



The impacts of economic growth, foreign direct investments, and gas consumption on the environmental Kuznets curve hypothesis CO₂ emission in Iran

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Abstract

Economic development is associated with higher energy consumption, which has a direct impact on climate change. As a result, today's growth policies should also align with environmental sustainability goals. Although socioeconomic variables related to air pollution have been extensively studied in previous studies, little research has examined their long- and short-term effects. This study aimed to investigate the long-run and short-run relationship between carbon dioxide (CO₂) emissions, energy consumption, especially gas as a clean fuel, foreign direct investments (FDI), and gross domestic product (GDP) using autoregressive distributed lag (ARDL) model in Iran during the period of 40 years. The estimation results indicated the validity of the environmental Kuznets curve (EKC) hypothesis for Iran. Moreover, empirical findings illustrate that the impact of financial growth on CO₂ emissions, in the long run, is U-shaped in Iran. The reliance on gas as a fuel for the country led to a reduction of the carbon and ecological footprints in a short time compared to other polluting fuels. Further, our empirical results indicate that economic growth and foreign direct investment contribute to reducing pollutant and carbon emissions in Iran over long and short periods. According to the empirical findings, important energy policy recommendations are offered.

Keywords CO₂ emission · ARDL · Economic growth · Foreign direct investment · Gas consumption · Renewable energy

Nomenclature

EKC Environmental Kuznets curve
GDP Gross domestic product
FDI Foreign direct investment

BP British Petroleum
PLS Partial least squares
ARDL Autoregressive distributed lag
IEA International Energy Agency
 $\alpha_i \dots n$ Short-run coefficients
 Δ Promptness of correction
ECMt–1 First differences of variables over time
I (0) Lower boundaries
I (1) Upper boundaries
 $\hat{\epsilon}_t$ The error term
CUSUM Cumulative sum of recursive residuals

Highlights

- The ARDL lag bound test is used to determine the socioeconomic factors on CO₂ emission.
- The inverted U-shaped (EKC hypothesis) pattern is affirmed in Iran.
- The strongest interaction appears between FDI, gas consumption, GDP, and CO₂ emission which have both short and long run.
- In the long run, natural gas consumption shows a rising impact on CO₂ emissions, in contrast to the short-run impact.
- The Iranian energy portfolio needs to be diversified urgently.

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Introduction

One of the most urgent crises of our time is climate change. Human and natural systems are facing existential threats due to the increased severity of extreme weather events and changing climate patterns. As a result of these phenomena, the new epidemic of corona virus (COVID-19) poses an unprecedented parallel threat to the both human society and sustainability of our planet. The global community must respond immediately and significantly to the dual crises,

involving coordinated efforts between various state governments and contributions from both public and private sectors (Mahmood, Eqan, et al. 2020). Nowadays, nations all over the world are looking for approaches to mitigate the adverse effects of climate change. Despite the mentioned summary, there is still a lack of effective practical actions by most under-developed countries to combat climate change. However, despite Iran's struggles to formulate policies and plans related to sustainable development and low-carbon technologies, the desired outcomes from adopting such policies have not yet materialized (Razmjoo et al. 2019). According to a report of British Petroleum (BP) Statistical Review 2019 (Table 1), the top 10 carbon dioxide emitter countries reported their emission rate to become doubled since the Kyoto Protocol. The amounts of emissions in China and India, which are among the top 3 emitters, have both seen massive increases since 2005. According to Table 1, Iran is the eighth largest CO₂ emitter in the world. Emissions in Iran have increased by 50% since the Kyoto agreement. According to this report, global environmental degradation is reputed to be a significant barrier to socio-economic development. Iran is the world's largest oil producer after Venezuela, Saudi Arabia, and Canada (Davarpanah and Mirshekari 2020), with massive natural gas resources after Russia; so, it has a relatively large share in this field compared to other countries.

Although various socioeconomic variables are influential on CO₂ emissions, such as economic growth, energy consumption, trade openness, financial development, urbanization, capital investments, and labor force, a crucial question is which one of the mentioned variables is the most effective one (Lotalipour et al. 2010; Omri 2013; Hajilary et al. 2018). Historically, investment decisions and environmental protection policies have influenced the quality of the environment, which has also affected the economy. Consequently, long-run economic growth does not conflict with

social cohesion or with environmental preservation, but they strengthen each other. The environmental Kuznets curve (EKC) hypothesis developed by Grossman and Krueger has been a fundamental part of the study of economic growth and environmental impacts for over a century. According to Kuznets' original curve, inequality and economic growth are related in an inverted U-shaped way. According to this hypothesis, pollution increases in low-income countries and decreases as income increases. So, whether the EKC hypothesis holds for each country or not is one of the most critical questions relating this hypothesis. Whether other important parameters such as renewable or non-renewable energy usage are represented on this curve or not is another essential question. According to our previous investigations, energy consumption and its costs, citizen rates, non-oil gross domestic product (GDP), and foreign direct investments (FDI) significantly affect CO₂ emissions. There is a linear relationship between these factors and CO₂ emissions. By using a partial least square (PLS) method, the relationships among significant factors were evaluated for the first time. Results of the prior investigation show that a lower energy consumption leads to a lower CO₂ emission rate. It also indicates that FDI is the important factor that decrease CO₂ emissions, while citizens raise CO₂ emissions rate (shares of 13% and 4%, respectively). CO₂ emissions are slightly affected by energy costs or non-oil GDP (Hajilary et al. 2018). As a continuation of our previous research, the purpose of this study is to evaluate the environmental Kuznets curve hypothesis and to examine its connection between CO₂ emissions and economic growth, foreign direct investment, energy consumption, or income from a variety of angles in Iran over 40 years (1976–2016) with Pesarans Auto Regressive-Distributed Lag (ARDL) bound test. As the consumption of natural gas has increased considerably in Iran, as a common and non-renewable energy source, a more detailed assessment would be useful. Thus, the dynamic relationship between natural gas consumption and CO₂ emissions in Iran is examined. The study tests demonstrate the validity of the hypothesis and discuss both the short and long run. Hence, the results could be beneficial for policymakers to put forward specific policy measures to reduce carbon emissions in Iran. On the other hand, renewable energy sources such as hydro, nuclear power, wind, and solar have been found to produce energy with little or no effect on climate change, and thus they are less harmful to the environment and social well-being (Adedoyin et al. 2020)

The Iranian government has pledged to reset carbon dioxide to 4% by 2030 under the Paris agreement. But, upon receiving international support and no further sanctions, the Iranian government believes that a reduction of 12% is possible. IRAN's policy on sustainable development emphasizes using renewable energy sources and a rise in natural gas consumption (Hosseini et al. 2019).

Table 1 CO₂ emissions by the top 10 (BP Statistical Review 2019)

Country	CO ₂ emissions *(BMT)	Changes since Kyoto Protocol
China	9.43	54.6%
USA	5.15	-12.1%
India	2.48	105.8%
Russia	1.55	5.7%
Japan	1.15	-10.1%
Germany	0.73	-11.7%
South Korea	0.7	34.1%
Iran	0.66	57.7%
Saudi Arabia	0.57	59.9%
Canada	0.55	1.6%

*BMT billion metric tons

The following questions are typically addressed in this paper:

1. Has a U-shaped inverted EKC for gas consumption been identified in Iran?
2. What is the strongest interaction appearing between CO₂ emission and FDI, gas consumption, or GDP in the short and long run?
3. Does natural gas consumption show a positive impact on CO₂ emissions?
4. Which policy implies strengthening energy resilience and mitigating the greenhouse effect?

A review of the relevant literature is provided in Sect. 2 “Literature review” which is divided into two parts including “Important theoretical factors for EKC hypotheses” and “Iran’s CO₂ emission factors.” Section 3 discusses “Statistical and methodological information,” Sect. 4 presents “Empirical results and discussion,” and finally Sect. 5 “Conclusions and policy recommendations” concludes and highlights policy implications.

Literature review

This section is divided into two subsections. The first part of this article discusses theoretical factors that are most important for EKC hypotheses and carbon emission (based on previous studies (Hajilary et al. 2018), and actual parameters of “Iran’s CO₂ emission factors” during the years 1976–2016 are examined in the second part.

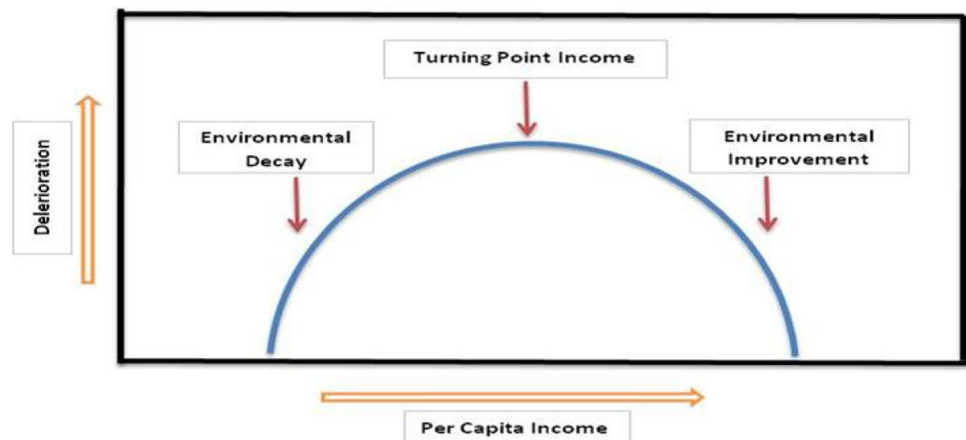
Theoretical important factors on the EKC hypotheses

Researchers have confirmed the negative impact of economic growth and the positive impact of energy decline on carbon emissions at the provincial, national, and global

levels. (Li et al. 2021). Therefore, economic growth cannot be sustained without environmental sustainability in tandem. Consequently, the relationship between economic growth and environmental quality has become a significant area of research in the contemporary era (Murshed et al. 2021a). One popular theory that explains the correlation between environmental pollution and economic growth from both academic and policy-making perspectives is the EKC hypothesis, by Grossman and Krueger (1991). There is an inverse relationship between a nation’s economic growth and its environmental quality (Murshed et al. 2021b). According to Fig. 1, environmental degradation increases up to a certain level as income increases, called the inflection point, then decreases once income per capita reaches a certain level and contributes to environmental betterment.

It has been noted in the literature that EKC curvature and shape are a function of various macroeconomic aggregates that have direct and indirect effects on the relationship between economic growth and the quality of the environment. Therefore, scientists have conducted a significant amount of research on structural factors and carbon emissions, particularly in the energy, trade, and society. Nevertheless, examining the parameters that have a more direct impact on CO₂ emissions is relatively few for a country like Iran, one of the significant producers of energy and, unfortunately, a major emitter of environmental pollutants. Among mentioned variables, energy consumption is one of the effective parameters of the EKC hypothesis. The validity of the EKC hypothesis is also influenced by the level of energy consumption. A relevant explanation for this phenomenon is that as a result of the energy push emission hypothesis, energy consumption within the economic growth will rise, and as a consequence, greenhouse gas emissions are likely to increase (Khan et al. 2019). Moreover, the environmental impacts associated with energy use are acknowledged depending on the type of energy consumed; as an example, it is thought that the use of fossil fuels contributes to environmental degradation (Ito 2017). Based on actual data, one

Fig. 1 EKC curve (environmental Kuznets curve)



of the main reasons for Iran's energy consumption is the population growth over recent years. However, Iran is one of the largest producers of gas and oil in the world and in the Middle East. In recent years, Iran has tried to shift its primary energy consumption sources, including domestic consumption and many large industries, from oil to gas. Therefore, gas consumption has increased in recent years. Due to the importance of changing the type of energy and its consumption of gas in Iran, the short-run and long-run effects of gas consumption as a common energy source have been investigated.

In addition, foreign direct investment is also relevant when explaining environmental variations within a host country. Whether FDI always has positive effects on host countries or it leads to environmental degradation is fundamental for many governments (Peng et al. 2016). The effect of this parameter has been studied in different countries and also Iran. Due to the effect of various parameters on the changes in the EKC chart, the authors confirmed the presence of the EKC hypothesis for Iran's case, too.

Examining the relation between foreign direct investment and CO₂ emission

Gross domestic product is the most commonly used measure for the size of an economy, and it can be calculated in three ways, using expenditures, production, and income. The environmental Kuznets curve suggests that economic development initially leads to a deterioration in the environment, after a certain level of economic growth, a society begins to improve its relationship with the environment, and levels of environmental degradation reduce. The results of studies that have been conducted for European countries indicate that CO₂ emissions and gross GDP correlate positively (Dogan and Inglesi-Lotz 2020). In another article studying G-20 nations, the positive impact between GDP and CO₂ emission is clear (Han and Lee 2013). A direct relationship between GDP and carbon dioxide emissions in China is found by Michael and Xibao (Minlah and Zhang 2021). China's CO₂ emissions invert the U-shaped EKC effect (Yin et al. 2015). A panel of fourteen Asian countries was used to test the EKC hypothesis from 1990 to 2011. According to the results, emissions and per capita income exhibited an inverted U-shape relationship (Apergis and Ozturk 2015). Some studies have found that economic growth and CO₂ emissions follow an N, M, and W-shaped relationship. Over a long period of time, Canada, Japan, and the USA have experienced M-shaped financial development. France, Italy, and the UK experience inverted N-shaped financial development, while Germany experiences inverted M-shaped (W-shaped) financial development (Shahbaz et al. 2021). There is also a linear relationship between

these economic growth and CO₂ emissions, according to other scholars (Farhani and Hossein 2012). Some studies, however, have not found a significant relationship between these two variables (Lantz and Feng 2006). Based on these empirical findings, policymakers can now adopt comprehensive economic policies for using financial institutions as economic tools to keep environmental quality at sustainable levels.

Examining the link between foreign direct investment and CO₂ consumption

FDI and the ecological greenhouse gases proxy CO₂ have been studied widely in the environmental literature for the past few decades. Foreign direct investment is an investment controlling ownership in a business in one country by an entity based in another country. Countries can divide into three groups according to their real gross national income per capita: high-income, upper-middle-income, and lower-middle-income countries. Possibly, there are various reasons directly affecting FDI in developing and developed countries. Indeed, foreign direct investment is an indispensable source of finance for developing countries, but policymakers must minimize their risks. Host countries can benefit from FDI through employment creation, technology diffusion, economic growth, and sustainable development (UNCTAD 2015). As a result, Alfaro et al. (2004) state that absorption capacities include macro-economic management, infrastructure, human capital, industrial share, potential rise, high absorption capacity, and an adequate legal framework (UNCTAD, 2015). A study conducted on 26 European countries showed that foreign direct investment deteriorates pollution levels in most EU countries (Mert et al. 2019). According to the analysis of 57 developing countries from 1980 to 2013, FDI does not directly cause CO₂ emissions in the short-run. In addition, even though CO₂ emission elasticity is statistically significant, it is minimal in the long run (Kim 2019). A considerable amount of economic growth has occurred in the emerging markets of Asia for decades. Foreign direct investment (FDI) has been attracted to the nations, which has positively impacting economic growth in the countries. The increased importance and flow of foreign direct investment have helped to transfer management skills and technologies, create jobs, and improve the standard of living for millions of people in the region since the early 1970s (To et al. 2019). FDI has a linear relationship with environmental degradation in Asia, and the EKC hypothesis holds for selected developing countries (To et al. 2019). With half of Asia's FDI share, China has been positively affected by FDI on environmental degradation (He and Yao 2017).

Examining the link between energy consumption and CO₂ emissions

Due to the inextricable link between energy use and economic growth, it is quite likely that it would affect environment, as well (Destek and Sarkodie 2019; Murshed et al. 2021b). Several studies have indicated a positive relationship between per capita emissions and energy consumption. The result of one study asserts that the adverse environmental impacts of energy use are comparatively higher in the long run than in the short run (Khan et al.). Two studies investigated selected EU countries and found a positive relationship between energy consumption and carbon emissions (Balsalobre-Loriente et al. 2018, and Bekun et al. 2019). Due to the use of renewable energy, developed countries have reduced fossil fuel consumption despite an increase in energy consumption. Renewable energy resources are not available to all countries because of their high costs, according to the EIA report. However, developed countries are investing in renewable energies through direct foreign investments, and energy consumption from renewable resources is growing rapidly (Rezagholizadeh et al. 2020). One study from Pakistan concluded that economic growth contributed to a certain amount of carbon emissions (Ahmed and Long 2012). In Chinese, pollution showed evidence of energy consumption contributing to carbon emission (Li et al. 2010). The analysis results determine carbon emissions in eight oil-rich MENA countries, including Iran, as a result of fossil fuel consumption (Magazzino and Cerulli 2019). Murshed, who recently published a study focusing on South Asia, argues that consumption of natural gas, petroleum products, and liquefied natural gas, and hydroelectricity will reduce CO₂ emissions. Since the impacts of energy use on the quality of the environment are determined by the nature of the energy resource consumed, many existing studies have probed into the heterogeneous impacts of renewable and non-renewable energy use on the energy friendly (Murshed et al. 2022).

Iran's CO₂ emission factors

In most regions, population growth is among the major factors that drive CO₂ emissions. Both developed and developing countries have a positive correlation between population and CO₂ emissions (O'Mahony 2013; He et al. 2017). Figure 2 shows the growth of Iran's population over the last four decades. Iran's population has become more energy intensive since 1995. In countries like Iran, where fossil fuels such as oil and gas are the main energy source, CO₂ emission is on the rise (Soytas et al. 2007; Kais and Sami 2016; Heydari et al. 2019). Figure 3 shows the increase in energy consumption per capita in Iran between 1976 and 2016.

According to Fig. 4, natural gas consumption in Iran is increasing the most among the main primary energy sources. According to state policies, oil consumption is declining, and more natural gas is used for industrial and domestic purposes. Other energy sources such as nuclear energy, hydroelectricity, and coal consumption are less influential on energy consumption in this country (Hajilary et al. 2018). Energy consumption in Iran is positively correlated with per capita CO₂ emissions, as a rise of 100% in energy consumption leads to an increase of 87% in CO₂ emissions. It is important to note that although natural gas is a fossil fuel, it is a relatively clean fuel. Therefore, natural gas is an alternative to conventionally consumed crude oils, and compared to other options, it is said to be cleaner. The few decreases in carbon emissions in Iran are connected to the use of more gas. Compared to coal and oil, natural gas emits 50% less pollution (Solarin and Shahbaz 2015). Taking advantage of natural gas as a cleaner alternative to other fossil fuels, the Chinese government adopts the energy consumption structure to address its increased energy needs and cope with environmental issues. Despite the fact that there is little discussion of CO₂ emissions and gas consumption in the literature, a study (Kanyin Dong

Fig. 2 Population changes and gas consumption per year in Iran (1976–2016)

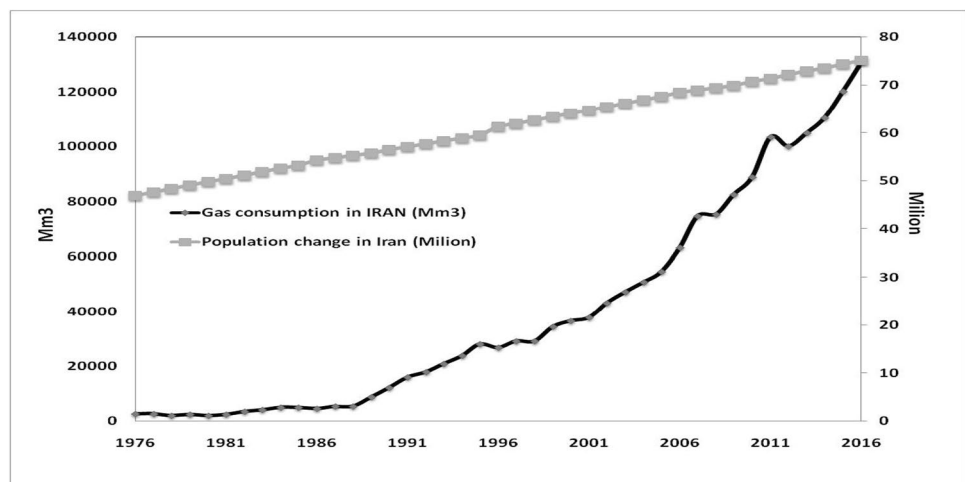


Fig. 3 Energy consumption and CO₂ emission per year in Iran (1976–2016)

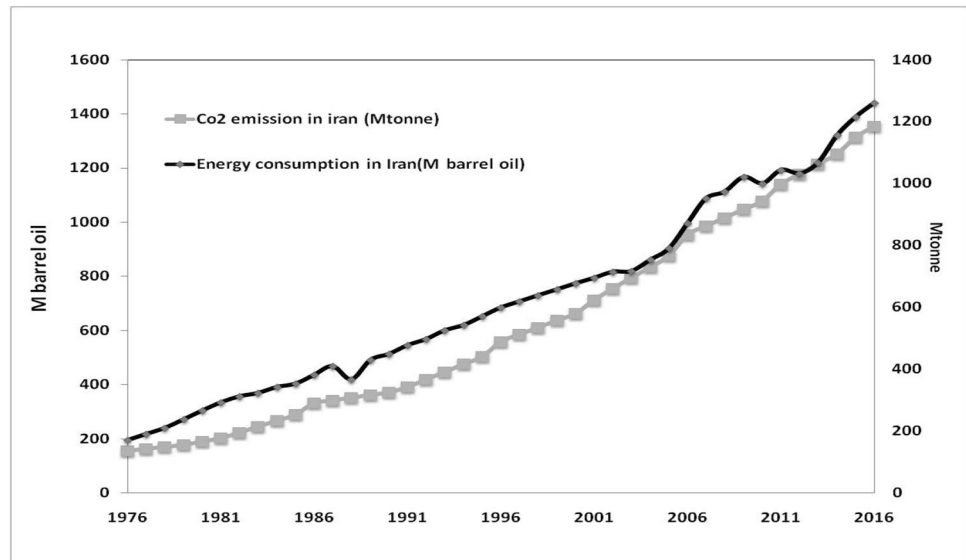
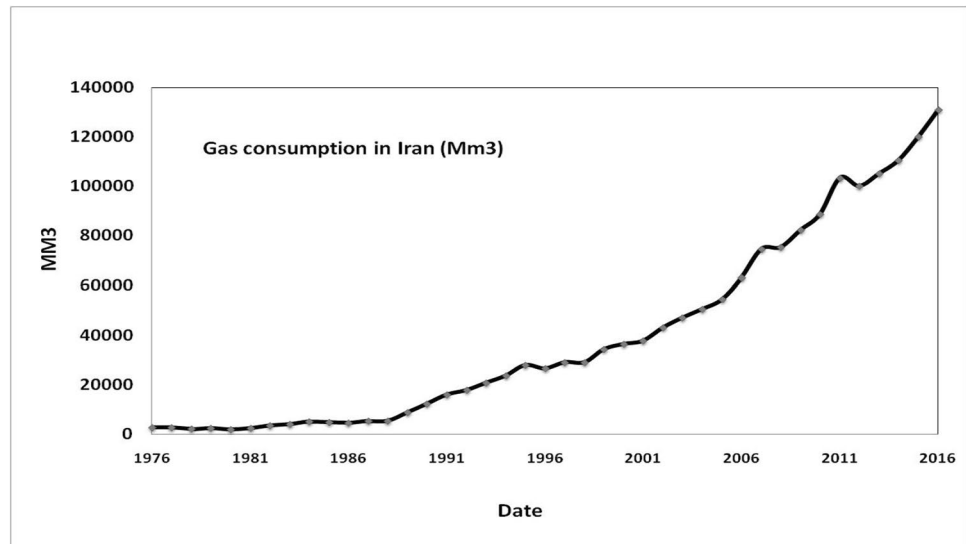


Fig. 4 Gas consumption per year in Iran (1976–2016)



et al. 2017) proposes a significant negative relationship between natural gas consumption and CO₂ emissions. Figure 5 depicts Iran's carbon footprint has increased gradually and somewhat linearly.

However, Iranians rely heavily on fossil fuels for their economic development. A considerable portion of Iran's export revenue in 2016 was from the sale of fossil fuels, specifically oil. GDP does not have a remarkable impact on CO₂ emissions, whereas GDP measured in non-oil terms does. The domestic GDP in Iran cannot represent real economic growth because oil exports make up a large share of the total. Non-oil GDP (GDP without considering oil exports) shows the real domestic economic growth. As a result, actual developments in industrial products lead to more significant CO₂ emissions (Ozcan 2013; Farhani and Shahbaz 2014; Hajilary et al. 2018).

It is accepted that FDI generates both positive and negative effects that involve costs and cause benefits. According to Fig. 6, FDI in Iran has undergone many changes between 2000 and 2016, related to various reasons, including the amount of foreign trade and privacy. According to the results of the Iranian studies, foreign direct investment is positively and significantly related to CO₂ emissions, which suggests that higher foreign investment leads to a reduction in environmental pollution. With a 100% increase in foreign investment, emissions per capita are reduced by 5% (Hajilary et al. 2018). According to Ghorashi, financial development has a statistically significant negative effect on CO₂ emissions in the long run. Accordingly, domestic credit to the private sector as a percentage of value-added in each economic sector subscriptions could reduce CO₂ emissions in Iran. However, the estimated coefficients in the short run indicate

Fig. 5 CO₂ emission and gas consumption per year in Iran (1976–2016)

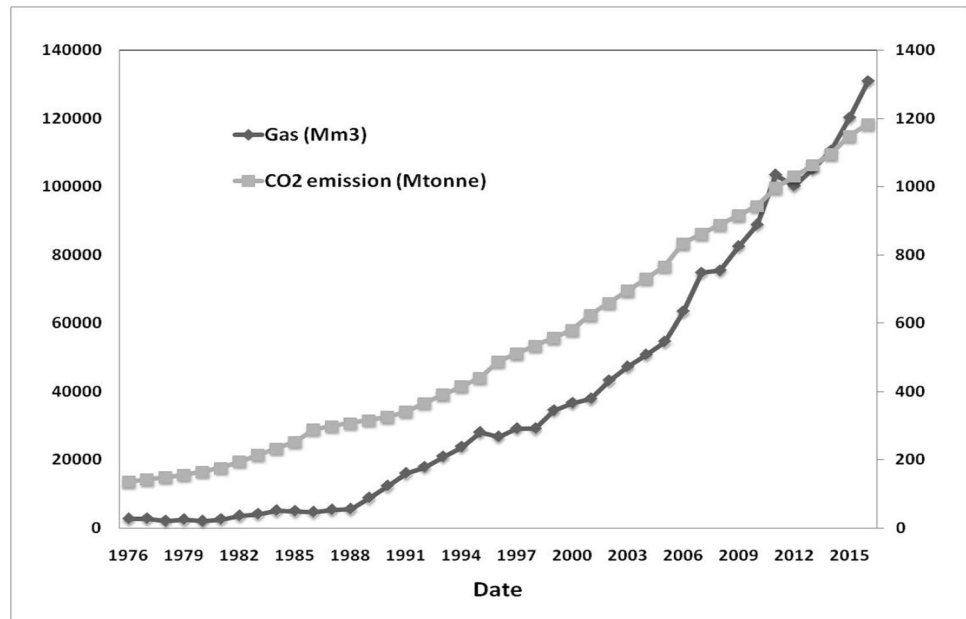
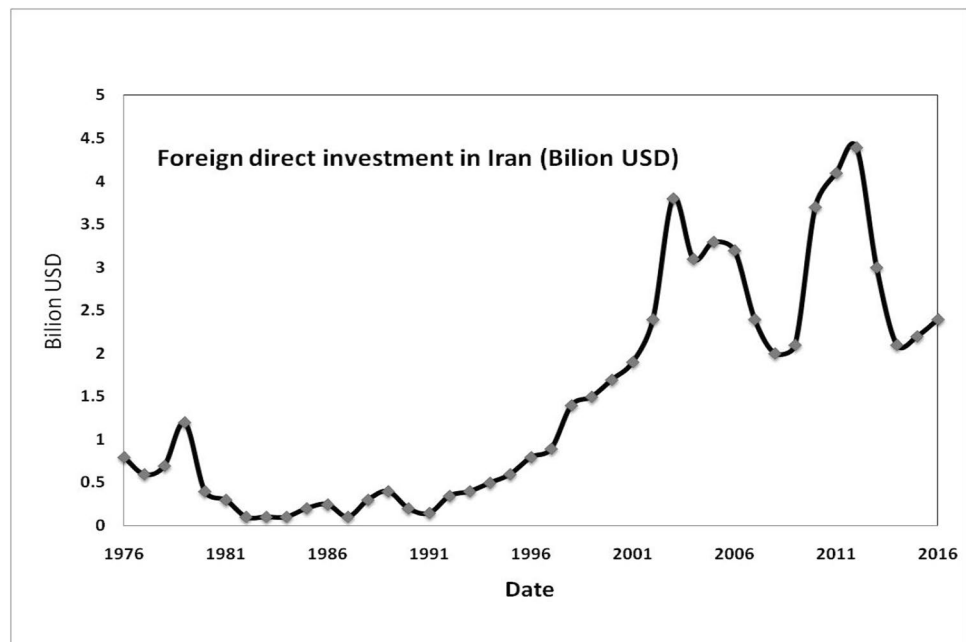


Fig. 6 Foreign direct investment per year in Iran (1976–2016)



that economic development does not have a statistically significant negative effect on CO₂ emissions in Iran. According to this study, policymakers should recognize the potential of financial development to minimize CO₂ emissions (Naghme-Ghorashi, Abbas Alavi Rad). The result of an investigation by Rafat over the period 1991 to 2014 about identifying the relationship between FDI and economic growth in Iran shows that economic growth and foreign direct investment have a positive impact on each other; hence, there is a reciprocal relationship between them.

So far, no consensus has been reached on CO₂ emissions and economic growth. Scholars have discovered the tradition of the inverted U-shape and others of the N-shape. There is also a research suggesting a linear relationship between these two variables (Dong et al. 2017). To demonstrate the validity of the hypothesis, the typical approach has been used to estimate the statistical relationship between environmental pollutants (such as emissions) and GDP in early EKC studies. Consequently, several studies have been conducted to examine the validity of the EKC hypothesis, whether for one

country or groups of countries using different econometric methodologies.

Statistical and methodological information

In this section, the theoretical framework and equations used are discussed. Among different methods, we decided to use ARDL equations since this cointegration technique is used in determining the long-run relationship between series with varying orders of integration. These parameterized result gives the short-run and long-run relationship of the considered variables.

The following variables have been chosen for the current study: Gross domestic product (GDP) in non-oil base (constant), CO₂ emissions (Million tons), Fuel consumption produces (Million tons), Foreign direct investment (FDI) (Billions USD\$), Gas consumption (Million cubic meters), and average income (Rials). All variables have been transformed into a logarithmic form from the World Bank development database (2018). The related data is indicated in Figs. 1, 2, 3 and 4.

Theoretical framework

Following preliminary study of Grossman and Krueger's (1991), recently there has been extensive literature analyzing the EKC hypothesis and its implications. EKC measures the number of pollutants emitted per capita about GDP. To put it another way, environmental degradation increases up to a point as income increases, but beyond some point in income per capita, it slows down. As part of proving the value of the hypothesis, the early studies of the EKC used the typical approach for estimating the statistical relationship between environmental pollutants (CO₂ emissions) and the per capita economy. Thus, it has been measured various times using econometric methodologies, whether for one country or several countries, to examine the validity of the EKC hypothesis. The empirical examination of its study demonstrates that alternative environmental quality measures can be applied instead of the traditional EKC theory, which studies the association between GDP and environmental degradation using either the U-shaped or the N-shaped pattern (Udemba et al. 2020). As global warming and other environmental problems become more severe, the effects of economic growth on the environment have become more prominent. Numerous empirical studies explain the nexus between emissions of carbon dioxide models such as the GDP model can promote economic growth Kuznets curve for the EKC theory. However, the assumptions of these models have not been rigorously tested with a large data set and, therefore, may not be appropriate to describe the relationship. According to the standard EKC form, economic growth and carbon dioxide emissions are linked by an economic U

shape. The economic model that was used to test EKC in Iran can be illustrated as follows:

$$CO_{2t} = f(GDP, FDI_t, Gas_t, Income_t) \quad (1)$$

The CO₂ is the carbon dioxide emissions in year t, GDP per capita of Iran's economy, FDI represents a foreign direct investment, gas is the gas consumption in Iran, and income is the income in Iran in year t.

Stationary tests

Several countries have experienced interruptions in social, political, and financial activities, which makes most yearly country data non-stationary. A time series analysis uses stationary estimation of the variables used in this study to eliminate errors and spurious results. In our model, stationary and unit root variables were analyzed in a mixed order of integration. Two-unit root tests were employed: Augmented Dickey-Fuller (Dickey and Fuller 1979) and Phillips Perron (Phillips and Perron 1988). There are three possible results for both tests: intercept, trend, and none.

Approach to ARDL-bound testing

This model uses the output of the unit root test from different techniques with an emphasis on the autoregressive distributed lag (ARDL) approach for a well-fitted model specification. The ARDL method, as described by Pesaran et al (2001), is considered suitable for this type of analysis with the usage of a mixture of the order of integration.

Following is the econometric arrangement of ARDL:

$$CO_2 = \beta_0 + \beta_1 GDP + \beta_2 GDP^2 + \beta_3 FDI + \beta_4 GAS + \beta_5 Income + \epsilon t \quad (2)$$

It is necessary to transform the linear model into a natural log form to examine the validity of the environmental Kuznets curve hypothesis. Compared to the linear model, the log-linear model can produce more consistent and efficient results.

$$\ln CO_2 = + \ln GDP + (\ln GDP)^2 + \ln FDI + \ln GAS + \ln Income + \epsilon t \quad (3)$$

“CO₂” represents the log of carbon dioxide emission that is the dependent variable, “GDP” represents the log of GDP, “FDI” represents the log of foreign direct investment, “GAS” represents the log of gas consumption, “income” represents the log of income, and ϵt defines the error term. Different coefficients for income terms indicate different functional forms in Eq. (2); for example, $\beta_1 = \beta_2 = 0$ means that in this case, CO₂ has no direct relationship with income; $\beta_2 > 0$ and $\beta_1 = 0$. The relationship between CO₂ and income is gradually increasing; $\beta_1 > 0$ and $\beta_2 < 0$. A relationship between income and CO₂ (EKC hypothesis) is depicted

as an inverted U-shaped relationship; $\beta_1 < 0$ and $\beta_2 = 0$. Assume that CO_2 decreases monotonically with income, and $\beta_1 < 0$ and $\beta_2 > 0$. Determine how CO_2 and income are related in a U-shaped fashion $\beta_3 > 0, \beta_4 > 0$, and $\beta_5 > 0$. CO_2 emissions are positively impacted by FDI, natural gas, and income, respectively.

Models based on this are further advanced by ARDL long-path techniques, which are ARDL long-path models. Two sets of equations were constructed to account for the associations among CO_2 , GDP, FDI, income, and gas consumption; thus:

$$\begin{aligned} \ln CO_{2t} = & +C + \beta_1 \ln CO_{2t-1} + \beta_2 \ln GDP_{t-1} + \beta_3 \ln GDP_{t-1}^2 \\ & + \beta_4 \ln FDI_{t-1} + \beta_5 \ln GAS_{t-1} \\ & + \beta_6 \ln Income_{t-1} + \epsilon_t \end{aligned} \tag{4}$$

$$\begin{aligned} \Delta \ln CO_{2t} = & +C + \alpha_1 \sum_{i=1} \Delta \ln CO_{2t-i} + \alpha_j \sum_{j=1} \Delta \ln GDP_{t-j} \\ & + \alpha_k \sum_{k=1} \Delta \ln GDP_{t-k}^2 + \alpha_l \sum_{l=1} \Delta \ln FDI_{t-l} \\ & + \alpha_m \sum_{m=1} \Delta \ln GAS_{t-m} + \alpha_n \sum_{n=1} \Delta \ln Income_{t-n} + ECM_{t-1} + \epsilon_t \end{aligned} \tag{5}$$

Equation (4) describes long-run coefficients, and Eq. (5) describes $\alpha_1, \alpha_j, \alpha_k, \alpha_l, \alpha_m,$ and α_n as short-run coefficients. Δ and ECM_{t-1} measure the promptness of correction and the first differences of variables over time. To expand the ARDL exploration, abound testing strategy was used to test the long path associations among the chosen variables. We correlated the lower and upper I (0) and I (1) boundaries with F and T statistics to determine the long-run co-integration. F and T statistics exceeded the lower and upper limits, indicating long path association, and vice versa. The graphical representation of the ARDL model is shown in Fig. 7.

Empirical results and discussion

It is necessary to examine the stationary properties of the variable in the first step to avoid incorrect analysis. Table 2 presents the results of the unit root and stationary tests for each series. As shown, all series are unit root J (1) and J (0), indeed except GDP which is stationary in zero level J (0). In other variables, the first differences are stationary J(1).

Given the ARDLtest presented in the tables, it appears that the co-integration equation will be stable in both the short and long run if CO_2 production is taken into account as a dependent variable. A positive correlation between per capita CO_2 emissions and per capita income (the EKC hypothesis) is observed in Table 3, where the series show that quadratic per capita GDP negatively affects per capita CO_2 emissions. Indeed, the GDP coefficient in the long run has been $\beta_1 = 3.991$, and the GDP^2 coefficient has been calculated as $\beta_2 = -1.182$, based on Eq. (2).

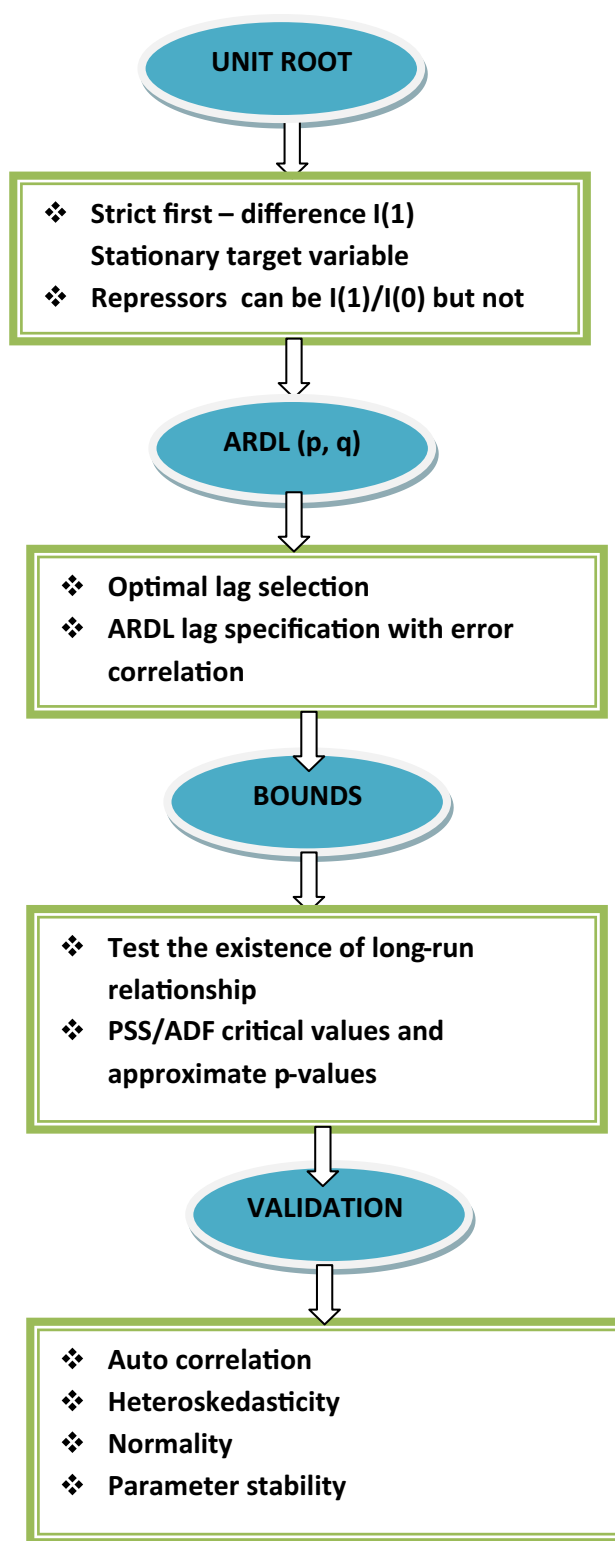


Fig. 7 ARDL model diagram

The estimation results for these data show that per capita CO_2 emissions are positively correlated to GDP and negatively associated with quadratic GDP per capita. According to these findings, an inverted U-shape relationship between

Table 2 Tests of stationery and unit roots of the variables on their long levels

Variables	(AFD) Augmented Dicky-Fuller test		(P.P.) Phillips-Perron test	
	Root	Stationarity	Root	Stationarity
CO2	J (0)	−4.092	J (0)	−4.106
GDP	J (1)	−4.279	J (1(0))	−4.236
GDP ²	J (0)	−4.053	J (0)	−4.041
GAS	J (0)	−4.287	J (0)	−4.285
FDI	J (0)	−6.391	J (0)	−6.367
Income	J (0)	−6.731	J (0)	−6.321

Variables are tested at long-term levels

Parentheses denote the values of 5% criteria $p < 0.01$, $p < 0.05$, $p < 0.1$

ADF augmented Dicky-Fuller test, P.P. Phillips-Perron test

Table 3 Results from ARDL estimation (EKC hypothesis in Iran)

Variable	Coefficient	SE	t-stat	p value
Short run				
D(LGDP)	0.133***	0.036	3.637	0.0009
D(LGDP ²)	−0.048	0.016	−2.963	0.0056
CointEq (−1)	−0.041	0.004	−9.952	0.0000
Long run				
LGDP	3.991***	0.668	5.847	0.0000
LGDP ²	−1.182	0.303	−3.9	0.0004

LGDP = Log (GDP); Prob.: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

CO₂ emissions and economic growth in Iran was in an inverted U-shaped relationship during this period. Since, according to the standard EKC form, economic growth and carbon dioxide emissions are linked by an economic inverted U shape. However, in some studies, the association between GDP and environmental degradation uses either the U-shaped or the N, M, and W-shaped pattern (Udemba et al. 2020). These findings enable policymakers to design comprehensive economic policies for utilizing financial institutions as economic tools to help maintain environmental quality (Murshed et al. 2021a). This result indicates economic development in Iran initially leads to a deterioration in the environment for a long time; after a certain level of economic growth, a society begins to improve its relationship with the environment, and levels of environmental degradation reduce. Based on the consideration of variables in the long run and short run and the diagnostic tests, the results of the ARDL test indicate the cointegration equation for the long-run stability pathway via GDP, FDI, gas, and income, with CO₂ as a dependent variable. The results confirm a possible significant relationship between CO₂ and all variables except GDP. The latter represents a negatively significant relationship both in the short and

long run. This indicates that the underlying variables (FDI, INCOME, and GAS) impact CO₂ emissions positively and significantly in Iran.

The long-run CO₂ emissions of the economy are likely to decrease by 0.969% if GDP increases by 1%. As a result, economic growth has a significant impact on pollution emissions in Iran. Following another study, economic activities are the most significant contributor to environmental pollution in Iran (Taghvaei and Hajiani, 2015a, b). In the work of Sarkodie (2019), there is a negative relationship between economic growth and pollution in developing countries. In another study by Emir (2019), similar trends were seen in Romania. Based on Shahbaz et al., because of its potential to promote the collaborative reduction of pollutants and carbon emissions, China's provincial and national development strategies should prioritize financial inclusion. Since CO₂ and GDP exhibit a negative relationship, it is clear that economic growth via manufacturing activities or outsourced industries enhances efficient management of carbon emissions in Iran (Shahbaz et al. 2022). As a result of this finding, a 1% increase in gas consumption will result in a 0.625% increase in CO₂ emissions in the long run. Alola et al. (2019) in their study of large economies in Europe provide affirmative evidence of this conclusion in their study on 16 EU countries. Bekun et al. also revealed other findings. In the short run, a 1% increase in gas consumption will result in a 0.125% reduction in CO₂ emissions.

Therefore, CO₂ emissions could be reduced in the short run by substituting natural gas with other fossil fuels. Economic growth and CO₂ emissions follow a U-shaped relationship. Natural gas consumption hurts emissions of CO₂ in the short run; since it burns cleaner than other fossil fuels (oil, petroleum, and coal), its use will lead to lower emissions when it becomes a major alternative fuel to other types. This trend has, however, shown positive results with CO₂ emissions, in the long run, proving that energy consumption is the most environmentally harmful factor and renewable energy sources such as solar or wind should be used instead (Al-Mulali et al. 2015; Omri et al. 2015; Taghvaei and Hajiani 2015a). Furthermore, a 1% upsurge of FDI would lead to 0.008 rises in CO₂ emissions in Iran in the short run. Saboori et al. (2012) found a similar relationship for Malaysia. Moreover, this finding supports the work of Alola (2019) on large European economies. Conversely, in long run, an increase of 1% in FDI induces the reduction of 0.233% in carbon dioxide emissions. Compared to the industrial sector, several items directly impact foreign direct investment. Modern technology, however, consumes less energy, resulting in fewer greenhouse gas emissions. In that case, Iran could invest in energy-efficient systems, technology that will decrease emissions, and policies designed to reduce carbon emissions without diminishing economic growth. According

to Table 4, the results indicate a significant negative relationship between CO₂ and other variables, including Gas, GDP, Income, and FDI, but they do not generalize because of the high amount of *p* value (upper 10%). According to this result, gas consumption and GDP significantly positively affect CO₂ emissions in the long run. There are no FDI and income coefficients that are positively related to CO₂ emissions in Iran in the long run, indicating that income has no direct relationship with CO₂ emissions that is positive in the run. To ensure the accuracy of the analyses, a diagnostic test was conducted to identify any approximations or estimation errors. ARDL models estimated by square tests were found to be stable and reliable. Figure 8 shows the cumulative sum of recursive residuals (CUSUM) test for the estimated model. The test clearly showed that the coefficients were stable over the explored period. If the blue line in Fig. 8 is considered the design of the cumulative sum of squares tests (CUSUM), then we will find that the parameters and variance are stable. The straight lines represent the mean level of 5%. According to the graph, the movement path of the test statistic is always between straight lines, so that the model is stable.

Conclusions and policy implications

The effect of carbon emissions on climate change makes it imperative to investigate carbon emissions. Based on the findings of this study, we used series data of Iran from 1976 to 2016 to explore the interacting forces between carbon emissions, GDP, FDI, income, and gas consumption as well

Table 4 ARDL estimates of the CO₂ equation

Variable	Coefficient	SE	<i>t</i> -stat	<i>p</i> value
Short run				
D(LCO2(-1))	-0.500***	0.184	-2.717	0.014
D(LGAS)	-0.125***	0.032	-3.829	0.001
D(LGDP)	0.106***	0.0383	2.736	0.013
D(LGDP ²)	-0.029	0.016	-1.732	.099
D(LINCOME)	-0.040	0.0329	-1.219	0.244
D(LFDI)	-0.082	0.0311	-2.653	0.016
CointEq (-1)	-0.109	0.048	-2.257	0.036
Long run				
LGAS	0.625***	0.027	2.298	0.000
LGDP	0.969*	0.539	1.796	0.089
LGDP ²	-0.232	0.190	-1.222	0.023
LINCOME	0.035	0.041	0.858	0.402
LFDI	-0.233	0.064	-3.623	0.001
Constant	0.710	0.508	1.397	0.185
<i>F</i> -stat	0.000			

*** *p*<0.01, ** *p*<0.05, * *p*<0.1

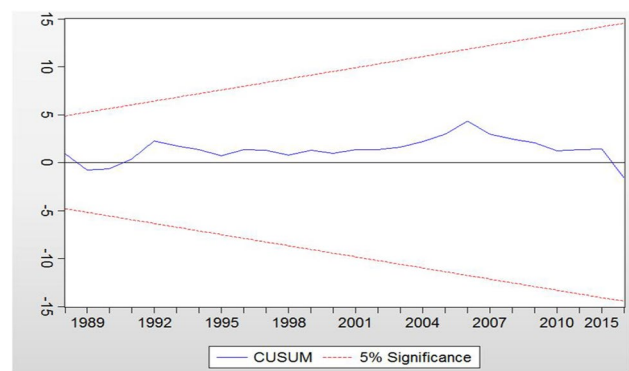


Fig. 8 CUSUM square graphical plot

as test the validity of the standard EKC curve. It also takes into account environmental impacts. CO₂ emissions and other outlined variables exhibit short and long-run associations, as shown by the ARDL bound estimate. By utilizing the ARDL approach, long-run and short-run equations for CO₂ emissions were specified, taking into account the other variables as independent variables and linear and non-linear effects of the variables on CO₂ emissions were investigated. To begin with, according to these findings, CO₂ emissions and economic growth in Iran were in an inverted U-shaped relationship during this period. The estimation results for these data show that per capita CO₂ emissions are positively correlated to GDP and negatively associated with quadratic GDP per capita. This result indicates economic development in Iran initially leads to a deterioration in the environment for a long time; after a certain level of economic growth, a society begins to improve its relationship with the environment, and levels of environmental degradation reduce.

Secondly, along with dramatic increases in Iran natural gas consumption and CO₂ emissions in recent years, a better understanding of the EKC and carbon emissions, economic growth, and natural gas consumption will help the country achieve a low carbon economic development and support the natural gas sector. ARDL results also indicate that natural gas consumption and CO₂ emissions in Iran exhibit a significant negative short-run relationship. Increasing natural gas consumption by 1% will decrease CO₂ emissions by 0.125% in the short run for the ARDL model. This energy source would dramatically reduce carbon emissions if it became a major replacement for other fossil fuels. With this finding, natural gas can serve as a viable alternative to hydrocarbon fuels. In any case, an increase of 1% in gasoline consumption results in an increase of 0.625% in CO₂ emissions, in the long run, suggesting that fossil fuels generally have a negative ecological impact.

Finally, recent results indicate a positive short-term and long-term change in the EKC curve, which will result in increased CO₂ emissions in Iran. A negative correlation

exists between FDI and CO₂ emissions. If foreign investors focus more on energy sectors, such as oil and gas, petrochemicals, telecommunications, and auto manufacturing, they will result in lower CO₂ emissions. According to our previous study, this result is also valid.

According to the main findings of this study, essential policy implications can develop using the following recommendations:

- 1) It is clear that the relationship between CO₂ emissions, economic growth, natural gas consumption, income, and FDI is more complex than what is deduced by the EKC model. Because this study showed natural gas to reduce CO₂ emissions in the short run, natural gas consumption could be considered an efficient alternative to other fossil fuels. It might even prove to reduce CO₂ emissions in the long run. So, to resolve the issue of increased carbon emissions, the development of the natural gas industry should be accelerated in long run. Technology policy includes technology push and demand pull. Although technology support policies have helped significantly in the diffusion and innovation of new technologies, it is often difficult to assess their cost-effectiveness. Despite this, program evaluation data can provide information on the relative effectiveness of policies and help design new policies (IPCC, 2014: Summary for Policymakers)
- 2) Increasing the share of renewable energy such as solar, wind, and other forms of renewable energy and reducing non-renewable energy intensity are still effective ways to reduce carbon emissions. This idea is accessible if the governments can further increase R&D investment to improve energy efficiencies, such as funding the development of low-carbon technologies or participating in the development of the private sector through the appropriate use of renewable energy, unbundling of power generation, transmission, and distribution processes (Shen and Lin 2020 & Adedoyin et al. 2020). Furthermore, the government can promote the use of renewable energy in manufacturing through fiscal subsidies, while simultaneously imposing carbon taxes on the use of fossil fuels (Li et al. 2021). A further suggestion is considering the heterogeneous environmental effects of non-renewable and renewable energy sources. Fossil-dependent countries should diversify their energy source by incorporating renewable energy into their energy mix (Murshed et al. 2021b).
- 3) Policymakers should minimize risk for foreign direct investment (FDI) to maximize its benefits. Environmental concerns can be addressed in several ways, including through effective governance, stakeholder participation, improving local capacities (entrepreneurship, technology, skills, communication), and creating a practical regulatory framework. The regulation of

the environment must therefore be strengthened, since strictly enforcing laws and regulations that protect the environment is likely to prevent inflows of dirty foreign direct investment. On the other hand, the economies of these regions will attract relatively cleaner foreign direct investment, especially for the development of renewable energy through technology (Murshed et al. 2021a). In general, there is an indirect effect of financial risk on global carbon emissions, with an increase in financial risk not only reducing global carbon emissions directly but also promoting technical innovation to mitigate carbon emissions (Zhao et al. 2021).

Although our study has made some contributions, there are still limitations. First of all, this paper tried to access a wide field of information and consider the range of data based on our previous study. However, this analysis can be extended by expanding the database and updating it. Besides, this paper focused on the ARDL method due to the ability to determine the short and long-run relationship between series with different orders of integration. As part of the future scope of research, this method could revise to dynamic simulations of autoregressive distributed lag models. This paper mainly focuses on fossil fuel energy with considering the advantage of using gas comparing other types. The research can be further refined for different kinds of energy like electricity which is cleaner than fossil fuels or renewable energy such as wind or solar in the future.

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