pathway toward low GHG emissions and climate-resilient development (UNFCCC, 2015). China, the world's largest emitter of greenhouse gases, pledged to reduce its emissions by 20% to 26% below 2005 levels by 2030 (Yun, 2016).

There is no doubt that this commitment has received widespread support from the international community, which won the climate change bet through the cooperation of the sleeping giant. In addition, the meetings of cooperation and twinning successively continued until China found itself announcing to the whole world its millennium plan to achieve carbon neutrality in the year 2060, during the United Nations climate change gathering in 2020 (Zhu Liu, 2022). It was and still is really a prominent challenge. Is the state capable of this alteration?

China has set ambitious targets for reducing greenhouse gas (GHG) emissions, and it has made significant progress in developing renewable energy sources, through a combination of policies, regulations, and investments including:

- Policies to promote renewable energy. The Chinese government has implemented several policies to promote renewable energy, such as feed-in tariffs and tax breaks. These policies have helped to make renewable energy more competitive with fossil fuels.
- Regulations to control emissions. The Chinese government has also implemented a few regulations to control emissions, such as emissions trading schemes and fuel efficiency standards. These regulations have helped to reduce emissions from the energy sector.
- Investments in low-carbon infrastructure. The Chinese government has also invested heavily in low-carbon infrastructure, such as wind farms and solar power plants. These investments have helped to increase the share of renewable energy in China's energy mix.

Therefore, the Chinese authorities have increased their efforts to control the level of balance in natural and energy resources, as well as to respond to what has come to be known as the low-carbon market. However, the vital dimension occupied the entire scene, so nature had another talk. On the one hand, climate change has increased agricultural productivity, which has helped lift millions of people out of poverty. On the other hand, climate change has also increased extreme weather events, which have displaced millions of people and made it more difficult for them to escape poverty.

Fuel substitution is an energy policy tool that can promote sustainable growth. To reduce global warming, many countries are considering replacing oil, natural gas or renewable energy with coal, as coal has the most harmful effect on the environment. Thus, the matter is not only related to coal but rather it extends to all forms of fossil fuels that the country employs in its manufacturing activities, including the provision of energy for public consumption. And given the development of the nation's inputs of this substance an extent that exceeds four times the total imports of commodities during a period of nearly 30 years. Hence, it is necessary to consider possibility of a correlation between them and the indicators of greenhouse-gases and their total trend.

To make meaningful political insights in this regard, this paper approves the subsequent question to be reacted in this study:

What is the impact of the accumulation of fossil fuel imports and renewable energy consumption on total greenhouse gas emissions in China during the period (1992-2019)?

The problem of study was split into the following sub-questions:

A/ Is there a one way-causal relationship between fossil fuel imports and renewable energy consumption during the study period?

B/ Is there a relationship in the short and long term between total greenhouse gas emissions and its hypothetical dependent variants for the same period?

In order to better guideline the study path we have selected following as preliminary hypotheses:

- There is a one way-causal relationship between fossil fuel imports and renewable energy consumption during the study period.
- There is a relationship in the short and long term between total greenhouse gas emissions and its hypothetical dependent variants for the same period.

In the shed of the foregoing, this study aims to investigate the impact of fossil fuel inputs as well as renewable energy consumption on greenhouse-gas emissions regarding China's path to carbon neutrality.

Most of the studies dealing with global warming topic concluded that China's carbon neutrality is still uncompromising if unleashed given global manufacturing giant outputs but focuses on another aspect of the country's tight mixture without attention to the main stress of this impact on the control degree in low-carbon economies, which are reflected in global warming. Here, the study goal is to follow up the impact of the most important factors affecting China's carbon neutrality in accordance with a standard quantitative approach.

2. Literature Review

In recent years, the Chinese government has embarked on an ambitious experiment to combat climate change and reduce greenhouse gas emissions. Recognizing the urgent need to address global warming, China has shifted its course and set a remarkable goal: achieving carbon neutrality by 2060. This transition marks a significant departure from its previous focus on rapid economic growth, where fossil fuels played a dominant role.

Several recent studies have examined the econometric significance of fossil fuel in China's pursuit of carbon emission mitigation. These studies have found that fossil fuel consumption is a major driver of carbon emissions in China. They have also found that the country's reliance on fossil fuels is a major obstacle to achieving its climate change goals.

One study found that fossil fuel consumption is a major driver of carbon emissions in China. The study found that a 1% increase in fossil fuel consumption is associated with a 0.7% increase in carbon emissions (Zhang X. L., 2022). The study also found that the country's reliance on fossil fuels is a major obstacle to achieving its climate change goals. The study found that China would need to reduce its reliance on fossil fuels by 60% in order to achieve its carbon neutrality target.

Another study, by (Zhang J. L., 2022), found that the consumption of dirty energy in China is responsible for a significant average of emissions of pollutants, such as sulfur dioxide, nitrogen oxides, and particulate matter. These emissions are having a negative impact on the environment and public health in China. The study found that China needs to shift to renewable energy sources in order to reduce its environmental impact.

The studies cited above suggest that fossil fuel consumption is a major driver of carbon emissions in China and that the country's reliance on fossil fuels is a major obstacle to achieving its climate change goals. These studies also suggest that China needs to shift to renewable energy sources in order to reduce its ecological impact. In this regard, there were couple of attention-grabbing works examining China's response to climate change issues.

It is apparent that China has made significant progress in addressing climate change, but that more needs to be done, especially, regarding the top three key areas: (Yun, 2016)

- **Improving energy efficiency:** China needs to continue to improve the efficiency of its energy use. This can be done through a variety of measures,

such as increasing the use of renewable energy, improving the efficiency of power plants, and promoting energy-efficient appliances and vehicles.

- **Developing low-carbon technologies:** the state must invest in the development of low-carbon technologies, counting those for renewable energies, energy efficiency, as well as carbon capture, use and storage (CCUS).
- **Promoting international cooperation:** It should also continue to cooperate with other countries on climate change, to develop and implement emissions reduction targets, and to share clean energy technologies.

From another perspective, dealing with the Chinese aggregate production and consumption of three main energy commodities: coal, oil and renewable energy, and invoking ARDL and VECM, affirmed that the growth of Chinese economy is subject to the three energy sources, however, unlike Coal there were no significant causation on emissions for oil, wherefore making coal expensive to the other sources would be an encouraging to shift from Coal to oil and renewable energies resulting in time economic and environmental sustainability (Bloch, 2015).

China intends to transform the energy mix of the country away from its historical dependence on coal by promoting alternative sources in order to also combat air pollution issues (China, 2016i). However, the country remains reliant upon fossil fuel sources of electricity production. Further progress on renewable deployment will depend partly upon improvements to the electricity distribution system in order to reduce the curtailment of wind and solar power and the success of on-going reforms to the way in which renewables are financially supported (i.e., transition from FITs to forms of competitive auctioning for renewables).

Since the seminal paper of (Kraft, 1978), literature on the energy consumption and growth nexus has been growing in all sorts of directions. The notion that energy consumption is one of the basic indicators of economic development has attracted economists from all over the world to investigate the relationship between energy consumption and economic growth. Research on this issue has been aimed at providing policy guidelines in designing efficient energy conservation policies and generating a sustainable energy outline.

Actions to address climate change, such as substantially reducing dependence on fossil fuels and increasing the share of clean and renewable

energy, have synergies with environmental protection and public health (He & Teng, 2014).

GHG emissions can be affected by various attributes, and energy components are obviously in scene.

3. Methodological Analysis (Methods and Materials)

3.1. The Shift Towards Carbon Neutrality:

China's commitment to carbon neutrality by 2060 signifies a monumental shift in its climate policy. Previously, the nation was the world's largest emitter of greenhouse gases, primarily due to its heavy reliance on coal (International Energy Agency (IEA), 2021). However, the recognition of the environmental challenges and the need for sustainable development propelled China into action. Over the past two decades, the Chinese government has undertaken a series of concrete actions and implemented comprehensive measures to reduce emissions and transition towards low-carbon economy aiming for carbon neutrality. These efforts reflect a significant shift in their approach to address climate change and reduce greenhouse gas emissions (World Resources Institute (WRI), 2023). Let's explore some of the key initiatives taken by the Chinese government during this period:

1/ Renewable Energy Investment:

China has made substantial investments in renewable energy sources, establishing itself as a global leader in clean energy production. The government has implemented policies to promote the development and deployment of solar, wind, and hydropower technologies. China is now the world's largest producer and installer of renewable energy systems.

2/ Energy Efficiency Standards:

Recognizing the importance of energy efficiency in reducing carbon emissions, the Chinese government has implemented strict energy efficiency standards for buildings, appliances, and industrial processes. These standards aim to curb energy consumption and promote the use of energy-efficient technologies and practices.

3/ Coal-Fired Power Plant Upgrades:

China has embarked on an extensive program to upgrade and retrofit its existing coal-fired power plants. These upgrades include the installation of advanced technologies, such as ultra-supercritical and integrated gasification

combined cycle systems, which improve the efficiency of power generation and reduce emissions.

4/Emission Control Measures:

To address air pollution and reduce carbon emissions, the Chinese government has implemented stringent emission control measures. These include the installation of pollution control equipment in industries, the implementation of stricter vehicle emission standards, and the promotion of cleaner fuels.

5/ Carbon Market:

China has launched a national carbon market, which is the world's largest emissions trading system. It covers key sectors such as power generation, iron and steel, and cement.

By placing a price on carbon emissions, this market incentivizes companies to reduce their emissions and invest in cleaner technologies.

6/ Electric Vehicle Promotion:

The Chinese government has actively promoted the adoption of electric vehicles (EVs) to reduce emissions from the transportation sector. It has introduced favorable policies, including subsidies and incentives for both manufacturers and consumers, to accelerate the production and uptake of EVs.

7/Afforestation and Forest Conservation:

Recognizing the role of forests in carbon sequestration, China has implemented large-scale afforestation programs and initiatives to conserve existing forests. These efforts aim to increase forest coverage and enhance carbon sinks, contributing to carbon neutrality goals.

8/ International Cooperation:

China has actively engaged in international cooperation on climate change, participating in global climate agreements and initiatives. Notably, China played a significant role in the negotiation and ratification of the Paris Agreement, demonstrating its commitment to global efforts in combating climate change.

3.2. Overview of the GHG emissions evolution: reasons and etiology

This section provides an overview of the GHG emissions evolution in Zhongguo's (China) from 1992 to 2022, focusing on understanding the reasons and etiology behind their changes. It aims to examine the factors that influenced the emissions trajectory and uncover the underlying causes.

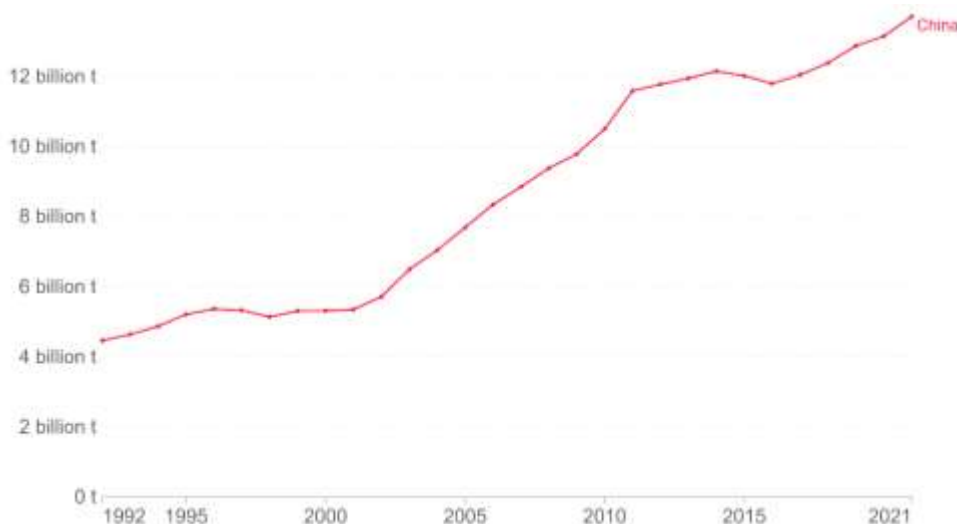
3.2.1. Trends in GHG Emissions:

Carbon dioxide is considered as the most important greenhouse gas, but it is not the only one. To capture all greenhouse gas emissions, researchers express them in 'carbon dioxide-equivalents' (CO₂eq). This takes all greenhouse gases into account, not just CO₂.

To express all greenhouse gases in carbon dioxide-equivalents (CO₂eq), each one is weighted by its global warming potential (GWP) value. GWP measures the amount of warming a gas creates compared to CO₂. CO₂ is given a GWP value of one. If a gas had a GWP of 10 then one kilogram of that gas would generate ten times the warming effect as one kilogram of CO₂.

The worldwide GHG emissions from 1992 to 2021 exhibit an overall increasing trend, with fluctuations in annual levels (as shown in **Figure 1**). Recent years show steady growth, apart from a temporary dip in 2020 likely caused by the COVID-19 pandemic. Emissions reached a new high of 54.59 Bt in 2021. The data emphasizes the need for sustained efforts to mitigate GHG emissions and address climate change. Further analysis is required to understand specific regional and sectoral emission patterns.

Figure 1 | Greenhouse Gas Emissions Worldwide (1992-2021)

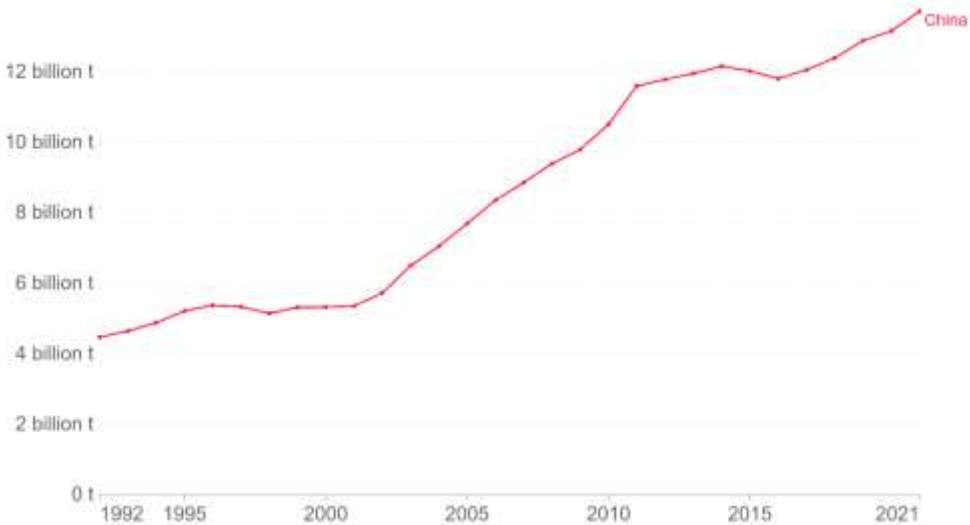


Source: Data source based on (ourworldindata.org) statistics.

Digging for further weighty proofs, the subsequent chart depicts the trends in greenhouse gas (GHG) emissions in China from 1992 to 2021, that have

witnessed fluctuations until 1998, followed by significant growth from 2011 to 2014. Emissions remained relatively stable from 2016 to 2019, with an upward trend observed in recent years (2019-2021). The data underscores the need for continued efforts to mitigate GHG emissions in China.

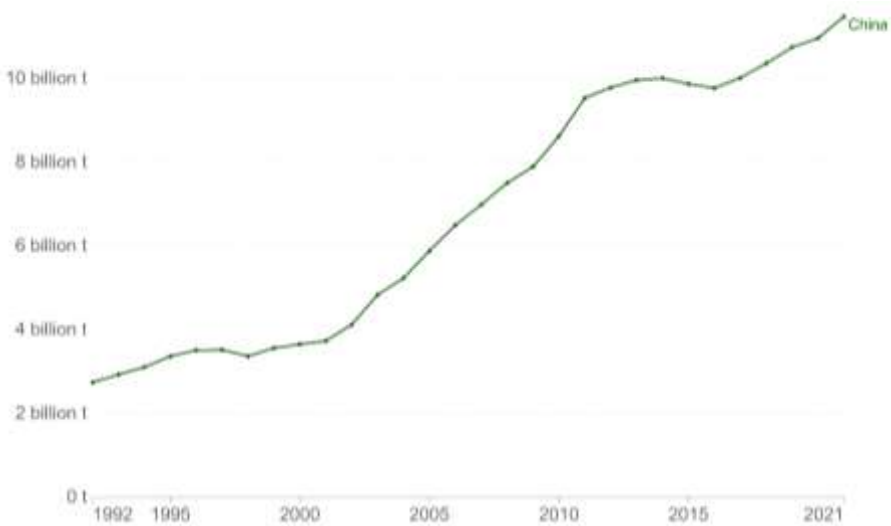
Figure 2 | Greenhouse Gas Emissions, China (1992-2021)



Source: Data source based on (ourworldindata.org) statistics.

Analyzing precisely the annual CO₂ emissions data from 1992 to 2022, we observe fluctuations in emissions levels over time (as revealed in **Figure 3**). This indicates the presence of dynamic factors influencing GHG emissions.

Figure 3 | Annual CO₂ Emissions, China (1992-2021)



Source: Data source based on (ourworldindata.org) statistics.

3.2.2. Factors Influencing GHG Emissions: Various factors contribute to the evolution of greenhouse gas (GHG) emissions. These factors encompass a range of human activities and natural processes, each playing a distinct role in shaping emissions changes.

A/ Energy Consumption: Energy consumption, particularly from fossil fuels such as coal, oil, and natural gas, is a significant contributor to GHG emissions. Combustion of these fuels releases (CO₂), the primary greenhouse gas, into the atmosphere (IPCC., 2014).

B/ Industrial Activities: Industrial processes, including manufacturing, construction, and even mining, contribute to GHG emissions through energy use, emissions from industrial facilities, and the production of GHG-intensive products (IEA, 2020). The manufacturing sector, for instance, emits GHGs through the combustion of fossil fuels in production processes.

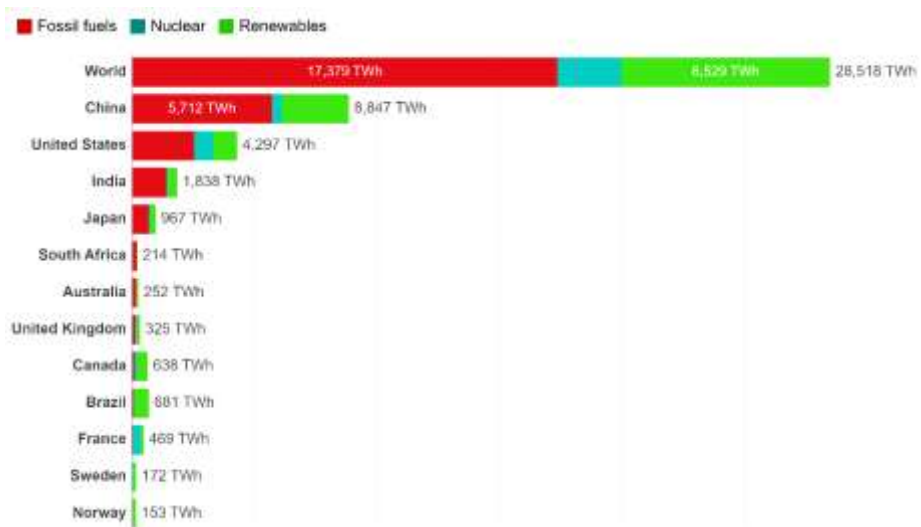
C/ Land-Use Changes: Land-use changes, such as deforestation, urbanization, and agricultural expansion, affect GHG emissions. Deforestation and land degradation lead to the release of stored carbon as CO₂, contributing to emissions (Houghton, 2003). Agricultural activities, including livestock production and rice cultivation, also emit GHGs, primarily methane (CH₄) and nitrous oxide (N₂O) (Smith, 2014).

D/ Transportation: The transportation sector is a significant source of GHG emissions, primarily from burning fossil fuels in vehicles (IPCC., 2019). Road transportation, aviation, and shipping contribute to CO₂ emissions, while other activities like refrigerant leaks from air conditioning systems release potent GHGs such as hydrofluorocarbons (HFCs).

E/ Agricultural Practices: Agricultural practices, including enteric fermentation from livestock, rice cultivation, and the use of synthetic fertilizers, result in significant emissions of methane and nitrous oxide. Livestock production is a major source of methane emissions.

3.2.3. Effect of Fossil Fuel: Fossil fuel combustion plays a significant role in GHG emissions, especially in the case of China as one of the Top three worldwide emitters, in addition to its central reliance on that energy source for electricity generation by an average reaching 64.67% in 2022 on a total of 8847 TWh (Hourly-Terawatts).

Figure 4 | Electricity consumption from fossil fuel, nuclear and renewables (2022)



Source: Data source based on (ourworldindata.org) statistics.

Figure 5 | Global CO₂ Emissions from fossil fuel and land use change, China (1992-2021)



Source: Data source based on (ourworldindata.org) statistics and the Global Carbon Project.

Once exploring the relationship between fossil fuel consumption and GHG emissions, we find a positive correlation, highlighting the influence of fossil fuel usage on emission levels.

Econometric Analysis: Employing an econometric analysis, such as autoregressive distributed lag (ARDL) models, allows for quantifying the relationship between GHG emissions, fossil fuel consumption, and other relevant variables. This analysis considers lagged effects, endogeneity concerns, and the potential impact of policy interventions, technological advancements, and energy efficiency improvements.

By providing an overview of the GHG emissions evolution, examining the factors influencing emissions changes, and utilizing econometric analysis, this section sets the foundation for a comprehensive understanding of China's transition to carbon neutrality.

4. Empirical Findings (Results and discussion)

In this section, we present and discuss the results of the economic standard approach for the extent impact of Fossil Fuel Imports as well as renewable energy consumption on total greenhouse gas emissions regarding China's Transition to Carbon Neutrality (1992-2022).

4.1. Determine study variables.

Determining the model variables is the first step in defining the study model and based on the economic theory and information available from previous studies on the subject (as shown in **Table 1**), we identified the dependent variable (expressed as the total greenhouse gas emissions measured by Kilotons of CO₂ equivalent and symbolized by **TGX_CN**), and the explanatory variables: (Fossil Fuel Imports expressed by proportions on global imports of goods and denoted by **FFI_CN**, and Renewable Energy Consumption represented by rates on global energy consumption and symbolized by **REC_CN**).

Table 1 | Data of the economic variables used in the standard study.

Year	TGX_CN	FFI_CN	REC_CN
1992	3516609	4.43041974985852	32.9312779040239
1993	3746364	5.597016520492029	31.6777918019623
1994	3905933	3.489465449168847	31.2494841669185
1995	4309242	3.881477403691041	29.4721113943924
1996	4330228	4.953812928105127	30.5371754582264
1997	4325695	7.238651513678141	30.1834816771978
1998	4443771	4.831367320947458	29.7399014806871
1999	4376499	5.378242835732896	30.506048980242
2000	4568808	9.467015325377608	29.63
2001	4761564	7.436192981821435	28.36
2002	5068783	6.880289255281002	27
2003	5718044	7.527571407923139	23.86
2004	6503953	9.182189948317116	20.17
2005	7266526	10.57223846087455	17.44
2006	7946143	12.39268331594586	16.39
2007	8555800	12.07745746778062	14.88
2008	8810967	16.27112919774772	14.14
2009	9386580	13.48473855415301	13.43
2010	10218510	14.65703679519922	12.26
2011	11098190	17.01185965091004	11.34
2012	11385460	18.68462996002961	11.53
2013	11878030	17.58243201239035	11.45
2014	11938030	17.45819200065844	11.94
2015	11818470	12.92719127586707	12.18
2016	11800830	12.09173391506548	12.56
2017	12035270	14.58510370461122	13.13
2018	12471090	17.46881691878176	13.71
2019	12705090	17.85628230082966	14.45

Source: prepared by researcher based on (ourworldindata.org) statistics.

The main reason that prompted us to consider the year 2019 as the last limit for the study period is the absence of official statistics on both greenhouse gas emissions and levels of renewable energy consumption after this year, in addition to the lack of data on China's imports of fossil fuels before 1992.

4.2. Building model

After identifying the variables contained in the model, and after collecting data on the variables, **ARDL will be used.**

4.2.1. Unit root tests

The developed Dickie-Fuller Test Will take place upon as of the most significant time series stability tests. The results table must include either **I (0)** or **I (1)** or a mixture of them.

Table 2 | Report of Augmented Dickie-Fuller's ADF test for the considered variables

UNIT ROOT TEST RESULTS TABLE (ADF)				
Null Hypothesis: the variable has a unit root				
	<u>At Level</u>			
With Constant	t-Statistic	TGX -0.4579	FFI -1.0173	REC -2.2760
	Prob.	0.8844 n0	0.7323 n0	0.1874 n0
With Constant & Trend	t-Statistic	-2.4136	-2.7089	-1.0238
	Prob.	0.3645 n0	0.2410 n0	0.9229 n0
Without Constant & Trend	t-Statistic	1.1141	0.6904	-2.2148
	Prob.	0.9266 n0	0.8587 n0	0.0286 **
	<u>At First Difference</u>			
With Constant		d(TGX)	d(FFI)	d(REC)
	t-Statistic	-2.2393	-5.5591	-1.9508
With Constant & Trend	Prob.	0.1981 n0	0.0001 ***	0.3049 n0
Without Constant & Trend	t-Statistic	-2.1686	-5.4496	-2.6110
	Prob.	0.4861 n0	0.0008 ***	0.2790 n0
Without Constant & Trend	t-Statistic	-1.3991	-5.3680	-2.0645
	Prob.	0.1467 n0	6.3222 ***	0.0395 **

Notes:

a: (*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1% and (no) Not Significant

b: Lag Length based on AIC.

c: Probability based on MacKinnon (1996) one-sided p-values.

Source: prepared by researcher through EViews outputs.

The above table specifies that time series of the considered variables are stable at the level. Wherefore, we rely on the ARDL estimation model since the data in use reveal in a small size.

4.2.2. Bound Test Approach to Co-integration ARDL

To determine the optimal time delay periods for the variables used in the study according to the ARDL Model, “Akaike Information Criterion” was used to determine the rank of the model, which is the most common criterion, it is based on the lowest statistical value in determining the appropriate model of the study (1.0.1), and this value is (1.0.1 = 27.089950), as shown in the following.

Table 03 | Model Selection Criteria

Model Selection Criteria

Dependent Variable: TGX

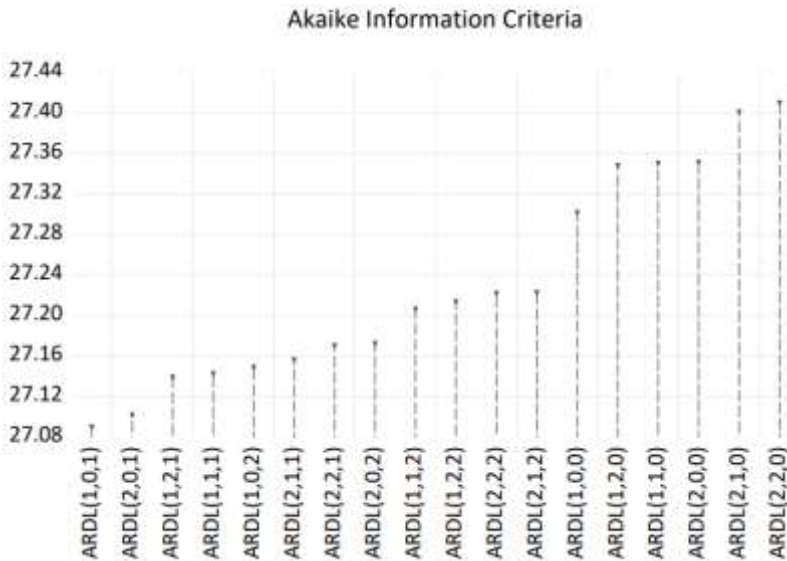
Sample: 1992 2019

Included observations: 24

Model	LogL	AIC*	BIC	HQ	Specification
4	-317.7636	27.0636	27.4072	27.1548	ARDL (4,0,0)
3	-316.9568	27.0797	27.4724	27.1839	ARDL (4,0,1)
2	-317.3345	27.1112	27.5039	27.2154	ARDL (4,1,0)
7	-318.6814	27.1401	27.4837	27.2313	ARDL (3,0,1)
1	-316.7557	27.1463	27.5881	27.2635	ARDL (4,1,1)
15	-320.8054	27.1504	27.3959	27.2156	ARDL (1,0,1)
11	-320.2447	27.1871	27.4816	27.2652	ARDL (2,0,1)
13	-320.4912	27.2076	27.5021	27.2857	ARDL (1,1,1)
5	-318.6799	27.2233	27.6160	27.3275	ARDL (3,1,1)
9	-319.9734	27.2478	27.5914	27.3389	ARDL (2,1,1)
8	-321.0516	27.2543	27.5488	27.3324	ARDL (3,0,0)
6	-321.0347	27.3362	27.6798	27.4274	ARDL (3,1,0)
16	-324.0522	27.3377	27.5340	27.3898	ARDL (1,0,0)
14	-323.7673	27.3973	27.6427	27.4624	ARDL (1,1,0)
12	-323.8354	27.4030	27.6484	27.4681	ARDL (2,0,0)
10	-323.5775	27.4648	27.7593	27.5429	ARDL (2,1,0)

Source: prepared by researcher through EViews outputs.

Figure 06 | Optimum deceleration times test



Source: prepared by researcher through EViews outputs.

4.2.3. Granger causality test

This test is relied upon in order to determine the direction of the causal relationship (Unilateral or mutual) between the study's variables. Sometimes there may not be a causal relationship between them, but the process of determining the direction of that relationship remains significant in order to clarify the association that exists between economic variables.

Table 4 | Report of Causality test for the considered variables

Pairwise Granger Causality Tests

Sample: 1992 2019

Lags: 1

Null Hypothesis:	Obs	F-Statistic	Prob.
FFI does not Granger Cause TGX	27	1.69388	0.2054
TGX does not Granger Cause FFI		5.75498	0.0246
REC does not Granger Cause TGX	27	19.371	0.0002
TGX does not Granger Cause REC		13.5174	0.0012
REC does not Granger Cause FFI	27	11.0248	0.0029
FFI does not Granger Cause REC		0.72261	0.4037

Source: prepared by researcher through EViews outputs.

Granger causality test by Fisher's F-statistic showed that:

- 1/ There is no causal relationship between fossil fuel import rates (FFI) and the renewable energy consumption averages (REC) at the 5% significance level.
- 2/ There is a one-way causal relationship between fossil fuel import rates (FFI) and the renewable energy consumption averages (REC) at the 5% significance level. A change in FFI causes a change in REC, but REC does not cause a change in FFI.

4.2.4. Co-integration Test

To ensure that there is a long-term equilibrium relationship between the variables included in the model, the co-integration test is used according to the ARDL methodology through the two hypotheses:

Null hypothesis: there is no long-term equilibrium relationship between the variables of the study: $H_0: \partial_0 = \partial_1 = \partial_2 = \partial_3 = 0$

Alternative hypothesis: there is a long-term equilibrium relationship between the variables of the study: $H_1: \partial_0 \neq \partial_1 \neq \partial_2 \neq \partial_3 \neq 0$

To find out if there is a long-term equilibrium relationship between the variables of the study, we compare the calculated Fisher F-statistic value with the tabular values developed by Narayan (2005).

Table 5 | Report of Co-integration test using the Bound Test Approach for the considered variables.

Null hypothesis: No levels relationship

Number of cointegrating variables: 2

Trend type: Rest. constant (Case 2)

Sample size: 24

Test Statistic	Value
F-statistic	8.778685

	10%		5%		1%	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
Sample Size						
30	2.915	3.695	3.538	4.428	5.155	6.265
Asymptotic	2.63	3.35	3.1	3.87	4.13	5

* I (0) and I (1) are respectively the stationary and non-stationary bounds.

Source: prepared by researcher through EViews outputs.

The results of the above table for the limits test showed that the calculated value for the Fisher test ($F = 8,778685$), which is greater than the upper (critical) tabular values at significant levels (1%, 5%, 10%), and accordingly the null hypothesis is rejected. The alternative hypothesis that there is a long-term equilibrium relationship between the explanatory variables and the dependent variable is accepted, and therefore we can test it according to the error correction model.

4.2.5. Estimating the model function using ARDL

In this section, we discuss the estimation of cointegration regression according to the ARDL model and the conduct of standard tests to ensure the integrity of the model.

The results of cointegration regression show that the calculated value of Fisher's statistic is statistically significant ($P = 0.000000$), in addition to that, the coefficient value is (0.998092), which means that the independent variables explain 99.80% of the change in Greenhouse-Gas Emissions, as shown in the following table:

Table 6 | Report of Co-integration test using the Bound Test Approach for the considered variables.

Dependent Variable: TGX

Method: ARDL

Sample: 1996 2019

Included observations: 24

Dependent lags: 4 (Automatic)

Automatic-lag linear regressors (4 max. lags): FFI REC

Deterministics: Restricted constant and no trend (Case 2)

Model selection method: Akaike info criterion (AIC)

Number of models evaluated: 100

Selected model: ARDL (4,0,0)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
TGX (-1)	0.910365	0.214411	4.245891	0.0005
TGX (-2)	-0.339884	0.292303	-1.162777	0.261
TGX (-3)	-0.16526	0.295889	-0.55852	0.5838
TGX (-4)	0.370914	0.160232	2.31486	0.0334
FFI	30131.77	22248.04	1.354356	0.1934
REC	-92915.48	17480.84	-5.315275	0.0001
C	3703758	675201.9	5.485409	0
R-squared	0.998092	Mean dependent var	8475514	
Adjusted R-squared	0.997418	S.D. dependent var	3182928	
S.E. of regression	161721.6	Akaike info criterion	27.06363	
Sum squared resid	4.45E+11	Schwarz criterion	27.40723	
Log likelihood	-317.7636	Hannan-Quinn criter.	27.15479	
F-statistic	1482.057	Durbin-Watson stat	2.355484	
Prob(F-statistic)	0			

*Note: p-values and any subsequent test results do not account for model selection.

Source: prepared by researcher through EViews outputs.

5. Robustness

There are many diagnostic tests that we must perform in order to make sure of the quality of performance of the chosen model estimated in order to be free of standard problems, the following tests were carried out:

5.1. Errors Autocorrelation Test (Correlogram Q-Statistic):

To ensure that there is no autocorrelation, we resort to autocorrelation tests, the results are shown in the following table:

Table 7 | Report of Errors Autocorrelation Test (Correlogram of Residuals)

Sample (adjusted): 1996 2019

Q-statistic probabilities adjusted for 4 dynamic regressors

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob*	
		1	-0.193	-0.193	1.0064	0.316
		2	-0.237	-0.285	2.6027	0.272
		3	-0.004	-0.133	2.6033	0.457
		4	-0.012	-0.131	2.6076	0.625
		5	-0.388	-0.538	7.5619	0.182
		6	0.124	-0.332	8.0966	0.231
		7	0.259	-0.211	10.562	0.159
		8	0.079	-0.108	10.808	0.213
		9	0.084	0.147	11.104	0.269
		10	-0.111	-0.127	11.655	0.309
		11	-0.125	-0.087	12.410	0.334
		12	-0.082	-0.030	12.757	0.387

*Probabilities may not be valid for this equation specification.

Source: prepared by researcher through EViews outputs.

The results of the above table showed that all columns within the confidence interval and the Q-Stat test statistic are not significant. According to the LM Test (as shown in Table 8), the (Prob Chi-Square) is lower than (0.05), and therefore we reject the null hypothesis that there is no autocorrelation and accept the alternative hypothesis.

Table 8 | Report of Errors Autocorrelation Test (Correlogram of Residuals)

Breusch-Godfrey Serial Correlation LM Test

Null hypothesis: No serial correlation at up to 2 lags

F-statistic	2.563874	Prob. F (2,15)	0.1102
Obs*R-squared	6.114244	Prob. Chi-Square (2)	0.0470

Source: prepared by researcher through EViews outputs.

5.2. Contrast Instability Test (Heteroskedasticity Test):

To detect variance instability, we use the “Breusch-Pagan- Godfrey” method to run the test, the results are shown in the following table:

Table 9 | Report of Heteroskedasticity Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey

Null hypothesis: Homoskedasticity

F-statistic	1.595827	Prob. F (6,17)	0.2087
Obs*R-squared	8.647202	Prob. Chi-Square (6)	0.1944
Scaled explained SS	6.716470	Prob. Chi-Square (6)	0.3479

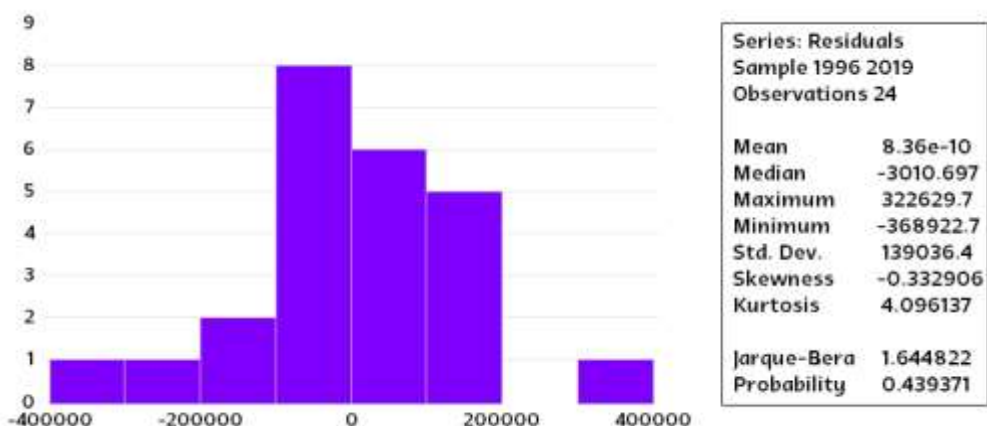
Source: prepared by researcher through EViews outputs.

The results of the overhead Table which examines the stability of error variances, showed that the probability value of Fisher (F-statistic) is greater than the significance level of 5%, which confirms that the estimated model is free from the problem of instability of error variance.

5.3. The Normal Distribution of Residuals:

We use (Jarque-Bera) to verify the condition of the normal distribution, so the test result was not significant ($\alpha > 0.05$), which confirms that the residuals are subject to a normal distribution, and through the value of (JB = 0.027256) and its significant value (0.986465), that is greater than (0.05), which confirms that the model residuals are subject to a normal distribution, as shown in the following figure:

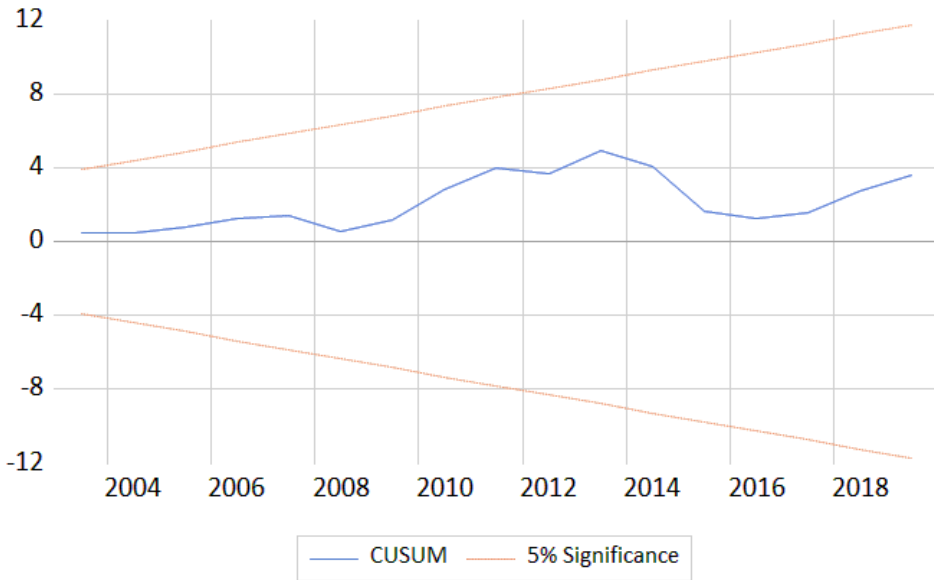
Figure 7 | Normality Test Histogram



Source: prepared by researcher through EViews outputs.

5.4. Structural Stability Test:

To verify the structural stability of the estimated parameters of the short-term and long-term relationship according to the ARDL model, a test was used for the cumulative sum of the recurrence of the remainder (CUSUM). If the graphs fall within the limits of confidence at a moral level of 5%, the null hypothesis will be accepted, which means that all estimated parameters are stable and stationary, the following figure represents the test results:

Figure 8 | Cumulative Total Frequency of the Remainder

Source: prepared by researcher through EViews outputs.

We notice through the graphic representation of each of the results of the cumulative sum of the recurrence of the remainders (CUSUM), that two forms form two median lines within the limits of the confidence interval at a significant level of 5%, from which the null hypothesis is accepted, asserting the stability of the short and long-term parameters, and rejecting the alternative hypothesis, that claims, the presence of structural stability in the form during the study period.

6. Estimating ECM model (including short-and long-run relationship)

After confirming the existence of a long-run relationship by testing limits, the error correction coefficient in the short-run ARDL model should be negative and significant for the ECM.

6.1. Short-term relationship and Error Correction Coefficient:

It is clear from the below table that there is a short-term dynamic relationship between the variables. Since the error is negative and significantly with a value of (COINTEQ* = -0.223865). as a probability of (0.0000), which is less than 0.05, and it measures the percentage of imbalance in the dependent variable that can be corrected over a period.

Table 10 | Estimating the error correction model and the short-term relationship.

Dependent Variable: D(TGX)

Method: ARDL

Sample: 1996 2019

Included observations: 24

Dependent lags: 4 (Automatic)

Automatic-lag linear regressors (4 max. lags): FFI REC

Deterministics: Restricted constant and no trend (Case 2)

Model selection method: Akaike info criterion (AIC)

Number of models evaluated: 100

Selected model: ARDL (4,0,0)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ*	-0.2238646112499283	0.03482973507697385	-6.42739919655394	2.867448511412069e-06
D (TGX (-1))	0.1342295583243573	0.1626865452054228	0.8250808827175409	0.4190584616126074
D (TGX (-2))	-0.2056541284179869	0.1684438789378998	-1.220905916645421	0.236320342819808
D (TGX (-3))	-0.3709139099111675	0.1404451064085234	-2.640988492915246	0.01567046074231457
R-squared	0.798818522835407	Mean dependent var		349827
Adjusted R-squared	0.768641301260718	S.D. dependent var		309980.624342176
S.E. of regression	149099.9387825908	Akaike info criterion		26.81363302329513
Sum squared resid	444615834899.4466	Schwarz criterion		27.00997532835313
Log likelihood	-317.7635962795416	Hannan-Quinn criter.		26.86572269209732
F-statistic	26.47091021478973	Durbin-Watson stat		2.355483691374622
Prob(F-statistic)	3.632580044961598e-07			

* p-values are incompatible with t-Bounds distribution.

Source: prepared by researcher through EViews outputs.

6.2. Long-term relationship:

The long-term relationship can be expressed via the following formula, as shown in Table 11:

Table 11 | Estimating the long-term relationship.

Variable *	Coefficient	Std. Error	t-Statistic	Prob.
FFI	134598.2	85144.19	1.580826	0.1289
REC	-415052.1	56136.38	-7.393638	0.0000
C	16544635.8	2159185.97	7.662441	0.0000

Deterministics: Rest. constant (Case 2)

$$CE = TGX (-1) - (134598.169176*FFI - 415052.091922*REC + 16544635.774664)$$

Note: * Coefficients derived from the CEC regression.

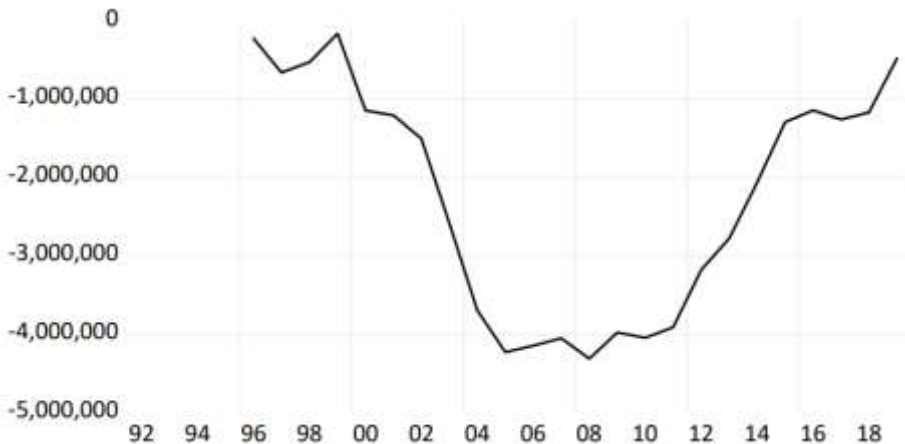
Source: prepared by researcher through EViews outputs.

From the above table, we conclude the following equation:

$$CE = TGX (-1) - (134598.169176*FFI - 415052.091922*REC + 16544635.774664)$$

Which can be represented by the following Graph:

Figure 9 | Graph for ARDL Cointegrating Series



Source: prepared by researcher through EViews outputs.

The upper table indicates that the variables FFI and REC do not have a significant impact on the long-term evolution of TGX, as their coefficients are not statistically significant at the 5% level. This implies that an increase in the rates of FFI and REC in the long run does not affect the evolution of TGX (see **Appendix 1.**). This finding is unexpected and goes against economic theories. Moreover, it aligns with the current reality of the Chinese energy economy, where the contribution of the energy sector towards achieving Carbon Neutrality is relatively small, highlighting its limited influence. This lack of influence from FFI and REC could potentially hinder the growth of the Chinese economy, impeding the process of economic take-off on the parallel pursuit for GHG mitigation regarding carbon neutrality.

7. Conclusion

In conclusion, China has made significant progress in addressing climate change, but more needs to be done. The country needs to continue to improve energy efficiency, develop low-carbon technologies, and promote international cooperation.

Fossil fuel consumption is a major driver of carbon emissions in China, and the country's reliance on fossil fuels is a major obstacle to achieving its climate change goals. China needs to shift to renewable energy sources in order to reduce its environmental impact.

The studies cited in the text suggest that China has made significant progress in addressing climate change, but that more needs to be done. The country needs to continue to improve energy efficiency, develop low-carbon technologies, and promote international cooperation.

The present study has conducted a metric framework better describing both of fossil fuel import averages and renewable energy consumption rates as a footprint on total GHG emissions and served a clean sight to energy producers and clients as well as decision makers in China in the run to optimize the ecosystem and adjust the power mix transition strategies, without harming the Carbon mitigation roadmap in the pursuit of Neutrality.

Thus, it has become indispensable for the state to focus on the following three key areas:

Improving energy efficiency: China needs to continue to improve the efficiency of its energy use. This can be done through a variety of measures, such as increasing the use of renewable energy, improving the efficiency of power plants, and promoting energy-efficient appliances and vehicles.

Developing low-carbon technologies: China needs to invest in the development of low-carbon technologies. This includes technologies for renewable energy, energy efficiency, and carbon capture and storage.

Promoting international cooperation: China needs to continue to cooperate with other countries on climate change, to develop and implement emissions reduction targets, and to share clean energy technologies.

If China can make further progress in these areas, it will be well on its way to achieving its goal of carbon neutrality by 2060.

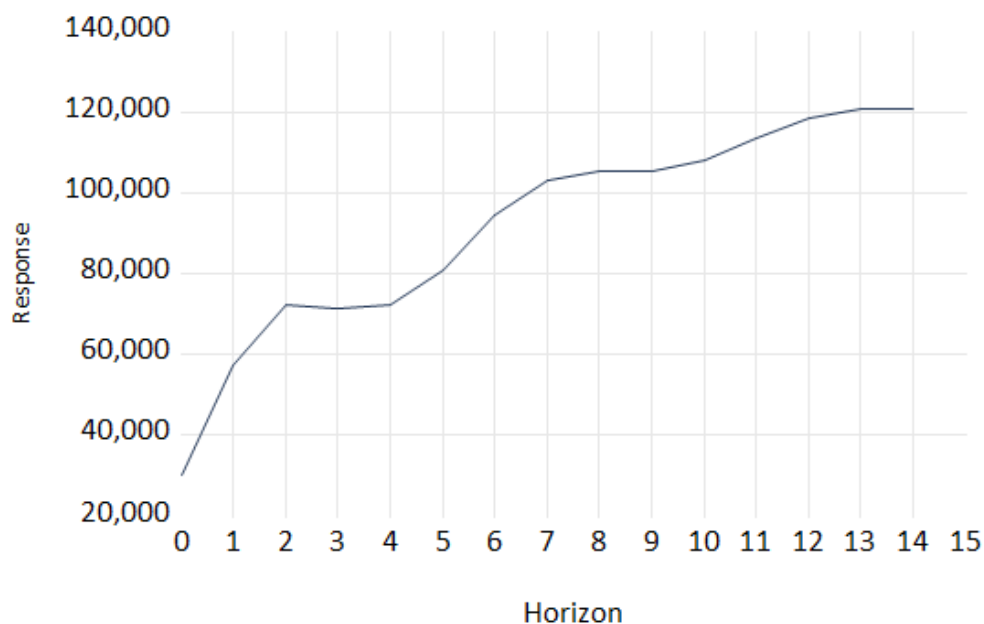
In addition to the above, China also needs to consider the following factors in its efforts to achieve carbon neutrality:

- The impact of climate change on its economy and society.
- The availability of renewable energy resources.
- The cost of low-carbon technologies.
- The willingness of its citizens to make changes to their lifestyles.

China's journey to carbon neutrality will be a challenging one, but it is one that the country is committed to undertaking. By taking the necessary steps, China can play a leading role in the global fight against climate change.

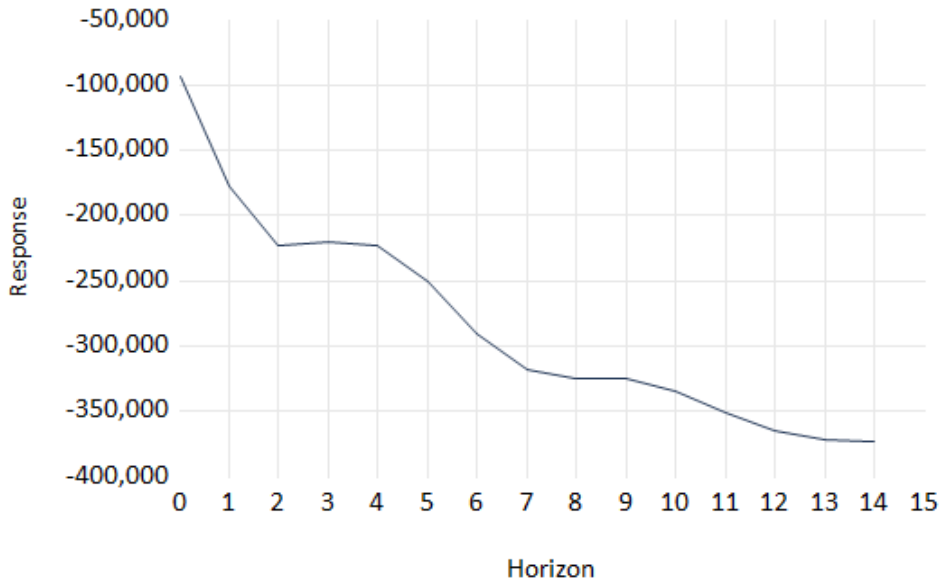
Appendix 1.

Figure 10 | Graph for Cumulative dynamic Multiplier: FFI on TGX Shock Evolution



Source: prepared by researcher through EViews outputs.

Figure 11 | Graph for Cumulative dynamic Multiplier: REC on TGX Shock Evolution



Source: prepared by researcher through EViews outputs.

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