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The impact of renewable energy and energy transitions index on climate change

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Abstract

Considering that fossil fuels are the initial source of carbon emission in today's industrialized world, a successful transition to clean energy is essential in order to mitigate the effects of climate change. In this context, the World Economic Forum created the Energy Transition Index (ETI) intending to perform an all-encompassing analysis of the ongoing energy transition across the globe. In this study, the impact of variables such as economic growth, urbanization growth rate, industry structure, as well as the ETI, and the amount of renewable energy consumption on climate change in Iran has been investigated using the SVAR model for 2000-2020. The necessary data were obtained from the World Bank, the Central Bank of the Islamic Republic of Iran, the Iranian Statistical Center, and the Ministry of Energy. The study's findings revealed that economic growth, urbanization, and industrial structure had a positive ETI, and renewable energy negatively affected climate change in Iran. The results of this study showed that the ETI had a more substantial effect on reducing greenhouse gas (GHG) emissions than renewable energy. Considering the greater significance of the Energy Transition Index (ETI) in addressing climate change compared to renewable energy usage alone, and given the multidimensional nature of this index, it becomes evident that energy policies do not operate in isolation. Rather, they interact dynamically with macroeconomic conditions, institutional frameworks, social factors, and geopolitical considerations.

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Introduction

One of the most important goals of any economic system is to reach and keep a high and stable rate of growth (Esmaeili & Rafei, 2021). The rise in the frequency and severity of natural disasters that have been attributed to climate change has resulted in a lack of certainty due to the instability of the climate and prompted concerns regarding the possibility of sustainable economic growth and economic vulnerability (Esfahani, 2022; Yang & Khan, 2022). The ongoing rise in the average temperature of the planet causes unpredictability in the natural world and in the structures of the natural environment, both of which have a deleterious effect on human life (Clayton & Karazsia, 2020; Esfahani & Rafati, 2022; Zhenmin & Espinosa, 2019). This phenomenon is a byproduct of human interventions, and it has become a major problem due to the negative effects it has had, not only on human health but also on sustainable economic growth and development (Creutzig et al., 2022; Devi & Gupta, 2019; Lehmann et al., 2021).

The International Energy Agency (2024) estimates that emissions from energy is the vast majority (75%) of all emissions (IEA, 2020). The primary cause of carbon emissions in today's industrialized world is burning of fossil fuels, which also account for 73.2% of global greenhouse gas (GHG) emissions (Ding et al., 2022). From 2000 to 2015, the average annual growth rate of the world's GHG emissions from industrial production and fossil fuel increased from 1.3% to 2.3% (Espinosa Valderrama et al., 2019). Renewable energy has emerged as an alternative energy source as a result of growing worries about the environmental effects of GHG emissions from fossil fuels. Literature shows significant relationship between clear energy and mitigation of ecological footprint (Khan et al., 2022; Murshed et al., 2023; Wang et al., 2023). By encouraging the use of renewable energies, it is possible to provide affordable and clean energy sources, which can reduce GHG emissions, create job opportunities, and generally improve quality of life to some extent (Azam et al., 2021). As such, efforts to lower CO_2 emissions and control climate change must unquestionably include a reorganization of the energy sector (Baiardi, 2020; Santillán Vera et al., 2023). Reorganization of the energy sector is more complex than the use of renewable energies and consists of technological, social, and cultural contexts (Ahlborg, 2024; Nyberg, 2018). The global energy system is in the process of undergoing a fundamental transformation at this time, which is being driven by factors such as technological advancements, policies to mitigate the effects of climate change, and developments in geopolitics. By making a successful transition to cleaner forms of energy, several advanced economies, including the United States, Germany, the United Kingdom, and Japan, have successfully cut the carbon emissions caused by their energy production. On the other hand, developing countries see the opposite trend, which makes sense given that economic growth is the primary factor driving both the demand for energy and the resulting carbon emissions (Nam & Jin, 2021). Within this framework, the World Economic Forum established the Energy Transition Index (ETI), intending to perform an all-encompassing analysis of the ongoing energy transition across the globe. This indicator is based on an analytical framework that measures transition as a shift towards an energy system that supports sustainability, security, and access, as well as a shift towards the institutions that enable this performance (Singh et al., 2019). This framework is at the heart of this indicator. The World Economic Forum releases an ETI on an annual basis. This index is comprised of two sub-indices: system performance and transition readiness. The index falls between 0 and 100, and a higher number indicates a better situation. Additionally, the term "energy transition" is used to refer to the process of shifting away from the current energy consumption and production systems, which are primarily based on non-renewable energy sources like oil, natural gas, and coal, and toward energy combinations that are more efficient and produce less carbon (Bocca et al., 2021).

Considering the greater significance of the Energy Transition Index (ETI) in addressing climate change compared to renewable energy usage alone, and given the multidimensional nature of this index, it becomes evident that energy policies do not operate in isolation. Rather, they interact dynamically with macroeconomic conditions, institutional frameworks, social factors, and geopolitical considerations.

It is imperative for countries to focus on improving the Energy Transition Index (ETI) to achieve sustainable development goals, particularly energy affordability (SDG7) and climate action (SDG13) (Hu et al., 2022). While often presented as the primary solution to climate change, the energy transition involves complexities far beyond simply replacing fossil fuels with renewable energy (Schwab & Combariza Diaz, 2023). Although many nations are promoting renewable energy to mitigate climate impacts, the effectiveness of national energy policies within climate risk frameworks remains insufficiently understood (Shang et al., 2024). This underscores the need to examine the ETI's role alongside other climate change factors in the literature.

Existing research has extensively explored climate change drivers, including renewable energy (Lin & Zhu, 2019; Wang et al., 2023), nuclear energy (Muellner et al., 2021; Pan et al., 2023; Singh et al., 2023; Wang et al., 2024), urbanization, and GDP growth (Chien et al., 2022; Kahn et al., 2021; Li et al., 2022). However, climate change responses vary significantly across nations, as contributing factors exert differing influences depending on national contexts (Lee et al., 2022). Consequently, studies across different countries have yielded divergent findings and policy recommendations (Chien et al., 2022; Singh et al., 2023).

This variability necessitates careful prioritization of factors for optimal resource allocation, particularly in developing countries. These nations often face resource and technological constraints, forcing difficult trade-offs between economic growth and climate mitigation amid political and social pressures.

Iran's climate trajectory illustrates these challenges starkly. Projections indicate a 2.6°C temperature rise and 35% precipitation decline in coming decades. As the Middle East's top GHG emitter (616,741 million tons CO2) and seventh-largest global contributor, Iran's significant emissions stem from extensive oil/gas production and rapid urbanization (Mansouri Daneshvar et al., 2019). Climate models predict intensifying heat waves across Iran and West Asia (Zhang et al., 2005), making comprehensive GHG reduction strategies urgently necessary (Ghouchani et al., 2021).

Understanding the key drivers of climate change is crucial for Iran, given its high emission levels, to effectively prioritize and develop emission reduction strategies. Extensive research has established clear links between human activities and climate change, identifying several critical factors contributing to greenhouse gas (GHG) emissions. These include economic growth, rapid urbanization, and heavy dependence on fossil fuels (Alshubiri & Elheddad, 2020; Finn & Cobbinah, 2022; Maheshwari et al., 2020; Mohammed et al., 2019; Zheng et al., 2019).

Several studies have examined factors influencing climate change mitigation in Iran (Esfandiari et al., 2020; Omrani et al., 2019; Shahsavari et al., 2019). However, these investigations have primarily analyzed macroeconomic factors in isolation. Due to variations in research methodologies, timeframes, and data sources, it remains challenging to accurately assess the relative importance of each factor in relation to others. This limitation hinders the development of comprehensive climate change mitigation policies. Notably, while fossil fuels significantly contribute to environmental degradation and the Energy Transition Index (ETI) plays a vital role in addressing climate change, Iran has yet to examine the combined effects of this index with other economic factors.

A significant research gap exists regarding simultaneous examination of macroeconomic variables and the ETI's impact on climate change. This study addresses this gap by investigating the effects of urbanization, economic growth, industrial structure, renewable energy consumption, and the ETI on climate change in Iran. Through this comprehensive approach, we can better understand the relative significance of each factor in Iran's climate change dynamics.

Iran energy facts

In this section the energy facts of Iran are summarized as below:

Energy resources and consumption

- Production of 2623.7 Mboe of primary energy in the country. Of this, 58.0% was allocated to the natural gas, 40.2 to crude oil, gas liquids and condensates and additives, 0.7% to the hydro, wind, solar, 0.5% to nuclear energy, 0.3% to combustible renewables and 0.3 % to the coal.
- Final consumption totaled 1578.9 Mboe with the rise of about 9.2% considering its previous year.
- Energy consumption increased in residential, transport, industry, commercial and public and non-energy use sectors by 8.1, 0.8, 6.2, 5.9 and 40.9 respectively. Also, we see a decreased in energy consumption of agriculture and other sectors with the amount of 0.1 and 20.4% regarding its previous year.
- Supplying 56.4% of energy consumed in end use sectors by natural gas, 32.5% by petroleum products, 10.2% by electricity, 0.5% by renewables and 0.3% by coal(Shafiezadeh et al., 2022).

Energy economy indicators

- Per capita final energy consumption of Iran was 1.7 times higher than the global average and 0.8 times higher than the OECD countries.
- Per capita consumption of natural gas, crude oil and petroleum products were 6.1 and 1.5 times higher than the global average.
- Per capita consumptions of electricity, coal and renewable energy were lower than the global average.
- Per capita final energy consumption in different sectors including agriculture, household, public and commercial, transport and industry were 3.3, 2.1, 1.5 and 1.6 times over the global average.
- Energy efficiency decreased by 10.9% compared to previous year.
- Energy intensity based on primary energy supply and final energy consumption was 0.34 and 0.22 million barrels of oil equivalent respectively, with the decrease of 15.3% and 12.2% considering its previous year.
- Energy intensity (using exchange rate and power purchase parity) was 3.5, 1.5 times higher than the global average respectively (Shafiezadeh et al., 2022).

Renewable energies:

- The capacity of renewable power plants including hydro, wind, solar, biogas and heat recovery reached 12871.4 MW.
- Operation of 249.4 MW of new renewable projects (161.7 MW of hydropower, 17.5 MW of wind and 70.2 MW of solar electricity).
- Continuous operation of 58 hydro power plants with the total capacity of 12188.2 MW and electricity generation of 31087.5 GWh.
- Installing 277 wind turbines with the total capacity of 302.3 MW since 1994 and electricity generation of 615.6 GWh.
- Increasing capacity of the wind power plants by 17.5 MW.
- Installing PV system with the capacity of 369.3 MW since 1994 and generation of 672.8 GWh.
- Operation of three biogas power plants in Shiraz, Mashhad and Tehran sewage sludge and two landfills in Tehran and Tehran II sites with the nominal capacity of 11.6 MW and electricity generation of 18.6 GWh (Shafiezadeh et al., 2022).

The potentials and reserves of some new energy resources in Iran are represented in Figures 1 to 4:

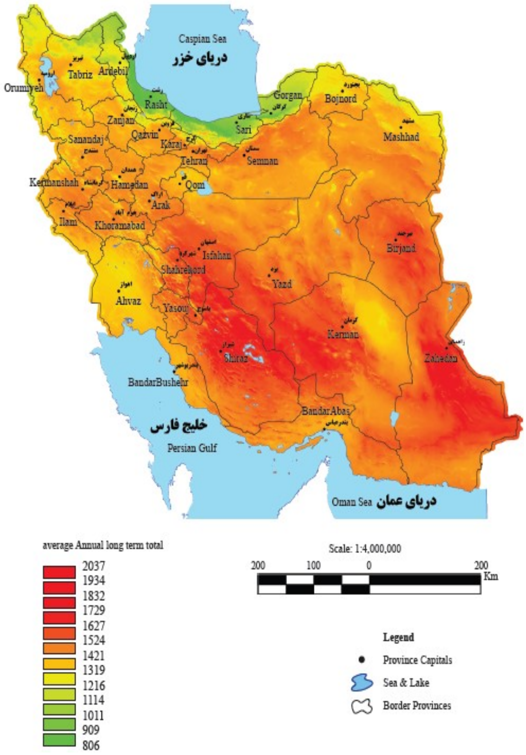

Figure 1. Atlas of average annual production of photovoltaics (kWh/kWp)

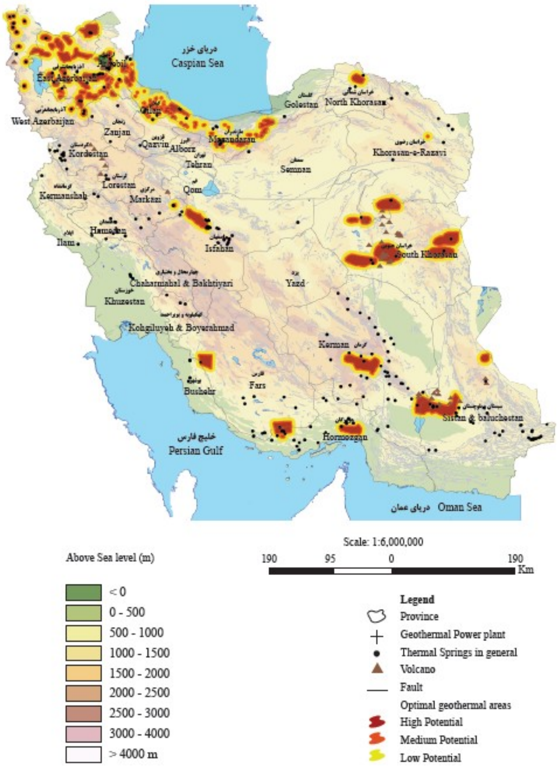

Figure 2. Atlas of geothermal energy resources

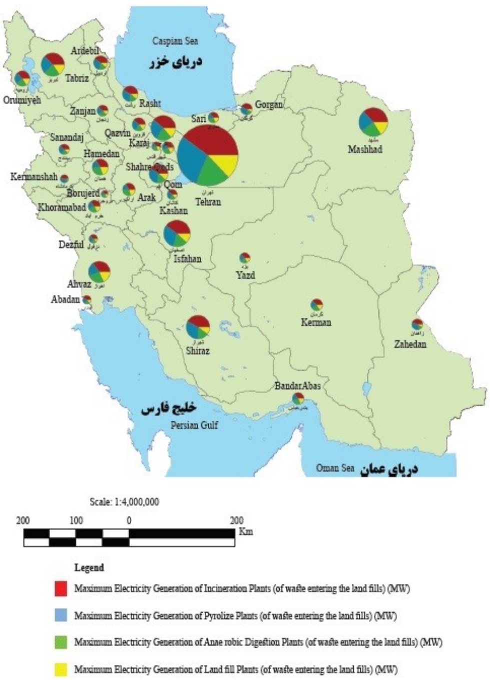

Figure 3. Atlas of biomass energy

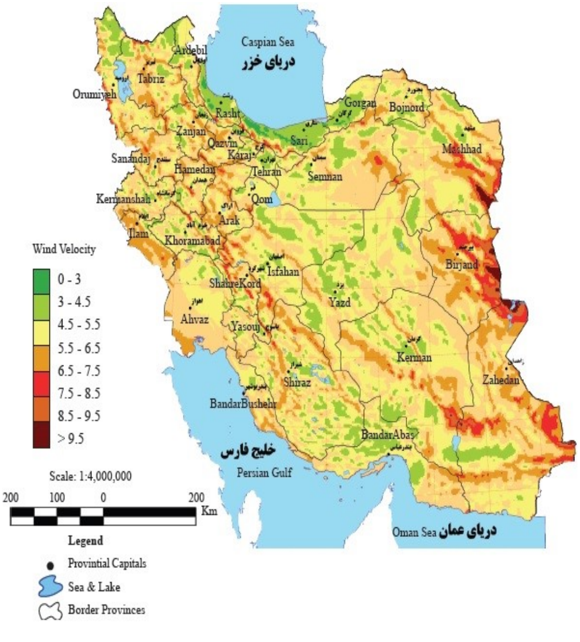

Figure 4. Atlas of average annual wind velocity at 100m above ground level (m/s)

Source: (Shafiezadeh et al., 2022)

The share of CO_2 emission by sectors and fuels in Iran is illustrated in Figure 5.

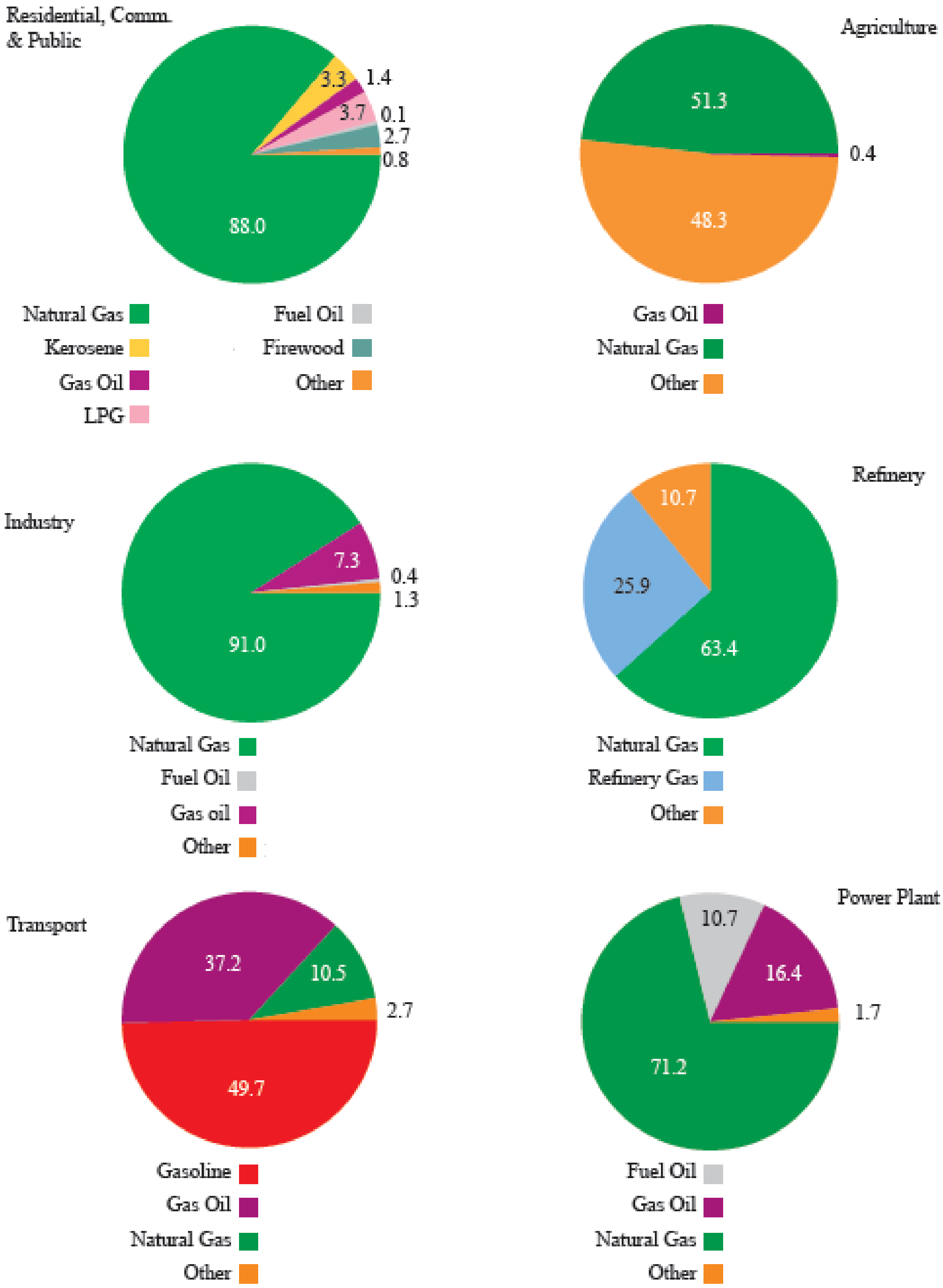

Figure 5. CO_2 emission by sectors and fuels in Iran Source: (Shafiezadeh et al., 2022)

Methodology

This study employs the structural vector autoregressive (SVAR) model for data analysis. The key distinction between the SVAR model and the conventional VAR model lies in their approach to identification: while the standard VAR model implicitly identifies structural shocks, the SVAR model explicitly incorporates economic theory through theoretically-grounded restrictions. These restrictions are imposed using economic relationships to achieve identification.

In contrast, traditional VAR models typically rely on Cholesky decomposition to derive impulse response functions (IRFs) (Boiciuc, 2015). The SVAR framework enables evaluation of how different shock dimensions from the independent research variables affect climate change. This analysis requires computation of the impulse response function (IRF), which measures both the magnitude of a shock's maximum impact and its persistence over time (Chatziantoniou et al., 2013). The SVAR model utilized in the present study is of order (P) and can be expressed in general form as follows(Büyükbaşaran et al., 2020; Restrepo-Ángel et al., 2022):

$$A_0 Y_t = C_0 + \sum_{i=1}^{p} A_i Y_{t-i} + \varepsilon_t \quad (1)$$

Where Yt is a 1×5 vector of endogenous variables of the system as follows:

$$\mathrm{PCCO2}_t = [RPCGDP \quad ETI \quad RES \quad UR \quad SI] \quad (2)$$

The RPCGDP stands for real gross domestic product per capita, $PCCO_2$ stands for "climate change index" (per capita CO_2 emissions); ETI is energy transition index; UR is urbanization rate (proportion of the country's population living in cities); RES equals the share of renewable energy consumption in the total energy consumption; SI is industrial structure (proportion of an industry sector's added value to the economy's overall added value); Ai is a 5×5 matrix of autoregression coefficients, and t is a 5×1 vector of structural disturbances, both of which are presumed to have zero covariance. C0 is a vector of 1×5 constants.

Finally, we consulted the World Bank, the Central Bank of the Islamic Republic of Iran, the Iranian Statistical Center, and the Iran’s energy balance sheet of the Ministry of Energy during the period of 2000–2020 for this study. The Software from Eviews was also employed.

Results

Economic studies frequently use unstable time series, which increases the risk of spurious regression. Tables 1 and 2 present the findings of the Dickey-Fuller and Phillips-Peron tests to determine the stationarity of the research variables.

Table 1. Generalized Dickey-Fuller Test Results to Examine the stationarity of Variables

Variable	level I(0)		First order difference I(1)	
	t-statistic	Sig.	t-statistic	Sig.
Logarithm of $PCCO_2$ (LPCCO2)	-1.271	0.199	-3.111	0.000
Logarithm of RPCGDP (LRPCGDP)	-1.423	0.151	-3.486	0.000
Logarithm of ETI (LETI)	-1.321	0.183	-3.231	0.000
Logarithm of RES (LRES)	-1.177	0.238	-2.881	0.003
Logarithm of UR (LUR)	-1.303	0.190	-3.185	0.000
Logarithm of SI (LSI)	-1.404	0.157	-3.433	0.000

Table 2. Phillips-Peron Test Results to Examine the Stationarity of Variables

Variable	Intercept		Intercept and trend	
	PP	Critical value	PP	Critical value
Logarithm of PCCO2 ($LPCCO_2$)	-1.321	-2.201	-3.522	-2.978
Logarithm of RPCGDP (LRPCGDP)	-1.572	-2.312	-3.646	-2.807
Logarithm of ETI (LETI)	-1.416	-2.538	-3.562	-2.791
Logarithm of RES (LRES)	-1.074	-2.313	-3.711	-2.796
Logarithm of UR (LUR)	-1.291	-2.404	-3.372	-2.913
Logarithm of SI (LSI)	-1.322	-2.389	-3.705	-2.862

The Dickey-Fuller test results indicate that none of the research variables are stationary in their level form, achieving stationarity only after first differencing (Table 1). The Phillips-Peron test confirms these findings, similarly showing that all variables become stationary after first differencing (Table 2). Consequently, all variables are integrated of order one (I(1)).

When estimating vector autoregression (VAR) models, determining the optimal lag length is crucial as it affects the system's degrees of freedom. The Schwartz-Bayesian criterion (SBC) was employed for lag selection, as it effectively balances model fit with parsimony (Wooldridge, 2013). The test results identify the second lag as optimal, corresponding to the lowest SBC value (Table 3), making this the most appropriate specification for our analysis.

Cointegration among the research variables was examined using the Johansen-Juselius method. Tables 4 and 5 present the results from both the trace test and maximum eigenvalue test. Given the model's six variables, up to five long-term relationships could potentially exist. However, the test statistics for both the trace and maximum eigenvalue tests exceed their respective critical values at the 95% confidence level, indicating no cointegration among the variables.

Figures 6 through 10 present the estimated impulse response functions (IRFs), demonstrating how the climate change index (PCCO2) responds to shocks in RPCGDP, ETI, RES, UR, and SI. In these figures, the dotted lines represent the 95% confidence interval. A shock's effect is considered statistically significant when both confidence bounds remain on the same side of the horizontal axis throughout the response period.

Table 3. The Results of Determining the Optimal Interval

Interval length		**0**	**1**	**2**	**3**	**4**	**5**	**6**
Schwartz-Bayesian criterion		-7.749	-19.058	-19.266*	-18.055	-17.507	-16.893	-16.191

Table 4. Effect Test Results to Determine the Number of Co-accumulated Vectors

	H_0	H_1	Statistics	Critical value 95%
Effect test	$r=0$	$r\geq 1$	80.845	69.831
	$r\leq 1$	$r\geq 2$	48.352	47.868
	$r\leq 2$	$r\geq 3$	24.154	29.809
	$r\leq 3$	$r\geq 4$	21.032	26.031
	$r\leq 4$	$r\geq 5$	18.331	16.232
	$r\leq 5$	$r\geq 6$	16.008	11.701

Table 5. Results of the Maximum Eigenvalues Test to Determine the Number of Co-integrated vectors

	H_0	H_1	Statistics	Critical value 95%
Maximum eigenvalue test	$r=0$	$r=1$	32.509	2.992
	$r\leq 1$	$r=2$	24.213	17.599
	$r\leq 2$	$r=3$	15.624	11.147
	$r\leq 3$	$r=4$	11.112	6.024
	$r\leq 4$	$r=5$	8.019	4.173
	$r\leq 5$	$r=6$	6.234	2.234

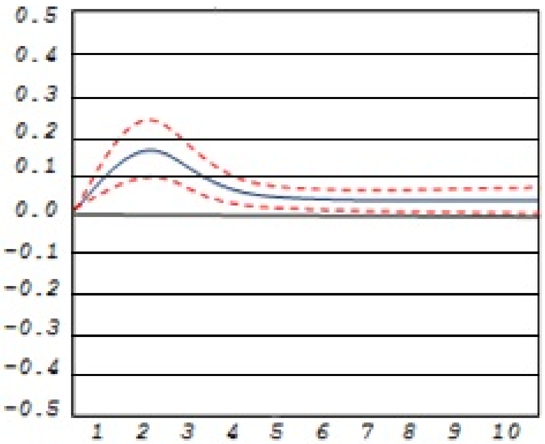

Figure 6. IRF of LPCCO2 on LRPCGDPF

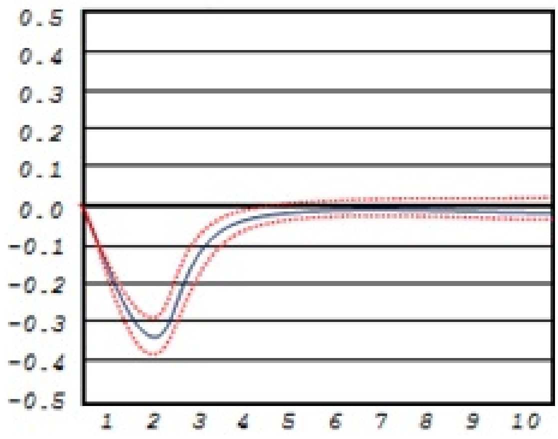

Figure 7. IRF of LPCCO2 on LETI

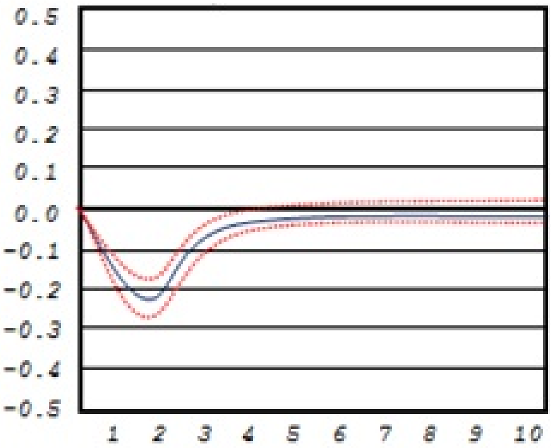

Figure 8. IRF LPCCO2 on LRES

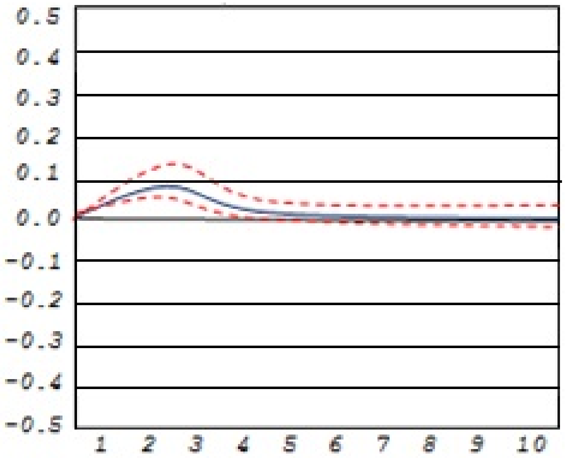

Figure 9. IRF of LPCCO2 on LUR

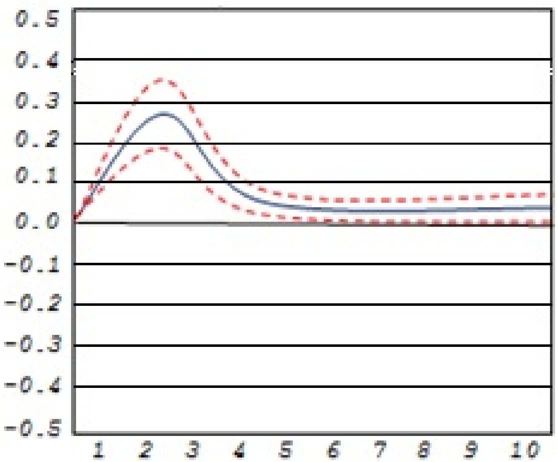

Figure 10. IRF of LPCCO2 on LSI

Figure 6 presents the impulse response function (IRF) of LPCCO2 to a shock from LRPCGDP. The results demonstrate that LRPCGDP significantly affects the climate change index LPCCO2 up to the tenth interval. This suggests that when using GDP per capita as an economic growth indicator, economic growth leads to increased GHG emissions and reduced environmental quality. This relationship between economic growth and environmental impact has been well-documented in previous studies (Adebayo & Kirikkaleli, 2021; Khan et al., 2020; Nasir et al., 2019).

Figure 7 shows the IRF of LPCCO2 in response to a shock from LRETI. The results indicate that the ETI shock significantly influences LPCCO2 up to the fifth interval. A one standard deviation positive shock to ETI reduces both the climate change index and per capita CO2 emissions by 0.11 units in the first period and 0.34 units in the second period, with effects diminishing to near zero thereafter. Previous research has established the energy transition's role in reducing ecological footprints (Afshan et al., 2022) and promoting sustainable development (Dong et al., 2021). The energy transition process is influenced by technological innovation, economic development, social adaptation, and regulatory frameworks (Cherp et al., 2018; Neofytou et al., 2020).

Figure 8 reveals that the LRES shock significantly impacts LPCCO2 up to the fifth interval, demonstrating that renewable energy use negatively and significantly affects Iran's climate change. A one standard deviation positive shock to renewable energy consumption decreases per capita CO2 emissions by 0.13 units in the first period and 0.22 units in the second period, with effects approaching zero subsequently. These findings align with existing literature advocating renewable energy to mitigate environmental impacts (Acaroğlu & Güllü, 2022; Akan, 2023; Sanaeepur et al., 2014; Sarkodie et al., 2020).

Figure 9 displays the IRF of LPCCO2 to LUR, showing that urbanization shocks significantly affect LPCCO2 up to the fifth interval. A one standard deviation positive shock to urbanization increases per capita CO2 emissions by 0.03, 0.07, and 0.09 units in the first three periods respectively, with effects eventually neutralizing. While urbanization is widely recognized as a climate change driver (Chapman et al., 2017; Liu & Bae, 2018; Ogwu, 2019), some studies report contradictory findings, showing urbanization may decrease GHG emissions in certain contexts (Asumadu-Sarkodie & Owusu, 2017b; Zheng et al., 2021). This suggests that urban planning approaches can significantly influence emission outcomes.

Figure 10 demonstrates that the LSI shock substantially impacts LPCCO2 up to the tenth interval, indicating industrial structure positively affects Iran's climate change. A one standard deviation positive shock to industrial structure increases per capita CO2 emissions by 0.08, 0.21, and 0.28 units in the first three periods respectively, with effects diminishing thereafter. This aligns with research identifying industrialization as a major pollution source (Li et al., 2016) and confirms the established industry-emissions relationship (Asumadu-Sarkodie & Owusu, 2017a; Liu & Bae, 2018). The primary mechanisms are increased energy consumption and emission intensity, which could be mitigated through renewable energy adoption and cleaner energy infrastructure.

Conclusions

This study aimed to fill a gap in previous studies on climate change in Iran. According to the results of this study, economic growth, increased urbanization, and a more diverse industrial structure all contribute to a unfavorable change in Iran's climate. Iran's reliance on fossil energy to provide the necessary resources for economic and industrial growth is one of the most important reasons for the positive relationship between these cases and climate change. Climate change is one of the most important issues facing the world today. Additional research has uncovered similar findings regarding this issue (Copiello & Grillenzoni, 2020; Wang et al., 2022). The greater importance of the structure of industry on the phenomenon of climate change compared to other variables such as urbanization and economic growth demonstrates that the reform of the structure of the industry in Iran, such as planning to increase the efficiency of energy consumption or reducing the share of fossil energies in the energy supply of this sector, has a higher effect and can have more tangible results. This is because the importance of the structure of industry on the phenomenon of climate change is greater than the importance of the other two variables, such as urbanization and economic growth.

On the other hand, climate change and temperature rise may have a detrimental impact on economic expansion (Abidoye & Odusola, 2015). Based on research was conducted in the US, Jeon (2022) claims that the development of renewable energy sources lowers costs and raises environmental quality. Burning fossil fuels will also make labor and capital less productive. According to the study's findings, expanding the use of renewable energy can lessen both the effects on economic growth and the emissions of pollutants.

This study revealed that both the ETI and consumption of renewable energy harm climate change and GHG emissions. Large-scale utilization of renewable energy will ensure energy supply and reduce GHG emissions(Kardooni et al., 2018; Leitão & Lorente, 2020; Mokhtara et al., 2021; Owusu & Asumadu-Sarkodie, 2016). Regarding the use of renewable energy, technological innovation can enhance the level of renewable energy technology and subsequently promote its development. A nation with a high level of renewable energy innovation can produce renewable energy outputs at a lower cost; in fact, a nation with a high level of renewable energy innovation can effectively increase the capacity of renewable energy supply to meet energy demand and alter the energy structure (Chen & Lei, 2018).

According to the findings of this study, using renewable energy had a smaller impact on lowering GHG emissions than the ETI. Beyond the technological perspective, the energy transition has socio-economic, ecological, and geopolitical dimensions. Taking into account the strong links between the energy transition and reducing climate change and, as a result, greener economic growth as well as the continuously rising energy demand requires a multifaceted view of economic and social dimensions. Given the multidimensionality of the ETI and the fact that it has a greater impact on climate change than the amount of renewable energy used, it can be said that energy policies do not act independently but rather respond to macroeconomic, institutional, social, and geopolitical factors or have an impact on them. Therefore, policy formulation and decision-making related to business can be more effective if a better understanding of the conditions that enable effective energy transfer exists.

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