Environmental impact of building construction and energy consumption; case study of Iran

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ABSTRACT
The main objective of the present study is to investigate the determinants of environmental impacts, focusing on the impact of construction and energy consumption on the environment in Iran from 1994 to 2019. The results confirmed the existence of a long-term relationship between the variables of construction, energy consumption, and environmental index. The variables of construction and energy consumption had a positive and significant impact on the country's environmental index. The estimated coefficient for the variable of housing investment also showed a positive effect on the environmental index. In general, it is concluded that to reduce the negative impact of construction on the environmental index, it is necessary to change the old construction styles and instead apply new construction strategies in favor of lower energy consumption and less CO₂ emissions into the environment.

1. Introduction
Economic growth and development depend on how resources and factors of production such as labor, land, machinery, raw materials, energy, and technology are used. The use of these factors in the process of producing and transforming raw materials into goods and services can have an impact on the environment and economic growth has both harmful and positive effects on the quality of the environment (Frankel, 2009). Economists believe that the main economic activities in different sectors of activity, especially industry, are associated with environmental degradation, and resources are not used optimally and efficiently (Khana et al., 2021). From the first decade of the 18th century, the detrimental effect of economic activities on the environment became a controversial issue; in general, environmentalists opposed economic growth from market failure and considered government intervention necessary (Ferrari et al., 2021). Economic growth in its early stages leads to environmental degradation and most of the greenhouse gases emitted in the world are in the form of carbon dioxide, which is due to fossil fuels; therefore the energy sector has the largest share of issues of changing environmental conditions and thus, energy policy and environmental policy are closely related (Beckerman, 1992). The importance of the construction industry and the impact of construction-related activities on the environment, particularly the effects caused by greenhouse gas emissions and global warming, are not lost on anyone and are highlighted by planners as an international concern. An upward movement in housing demand increases the price levels and encourages aggregate investment in this sector, which leads to growth not only in the number of housing production, but the rate of employment, and ultimately Gross Domestic Product. Most of the studies conclude that housing construction investment affects economic growth through five critical channels. An upward movement in housing demand increases the price levels and encourages aggregate investment in this sector, which leads to growth not only in the number of housing production, but the rate of employment, and ultimately Gross Domestic Product (Andersson & Turner, 2005).

At the macroeconomic level, housing sector investment is expected to lead to economic growth if it can increase the level of productivity. Triana et al. (2021) define the productivity in the construction industry through government interventions in the housing market by encouraging investment and improving labor productivity in this sector gaining economic growth ultimately. In this regard, Odugbesan and Rjoub (2020) examined the relationship between economic growth, carbon dioxide (CO₂) emissions, urbanization, and energy consumption in Mexico, Indonesia, Nigeria,
and Turkey (MINT countries) over the years; 1993–2017, and show that there is a two-way causal relationship between energy consumption and economic growth for all MINT countries. Zhang et al. (2014) studied the environmental impact of two-floor residential buildings in Canada and identified five cases with the most widely used materials in building construction and, by performing sensitivity analysis, estimated the role of increasing and decreasing the amount of these materials in the building’s environmental assessment. Sandanayake et al. (2019) examined the effects of building construction on environmental emissions and concluded that building centers and organizations are responsible for significant energy consumption and the production of Greenhouse Gases including carbon dioxide. Yan et al. (2020) studied construction activities and emphasized that the dust produced by construction activities strongly affects the air quality of the environment and the health of people living in the community, especially in the areas around construction sites. The release of various pollutants usually takes place in the stage of demolition, procurement of raw materials, and construction of the building. Enshassi et al. (2015) studied the evaluation of the environmental impact of construction sites in the Gaza Strip region and the results show that the construction sector has direct and indirect negative impacts on the environment, creating dust, noise pollution, and air pollution. Construction activities have a significant impact on the environment during their life cycle that ranges from the initial work during the construction period to the final demolition (Azqueta, 1992; Satola et al., 2020). In this regard, many efforts have been made to optimize construction activities and minimize the destructive and negative environmental impacts of construction worldwide (Hossain & Poon, 2018). For instance, Babak (2017), focused on the impact of construction activities on the environment in Russia and the results showed that the most significant negative effects are generated in the production stage of materials used in building construction. Ametepy and Ansah (2014) investigated the impact of construction activities on the environment in Ghana and showed that the energy consumption group had the most significant effect including electricity and fossil fuel consumption along with noise generation, water consumption, and dust generation, plant removal, and ecosystem interference.

Many countries have a comparative advantage in the use of construction techniques and use this ability to attract foreign direct investment. Like any other active sector of the economy, the construction industry produces a huge amount of waste and pollution with negative externalities on the quality of the environment, which deteriorates the status of human well-being, which is the ultimate goal of policymakers in a welfare society. The experience of developing countries with economies based on oil and petroleum products shows that not only the existence of underground oil reserves should be considered effective in increasing environmental pollution, but also the lack of proper training on how to consume energy is more effective. The findings of recent studies (Liu et al., 2022) show the asymmetric impact of educational spending on clean energy consumption and CO₂ emissions in the economies of Brazil, Russia, and India, showing that positive spending on education leads to increased clean energy consumption. In another important study, Jian et al. (2021) emphasized the impact of non-economic factors on energy consumption and carbon dioxide emissions. Their findings show that population growth exerts a positive pressure on energy consumption and CO₂ emissions, but that training costs in energy efficiency, law and order, and adherence to international obligations can reduce the negative impact on inefficient energy consumption and CO₂ emissions in the long run.

The Iranian economy is composed of four major sectors: Oil and Gas, Industry and Mining, Agriculture, and Commercial Services, with the maximum presence of the government, directly and indirectly, in the provision of products and financial services, advice, and supervision. Activities related to housing construction and its executive operations are of great economic importance in developing countries, including Iran, due to the high share of value-added in GDP. The housing sector in Iran is usually responsible for the construction of residential buildings to meet the housing needs of the people and households in the community, as well as the construction of commercial buildings with the participation of the private, cooperative, governmental and semi-governmental sectors; using the financial support of the credit facilities of the banks and the technical services of the governmental institutions (Sepehrdoust, 2013). Among the government institutions in Iran, we can mention the important role of the two main organizations, namely the Ministry of Housing and the organization Urban Development and Housing Foundation in approving, implementing, and monitoring special construction projects and the construction of buildings (Iranian Government News Agency, 2021).

Energy consumption figures, followed by the production of greenhouse gases and harmful to clean air, have been increasing over the decades so the increase of pollutants such as carbon dioxide and methane gas has affected the temperature of the earth’s atmosphere and increased it. Bad weather conditions and the
presence of various environmental pollutants in the country and recent years have drawn the attention of many planners to the factors that increase environmental pollution in the country. Regarding the impact of macro variables on environmental pollution, some researchers (M.T. Sohail et al., 2022) argue that political stability reduces environmental damage by reducing CO₂ emissions in the long run. These researchers believe that political instability not only reduces the consumption of clean energy but also leads to damage to environmental quality in the long run. Following the relationship between economic instability and environmental pollution, Sohail, Ullah et al. (2021) investigated the symmetric and asymmetric effects of the shadow economy on clean energy and air pollution in South Asian countries, and the findings show that the negative components of the informal sector economy (shadow economy) increases CO₂ emissions in Bangladesh and Nepal. These results provide important policy implications for achieving clean energy and better environmental quality in South Asian countries. Among the factors affecting pollution is the unhealthy and unplanned process of housing construction. The construction industry is the least environmentally friendly industry with profit motivation for builders and is expressed as an industry that destroys the environment instead of protecting it (Kein et al., 1999 & Li et al., 2015). Energy consumption is one of the most important factors of production and can always be extracted as a function of the level of production. One of the factors affecting economic instability is the existence of disorder and uncertainty in the money market of the economy, which can hurt the environment with non-optimal energy consumption. In this regard, Sohail, Xiuyuan et al. (2021) examined the asymmetric effects of monetary policy uncertainty on energy consumption and concluded that increasing monetary policy uncertainty in the United States has negative effects and reducing monetary policy uncertainty has positive effects on non-renewable energy.

(Sohail, Xiuyuan et al., 2021). Like any other factor of production, energy consumption depends on the level of economic activity in the production process, which in developing countries is strongly influenced by economic growth. In this regard, studies conducted for the economic development of tourism countries of the Association of Southeast Asian Nations (ASEAN) show that the consumption of renewable energy can have a positive impact on tourism and economic growth by reducing environmental pollution (Khan et al., 2022).

Based on the theoretical and empirical literature in economics, the impact of private and public construction investment on the environment can be studied from two perspectives. According to the first approach, it is expected that with the increase and growth of the factor of capital, there will be an increase in the volume of economic activities and eventually the growth of the country’s GDP. In this view, an increase in the volume of GDP is associated with increased energy consumption and hence increased emissions (Sohail, Ullah et al., 2021). According to the second approach, known as the optimistic and compensatory view, any increase in investment and increase in GDP brings technological changes and the use of technology in the construction process, resulting in environmentally friendly technologies instead of old technologies that emit fewer pollutants and thus improve the quality of the environment. The study of the relationship between economic growth and the index of environmental degradation is critical and necessary for each country now (Pablo-Romero Gil-Delgado et al., 2017). Recent studies show a systematic direct relationship between greenhouse gas emissions as substitutes for environmental effects and different fundamental and structural dimensions such as the size of the financial market and construction industry composition, which results in the positive effect of housing construction investment on environmental quality (Borghesi & Vercelli, 2003).

The results of an empirical study of Central European countries conducted by Khanb et al. (2021) show that there is a relationship between the health, economic and environmental factors using green energy so that the use of fossil fuels has a negative destructive effect on the quality of the environment and the risk of disease and respiratory system. Increases and thus increases the mortality rate. Moreover, Karasoy and Akçay (2018) examined the effects of renewable and non-renewable energy consumption as well as trade on environmental pollution concerning the environmental Kuznets curve (EKC) in Turkey during the period 1965-2019, and the results confirmed that the increase in trade and consumption of non-renewable energy, in the long run, caused carbon emissions and environmental pollution, while renewable energy consumption reduces emissions in both the short and long term.

On the other hand, the high consumption of natural resources and energy in the construction sector dramatically generates many socio-economic changes such as environmental indices through the emission of greenhouse gasses and construction waste. The emission of carbon dioxide (CO₂) into the atmosphere in large quantities has been identified as a major contributor to pollution and climate change. Global warming, rising sea level and temperature, fluctuating temperature events, and various extinct species threaten the planet (Sundarakani et al., 2014). Empirically, increasing energy consumption at transitional stages of
development has often raised the emission of pollutants into the environment of developing countries. In this connection, Shim (2007) describes the relationship between energy consumption and environmental degradation as; after the industrial revolution, especially in recent decades with more energy use, the average factor productivity increased, but its polluting effects destroyed the environment. Achieving the economic goals of eradicating poverty and reducing environmental degradation have become two interrelated challenges, and countries continue to place great emphasis on achieving poverty alleviation and reducing the environmental pollution. Findings from recent empirical studies in China and India to examine the effect of economic poverty on carbon dioxide (CO₂) emissions in both countries showed that a long-term increase in poverty leads to increased CO₂ emissions in India and China have been and poverty is the main source of pollution (Jiang et al., 2021).

The problem of air pollution in Iran, especially in urban areas, has become a socio-economic challenge for the people of the country and has made normal life difficult (Iranian Government News Agency, 2021). For Iranians, owning a house, in addition to consumption goals and the nature of demand for housing, also has investment goals, so owning housing not only meets people’s housing needs but is also an effective means of maintaining the value of assets compared to other investment opportunities such as buying shares from the stock market, investing in buying and selling foreign currencies, as well as buying cars and gold have lower investment risk.

In summary, the past studies have focused more on the relationship between energy consumption, environment, and economic growth, while this study aims to concentrate on the environmental impacts of building construction in Iran concerning energy consumption; using the ARDL method to analyze three important independent variables that are residential housing construction (RHC), housing sector investment (HSI), and household energy consumption (HEC) for the period 1994 to 2019.

2. Material and methods

To study the environmental impacts of building construction and energy consumption in Iran, the estimation model of this research inspired by the study of Lavagna et al. (2018) is introduced in Eq. 1 as follows:

\[ lCO_2 = \beta_1 + \beta_2 LHEC + \beta_3 LHSI + \beta_4 LRHC + u_t \]  

(1)

Where; the variable \( lCO_2 \) indicates the logarithm of environmental effects in terms of CO₂ emissions in metric tons, \( LHEC \) indicates the logarithm of household energy consumption in terms of petroleum products, coal, natural gas, electricity, and combustible renewable sources used in the household sector equivalent to crude oil barrels), \( LHSI \) indicates the logarithm of housing sector investment in terms of billion Rials, \( LRHC \) indicates the logarithm of residential housing construction in terms of the number of housing units constructed during the period of study. Moreover, \( u_t \) indicates the stochastic error term in the econometric model and \( \beta_2, \beta_3, \text{ and } \beta_4 \) are the dependent variable’s elasticity to the explanatory variables. The research estimation model is based on time-series data over the years; 1994-2019 in Iran. The relevant data for CO₂ emission quantity is collected from the World Bank database and data for energy consumption is collected from the world energy balance sheet. Data for housing sector investment and residential housing construction are collected from the database bureau of the Central Bank Iran.

3. Results and discussion

The analytical objective of the study was to examine the short-run and long-run relationship of the variables most responsible for the environmental impacts such as building construction and energy consumption in Iran from 1994 to 2019; using the auto-regression distributed lag model (ARDL), diagnostic and error correction tests. Table 1 represents the descriptive statistics of the variables.

| Variable       | Observation | Average | Min    | Max    | Std. Dev |
|----------------|-------------|---------|--------|--------|----------|
| CO₂ (metric-ton) | 26          | 79.04   | 35.16  | 106.69 | 22.99    |
| HEC (Million barrels) | 26          | 269.60  | 139.60 | 402.30 | 269.60   |
| HSI (billion Rials) | 26          | 210,315.7 | 29.44  | 810,562.6 | 267,726.9 |
| RHC (Housing units) | 26          | 166,662 | 94,232 | 263,491 | 43,956.45 |
variable CO₂ emission, the value of the computational statistic is greater than the value of the McKinnon table, so we can conclude that this variable is stationary at the level (I₀). The variables of housing construction investment (HSI), household energy consumption (HEC), and construction are stationary with first differentiation, and the application of the ARDL method is confirmed.

3.2 Model Estimation (ARDL)

The obtained value of the coefficient of determination \( R^2 = 0.97 \) in Table 3, shows the high explanatory power of the model. According to the results, the null hypothesis is rejected and indicates the significance of the model.

3.3 Diagnostic tests

The diagnostic test results of the functional form of the model in Table 4 show that at an error level of 0.05, the hypothesis of the correct functional form cannot be rejected. The result of the homogeneity variance presence test shows that there is no heteroskedasticity of variance. The results of the serial autocorrelation test show the absence of any autocorrelation of the error term. Moreover, based on the results of the normality test and considering the error level of 5 percent, it can be said that the null hypothesis about the normality of the error distribution is accepted and the error distribution is normal.

### Table 2. Results of augmented dickey fuller test

| Variable | Stationary level | Critical Value (5%) | Statistic | Prob. |
|----------|------------------|---------------------|-----------|-------|
| LCO₂     | I₀               | −2.99               | −3.59     | 0.01  |
| LHSI     | I₁               | −3/62               | −3.83     | 0.03  |
| LHEC     | I₁               | −3.61               | 7.91      | 0.00  |
| LRHC     | I₁               | −3.61               | −4.40     | 0.00  |

### Table 3. Model estimation results of ARDL (1,0,0,0)

| Variable | Coefficient | Statistic | Prob. |
|----------|-------------|-----------|-------|
| LCO₂     | 0.396       | 3.46      | 0.00  |
| LHSI     | 0.029       | 0.98      | 0.03  |
| LHEC     | 0.285       | 2.59      | 0.01  |
| LRHC     | 0.071       | 2.71      | 0.01  |
| C        | −0.125      | −0.23     | 0.81  |
| R² = 0.97| D.W = 2.561 | F = 15.16 | Prob. (0.00) |

### Table 4. Diagnostic tests

| Statistical Test       | Statistic | Prob. |
|------------------------|-----------|-------|
| Ramsey Reset           | F (19,1) = 3.06 | 0.09 |
| ARCH                   | 0.152     | 0.70  |
| Serial Autocorrelation | 1.92      | 0.17  |
| Normality (Jarque—Bera) | J-B = 1.97 | 0.37 |

### Table 5. Long-run ARDL model estimation

| Variable | Coefficient | Statistic | Prob. |
|----------|-------------|-----------|-------|
| LHSI     | 0.048       | 1.11      | 0.007 |
| LHEC     | 0.473       | 2.24      | 0.03  |
| LRHC     | 0.118       | 2.79      | 0.01  |
| C        | −0.207      | −0.23     | 0.008 |

3.4 Long-run relationship test

In the next step, the long-run relationship of the variables is examined. The results of the long-run estimation are shown in Table 5. Based on these results, all coefficients obtained from model estimation, are significant and compatible with the relevant theoretical foundations discussed. Each of the coefficients of the variables shows the elasticity of carbon dioxide emissions to that variable.

The coefficients of the investment variables, energy consumption, and construction are equal to 0.048, 0.473, and 0.118. This means with a one percent increase in investment variables, energy consumption, and construction, assuming other factors are constant, carbon dioxide emission increases by 0.048, 0.473, and 0.118. Thus, the long-run equilibrium relationship between the logarithm of CO₂ emission quantity as a dependent variable and residential housing construction (RHC), housing sector investment (HSI), and household energy consumption (HEC) variables as explanatory variables are as Eq. 2.

\[
EC = LCO₂ - (0.0484 * LHSI + 0.1185 * LRHC + 0.4732 * LHEC - 2080.0)
\]  

(2)

As the results show, the long-run coefficients of the logarithm of the energy consumption and construction variables are significant at the 95 percent level. Therefore, it can be said that the results of the relationship between residential housing construction, housing sector investment, and household energy consumption variables with CO₂ emission quantity are positive and significant.

3.5 Error correction model estimation (ECM)

After considering the long-run results and ensuring that the long-run regression is not spurious, the error correction model (ECM) can be obtained which indicates the adjustment of the short-run fluctuations toward the long-run equilibrium relationship and directly estimates the rate at which a dependent variable adjusts to the equilibrium level after a change in other variables. The presence of convergence among a set of economic variables provides the basis for error correction models. The
Table 6. Error correction model estimation (ECM)

| Variable | Coefficient | Statistic | Prob. |
|----------|-------------|-----------|-------|
| Coint. Eq (−1) * | −0.60 | −8.72 | 0.00 |

The error correction model relates short-run fluctuations in variables to their long-run values. In the study, the ECM error model was used to examine the short-run relationships between CO₂ emission quantity as the dependent variable and the variables of residential construction (RHC), residential investment (HSI), and household energy consumption (HEC) as explanatory variables. The error correction coefficient in Table 6 shows the speed of adjustment of the dependent variable. The error correction coefficient is estimated to be (−0.60), indicating that 60 percent of the disequilibrium is corrected to approach a long-run relationship in each period. The ECM coefficient in the model is negative and less than one and is significant, confirming the existence of convergence in the model.

4. Conclusions

The main purpose of the study was to investigate the environmental effects of energy consumption, housing investment, and construction sector investment in Iran from 1994 to 2019; using auto-regression and the error correction analysis method. The necessity for raising the problem and choosing the study was existing environmental problems that threatened the whole society and the concerns of the people living in Iran for undesirable environmental impacts during the last decades. The problem was aggravated by full wide financial and economic sanctions imposed by the U.S government over the last decade. Therefore finding out the factors that are more effective and responsible for environmental deterioration has become important. Among the principal factors is the building construction sector including residential buildings due to its high energy consumption.

The results of the model estimation show that the influence of construction is positive and significant. According to the results, a one percent increase in construction activity leads to 0.071 percent environmental degradation in the short run and 0.118 percent in the long run in terms of CO₂ emission. Considering the positive impact of construction on environmental pollution in Iran, planners must take the issue seriously and propose effective measures to eliminate uneconomic externalities caused by those construction activities that do not meet environmental standards in the production process. The results show that while motivating investment in housing strengthens economic growth and has positive externalities for the economy, the environmental effects of an investment in housing are positive in the long run. Promoting public awareness of the consequences of environmental degradation will do much to encourage the adoption of appropriate construction methods to improve construction quality, recycling of construction materials, and clean air. If environmentally-friendly construction methods and materials are used for such activities, the field of civil engineering can be very effective in reducing environmental damage.

The results of model estimation in the short run also show that the effect of energy consumption on the environment and CO₂ emission in Iran during the study period is positive and significant. Based on the estimated coefficient, a one percent increase in energy consumption increases the negative impact on the environment by 0.285 percent in the short run and 0.473 percent in the long run. Considering that energy consumption is one of the factors affecting environmental pollution, reducing fossil energy consumption can be proposed as a solution toward sustainable development and green economic growth by investing in renewable energy. In general, the activities of the construction industry must be directed towards environmental safety measures in terms of reducing the consumption of heating, cooling, and electrical energy and increasing the energy efficiency of the building.

Consideration of the various factors involved in the level of building energy consumption has a major impact on the provision of energy-saving solutions in the building sector and the reduction of energy consumption in the residential sector. Climatic conditions, building architecture, building materials, the efficiency of heating systems, the use of equipment with the required capacity effective in the heat load of the building, and also the control of heating systems are effective factors in the level of heating energy consumption. The role of materials in reducing pollution from construction also cannot be ignored. Estimates show that about 40 percent of the country’s energy consumption is attributed to the provision of building materials and housing production, which is a very high figure compared to other sectors such as industry, transport, agriculture, and services. This underlines the need to save energy both before construction and during the operation of the building and highlights the need to look for “low-consumption buildings” and “green buildings” to adapt to the environment and reduce energy consumption.
In summary, to reduce residential energy consumption, it is recommended that building designers take steps to minimize energy waste in the building, such as implementing high-performance windows, solar water heaters, and insulating the walls, roof, and floor of the building. In addition, substituting renewable energy sources such as wind, solar, and geothermal energy can have a positive and significant impact on the inhabitants of emerging economies. Obviously, by expanding green growth activities in the service and industry sectors, the health costs of environmental pollution can be reduced.

**Availability of data and materials**

Data are available on request after publication.

**Consent for publication**

All authors have seen and approved their consent for publication.

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