EXPONENTIAL ECONOMIC GROWTH OF HUNGARY: ANALYSIS OF THE IMPACT OF ECONOMIC GROWTH AND RENEWABLE ENERGY ON CARBON EMISSIONS

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Abstract

Hungary is aiming to increase its economic growth by establishing robust economic relations with China. China is also investing heavily in Hungary in areas such as technology, infrastructure, and energy. On one side, economic development is desirable for uplifting the living standards of the common masses, but at the same time, it also carries out very serious and injurious impacts on the environment of any country. In this article, we have analyzed the impact of economic growth on the carbon emissions of Hungary. We took annual time series data for the dependent variable (carbon emissions — CO_2) and explanatory variables (gross domestic product — *GDP*, renewable energy — *REW*) from the World Development Indicators (WDI) for the period ranging from 1990 to 2020. This study applies the autoregressive distributed lag (ARDL) Bounds testing approach to annual data from 1990–2020 to examine the long-run relationship between economic growth, renewable energy, and carbon emissions in Hungary. Results confirm a significant negative impact of renewable energy on carbon emissions, while GDP's impact is positive but insignificant. Furthermore, renewable energy is also unidirectionally granger-causing CO_2. The study contributes to understanding Hungary's sustainability pathway and recommends policy measures for enhancing renewable energy integration.

Keywords: Hungary, China, Economic Growth, Renewable Energy

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1. INTRODUCTION

Economic development often leads to increased carbon emissions due to higher industrial activity, energy consumption, and transportation needs. As economies grow, there is typically greater demand for energy, much of which is still sourced from fossil fuels such as coal, oil, and natural gas, leading to higher greenhouse gas emissions. Additionally, urbanization and the expansion of infrastructure contribute to a rise in emissions through construction activities and increased vehicle use. However, the relationship between economic development and carbon emissions is not entirely linear. With advancements in technology and the implementation of green policies, countries can decouple economic growth from carbon emissions, transitioning to renewable energy sources and adopting more efficient practices that mitigate environmental harm. In this way, economic development can potentially promote sustainability if paired with concerted efforts toward reducing carbon footprints. Like other countries, Hungary is striving to achieve economic development; in this regard, it is busy establishing robust economic relations with China as well.

In the 21st century, almost all nations worldwide have endeavored to enhance their relations with China, which is now the second-largest global economy and has a significant influence on international affairs. Governments are drawn closer to Beijing because of the economic advantages that may be gained from such collaboration. Both Europe and Hungary, including their governments, are unable to withstand these global upheavals. However, the way Hungarian people see and interact with the rapidly developing powerhouse of the East remains uncertain (Budd, 2021). After successfully integrating into the Euro-Atlantic region, Hungary was among the first nations in Central and Eastern Europe (CEE) to see China as a potentially significant international player. Since 2003, every Hungarian prime minister has visited Beijing; Budapest hosted the first summit of CEE nations and China in 2011. Budapest receives considerable attention from Beijing due to its substantial Chinese population, growing Chinese investment, strong bilateral cultural relations, and favorable political gestures by the Hungarian government (Vörös & Bretter, 2022).

Hungary attracted the highest level of foreign direct investment (FDI) from China. FDI is considered as one of the major driving forces behind gross domestic product (GDP) growth, and it also acts as a means for transferring the latest technologies to the host countries (Kayani et al., 2024; Kayani & Sadiq, 2022). The government anticipates that Hungary might have a significant impact on the Belt and Road Initiative (BRI) via its involvement in the Budapest-Belgrade railway link.

Hungary has a significant position as a trading partner among the 28 members of the China-CEE alliance, known as 17+1. However, multinational corporations generally dominate international trade (Marácz, 2022). The pleasant ties between the Hungarian government and China remained unaffected by the COVID-19 pandemic, which is remarkable. Official statements refrained from attributing blame to Beijing for the spread of the pandemic. Instead, they highlighted the substantial quantities of medical equipment that China has provided to Hungary. Concurrently, the general

attitude of the people towards China has greatly worsened, and the divide between the government's pro-China policies and the unfavorable sentiments of the public has been more profound than ever. This study offers an analysis of the accomplishments of the Sino-Hungarian collaboration and the consequences of the coronavirus outbreak on the relationship between the two countries (Antràs, 2020). The People's Republic of Hungary formally acknowledged the People's Republic of China on October 4, 1949, shortly after its establishment. Over the next decade, this relationship progressed swiftly, with several high-level visits occurring because of improved economic, political, and cultural connections (Strauss, 2007).

According to Turcsányi and Qiaoan (2020), owing to Hungary's historical communist background, both the People's Republic of Hungary and subsequently the Republic of Hungary unequivocally endorsed China's stance on Tibet, the One China Policy, and its participation in the United Nations Security Council right. Nevertheless, the relationship between China and the Soviet Union significantly worsened during the Sino-Soviet split and China's Cultural Revolution in the 1950s and 1960s. After the Communist Party of China underwent a reorientation and Deng Xiaoping's Reform and Opening-up Policy was put into effect in 1978–1979, the two nations slowly restored their bilateral relations. Due to their keen interest in the economic reform process of 1968, the Chinese leadership sent many teams to Hungary to thoroughly analyze the outcomes of the short-lived changes (Gewirtz, 2022). Diplomatic relations between the parties were restored to a normal state, and official visits between high-ranking officials resumed throughout the 1980s.

The political upheaval that occurred in Hungary in 1989 resulted in another cycle of depreciation of bilateral ties, as discussed by Ljungberg (2024). This was because Budapest was obsessed with its integration into the Euro-Atlantic region, while at the same time, contacts with communist nations became less appealing. Over a decade has passed during the period of low-profile relations, and Hungary did not begin to engage in reconciliation with the United States until 2003. In 2003, after joining the European Union (EU) and the North Atlantic Treaty Organization (NATO), Hungary recognized the potential of developing countries such as China. In that year, Hungarian Prime Minister Péter Medgyessy toured Beijing and established a new specialized post inside the Prime Minister's Office to promote the growth of Hungarian Chinese ties. The role also included coordinating public administration and governmental agencies' efforts toward China (Tarrósy & Vörös, 2020). In 2004, President Hu Jintao arrived in Budapest, which was a return visit of the Prime Minister. Although the first term of the Orbán Government from 1998 to 2002 expressed negative views towards China, the second and third terms (2010–2014 and 2014–2018) also showed a significant interest in China. This shift in focus may be attributed, in part, to economic and political turmoil in the EU (Matura, 2020).

In 2011, Hungary implemented the Opening to the East Policy in response to the 2008 global economic and financial crisis, aiming to explore new options for its recovery from a recession. It should be emphasized that this policy has not been officially documented as a strategy. However,

according to government declarations, the objective was to enhance Hungarian exports to non-European areas and attract more FDI to the nation (Király, 2020). Orbán decided to establish formal diplomatic ties between his party and the Communist Party of China before the 2009 election. Subsequently, as Prime Minister, he visited China at the end of 2010. His choice to cultivate robust connections with Beijing astounded many analysts, given that his last administration showed far less amicability towards China. He even met with the Dalai Lama in his official capacity in 2000. Premier Wen Jiabao reciprocated Mr. Orbán's visit by traveling to Budapest in May 2011. This visit also marked the first stage of establishing the annual China-CEE summit, which took place in Warsaw the following year (Matura, 2020). Jones and Zeng (2020) discussed in their study that providing a comprehensive scientific examination of the Opening to the East is challenging since there has been no concrete plan developed beyond mere platitudes.

Prime Minister Viktor Orbán said in 2010 that while aligned with Western values, the global economy was influenced by Eastern forces. As a result, the administration took steps to enhance trade and investment ties with nations outside the European Economic Area. Over time, the government's sectoral policies have outlined increasingly complex objectives. According to Völgyi and Lukács (2021), the Hungarian Growth Plan of the Ministry of National Economy outlines that Hungarian firms might potentially achieve greater profits by expanding their exports to rapidly emerging economies, such as China, India, Russia, and South Korea, which have increased import demands. Regarding Asia, it is anticipated that Hungarian exports will increase at a rate twice as fast as the regional average. By 2015, it was projected that Hungarian exports would account for 10% of the market share, up to the present 6%. The official communications indicate that the administration implemented an economically focused strategy of engaging with the East in line with global trends. Sino-Hungarian relations have a prominent place on the agenda of all major political parties despite the otherwise divided domestic political landscape. All parties acknowledge the significance of China, and liberal parties refrain from discussing human rights or other politically delicate matters.

The efforts of the Orbán administrations that came before them have not only been maintained by the second and third administrations, but they have also been enhanced to cultivate positive political ties with Beijing (Vámos, 2018). Since 2003, every administration in Hungary has tried to establish collaboration with China in the areas of commerce and investment. It is widely acknowledged that strong political connections are an essential instrument and the basis of business relationships. For the last decade, the main objective has been to enhance and reorganize the exchange of goods and services between the two countries while also reducing the deficit. In the wake of the economic upheaval in Europe, Chinese investments have assumed unprecedented significance (Kowalski, 2017). The successful institutionalization of the China-CEE project in Warsaw in 2012, after the inaugural summit in Budapest in 2011, demonstrated its evident success as reported by Kavalski (2018). The establishment of the Secretariat for China-CEE cooperation marked a significant step forward in the advancement of collaboration in September 2012.

The Hungarian government closely monitors the 16+1 collaboration, with a particular focus on the economic aspects of the program. It aims to use its relationship with China as a strategic advantage in negotiations within the EU.

Nevertheless, after the first years of the 16+1 initiative, interest has waned in Hungary. The administration has announced many significant Chinese infrastructure investments in the nation, but none of these projects has been realized thus far (Kowalski, 2017). According to Rencz (2019), the Budapest-Belgrade railway line represents the last opportunity and has significant importance for China. It is considered a vital component of the BRI project and the north-south transport corridor that extends from Piraeus through Central Europe to Western Europe. At the 3rd China-CEE conference in Belgrade, held in December 2014, agreements were formally inked. As per the initial schedule, the line was assumed to be completely operational by 2017. However, considering these delays, it seems that 2025 is a more realistic timeframe. The European Commission commenced an infringement process on the Sino-Hungarian agreement, prompted by legal concerns. However, this process did not ultimately disrupt the entire project and was finally resolved (Tzogopoulos, 2021).

The central problem addressed in this study is understanding how Hungary's economic growth trajectory affects its environmental sustainability, specifically in relation to carbon emissions. The role of renewable energy in mitigating these emissions is also analysed to inform Hungary's alignment with the EU Green Deal goals. In simpler words, this study aims to assess:

- whether Hungary's economic growth influences carbon emissions;
- the role of renewable energy in mitigating such emissions.

Grounded in the environmental Kuznets curve (EKC) hypothesis, this research evaluates the balance between industrial expansion and environmental sustainability.

The rest of the article is organized as follows. Section 2 comprises of extensive literature review. Section 3 describes the data and methodology. Section 4 details the results and their interpretation. Section 5 concludes the article.

2. LITERATURE REVIEW

2.1. Hungary's and China's foreign policy

Hungary's and China's foreign policy towards one another is marked by a diverse strategy that encompasses economic, political, and cultural interchanges. China has aimed to enhance its economic connections with Hungary by facilitating trade and investment via this effort. Chinese investments in Hungary include many areas such as technology, infrastructure, and energy, thus fostering Hungary's economic growth and upgrading its industry. The BRI is a worldwide development plan proposed by China to improve connectivity and commerce throughout Eurasia, serving as a key route for collaboration. Hungary actively engages in the BRI, contributing to various infrastructure endeavors such as the establishment of new transportation connections and enhancements to present networks. These initiatives not only enhance commerce between China and Hungary but also

further integrate Hungary into global trade channels (Li & Taube, 2018). As discussed by Baláž et al. (2020), Hungary is considered a main target for Chinese investment for many reasons, including its substantial Chinese population, the region's sole Chinese Hungarian bilingual elementary school, and the CEE headquarters of the Bank of China.

Despite several announcements and the laying of many foundations, there have been relatively few concrete accomplishments, and even those have been limited to investments of just a few million dollars. However, Hungary has a crucial position in the CEE area in terms of the total amount of Chinese direct investment. By the end of 2015, the accumulated Chinese investment in Hungary had reached USD 3.5 billion, as reported by Völgyi and Lukács (2021). Undoubtedly, the currently available statistical data exhibits a significant degree of ambiguity. According to the Hungarian Government, the amount of Chinese investment in the nation was approximately USD 4 billion. However, the Rhodium Group has documented a total of EUR 2 billion in transactions since 2000 (Kratz et al., 2025).

Regrettably, Hungary has not yet seen significant greenfield investments in its key industries despite the pressing need for employment creation in the nation. Several significant agreements were struck during Premier Wen Jiabao's visit to Budapest in 2011 and Vice-Premier Li Keqiang's visit in 2012. During his visit to Hungary, he saw a signing ceremony of seven bilateral agreements. For instance, there is a rail link in Budapest constructed by the Chinese.

Additionally, there is an agreement between the China Development Bank and the Hungarian Ministry of National Economy for a credit line of EUR 1 billion. Another agreement exists for collaboration between small and medium-sized enterprises. However, most of them only reaffirmed agreements from the previous year. None of the intended infrastructure development or collaborative investment projects has been accomplished to date (Mitrović, 2014). As part of the China-CEE collaboration, Hungary gained access to additional financial resources from China in 2013, as reported by Rózsás (2017). The Hungarian Exim Bank and its Chinese counterpart signed an agreement for a credit line of EUR 100 million to support export finance. A Chinese Central Eastern European Investment Fund valued at USD 500 million was founded, including a commitment of USD 30 million from Hungary. Owing to the limited number of successful initiatives, it is difficult to identify any obvious strategic-level motives in China. Chinese investment in Hungary is primarily driven by its advantageous geographic position, which provides easy access to EU markets, as well as the favorable political and investment climate at the corporate level. Undoubtedly, the 16+1 collaboration and Hungary's involvement in it have garnered further interest in China. However, the influx of Chinese government and corporate delegations has not yet resulted in concrete outcomes (Ramasamy & Yeung, 2022).

In contrast to several Western European nations and the United States, heightened Chinese involvement has not caused any concern among Hungarian political circles or the public. On the contrary, there seems to be consensus across political parties on the significance of maintaining relations with China, and none of the prominent political figures are against establishing ties with Beijing. This is mostly because of the generally favorable perception that many Hungarians have of the Chinese population, which makes it difficult for any political party to garner domestic political backing by criticizing China. Therefore, Prime Minister Orbán has often cited China as a commendable model of a prosperous society that prioritizes labor, contrasting it with Western economies that rely heavily on speculation (Bohle & Regan, 2021). However, the absence of significant Chinese investment in recent years has clearly resulted in a drop in public interest in the issue, and as a result, no security or political concerns have been raised. From a strategic standpoint, Hungary has high expectations for the potential of Chinese investment, notwithstanding the few tangible outcomes thus far, as per Matura (2021).

Although the Opening to the East program lacks a well-defined and refined plan, official media indicates that the primary goal of government efforts is to attract financial resources and investments from China to Hungary. Some people see it as a mere political label created by the Ministry of Foreign Affairs to obtain political backing. According to Szabó and Jelinek (2023), in recent years, Budapest has shown a strong desire to cultivate a close relationship with Beijing, to the extent that the government has provided significant political benefits to China, even in opposition to the EU's wishes. Many international observers were intrigued when the Hungarian Ministry of Foreign Affairs echoed Chinese statements on the South China Sea issue in 2016. Similarly, in May 2017, the Prime Minister signed a joint communique on the BRI, despite the objections of the EU and its prominent member states (Sarsenbayev & Véron, 2020). Moreover, according to a recent Handelsblatt article on a report compiled by EU ambassadors that harshly criticizes China's BRI, only the ambassador of Hungary declined to affix his signature to the report. It is unsurprising that an increasing number of experts inquire whether the substantial quantity of global political capital that Hungary has invested in China will ever yield economic benefits, or whether the government views China more as a partner in politics than a source of revenue.

Political adversaries of the governing party contend that the government's endeavours to establish a closer relationship with Beijing (and Moscow) are an attempt to undermine Brussels, with economic considerations constituting a tangential aspect of this tale. Regardless of the Hungarian side's intentions, the precedent has been established, and CEE nations, such as Poland, the Czech Republic, and Slovakia, are all seeking to strengthen ties with Beijing. Beyond economic collaboration, China and Hungary have maintained steady and mutually advantageous diplomatic ties. Consistently, high-level discussions and political conversations have been convened to deliberate on bilateral and global matters, thereby cultivating an atmosphere of collaboration and reciprocal regard. China has repaid Hungary's backing on several global problems by participating in dialogue concerning subjects of significance to Hungary. Additionally, cultural interactions have contributed to the improvement of relationships between the two nations. By means of historical events, linguistic programs, and educational exchanges, China and Hungary have endeavoured to strengthen interpersonal relations and promote greater mutual communication. These exchanges contribute to the development of a solid

groundwork of benevolence and trust, which can serve as a catalyst for more extensive collaboration in subsequent domains.

2.2. Hungary's alignment with the Belt and Road Initiative

Hungary actively contributes to the BRI at the regional level, even though the terms "OBOR" (One Belt and One Road) and "BRI" are not commonly employed within the nation. The fundamental rationale is that the collaboration between Budapest and Beijing primarily occurs mutually or within the context of the 16+1 network, which comprises China and CEE nations. As BRI would imply an additional layer or designation, it is uncommon for political figures to make any reference to it, and media outlets often overlook it entirely. Nonetheless, at least two significant undertakings within the nation are classified as BRI-related initiatives. The most prominent among them is the redevelopment of the railway network connecting the capitals of Hungary and Serbia, a project that was initially agreed upon by China, Hungary, and Serbia in 2013. An agreement worth EUR 1.5 billion has been granted to a consortium consisting of China Railway Group (CRG), China Railway Corporation (CRC), and the Hungarian State Railways (HSR) for the renovation of the 160 km long Hungarian segment. To make it to Belgrade, another 180 km will be constructed in Serbia; with the capacity of the new routes, trains can accelerate to a maximum of 160 km per hour ("Serbia unveils Chinese-built", 2024).

Regarding the financial context, China Exim Bank will offer an extended loan to the Chinese side in the amount of 85% of the total spending plan. Regrettably, the contract's most critical provisions remain undisclosed; however, the prevailing consensus among analysts is that the interest rate could be approximately 2.5% (European Systemic Risk Board [ESRB], 2016). This figure is deemed unfavourable to Hungary, particularly considering that the project primarily caters to Chinese interests. By utilizing this improved transportation corridor, containers originating from China could potentially reach the core of Europe more quickly and efficiently. Simultaneously, the Chinese Government provides its own construction firms with the chance to construct a reference project within the EU's borders, thereby mitigating their overcapacity concerns and generating potential investments for Chinese surplus capital by itself. In contrast, the Hungarian side anticipates some transfer costs as an immediate advantage of the initiatives; however, professional projections suggest that, considering current fees and prospective maximal shipping volume, the initiative would pay for itself across 2,400 years. Hence, China appears to place a higher priority on the development than Hungary does; consequently, it would have been reasonable to anticipate that Hungary would leverage its advantageous negotiating position throughout the negotiations. Nonetheless, the Chinese party appears to gain from the final contract. The Chinese Exim Bank will generate a respectable revenue on the funding itself, Chinese shipments will be hauled on the newly constructed route, and the Chinese construction firms CRG and CRC will be compensated for their efforts.

Hungary, in the meantime, will acquire a degree of significance in the transportation network of Central Europe; some Hungarian firms will have the opportunity to serve as consultants on the initiative; and Budapest may earn a higher geopolitical status in Beijing. Without a doubt, Hungary would benefit considerably more from implementing a plan to entice foreign (Chinese) capitalists to industrial regions across the railroad corridor for the purpose of constructing shared services centers, manufacturing facilities, and logistical centres — ultimately, to generate employment. It is also true, nevertheless, that a significant number of Hungarians have emigrated in recent years, resulting in a labour deficit that has become a major issue for the nation at present. However, such an approach does not currently exist, or at the very least, no one is aware of it. The second undertaking is a collaboration between OBOR and 16+1 in the tourism industry. Hungary, in accordance with the Bucharest Guidelines for Cooperation between China and European Countries, has had the honour of hosting the China-CEE Countries' Tourism Coordination Centre (TCC) in Budapest since May 2014. This is in accordance with Hungary's membership in the 16+1 cooperation. The Beautiful China, Silk Road's advertising campaign was launched shortly after the China National Tourism Administration established its inaugural office in the CEE territory in Budapest.

Notwithstanding the significance of the initiatives, China has yet to execute any noteworthy approaches for marketing or promoting the BRI in Hungary. The Chinese embassy in Budapest maintains a low profile, and while ambassadors may make passing references to BRI in discussions or remarks, the general population is largely uninformed or lacks awareness regarding this initiative. Concurrently, Beijing institutes have engaged with Hungarian researchers and academics and integrated them into numerous BRI networks. From the perspective of reporters, bilateral, 16+1, and EU-China relationships offer ample material for coverage. In contrast, many policymakers perceive the BRI as an elusive prospect, and the Hungarian public does not deliberate on apparent hazards and risks. Given the inherent difficulty in distinguishing BRI-related Chinese efforts from non-BRI Chinese endeavours in Hungary, the latter are arbitrarily categorized as "Chinese". In addition to undertaking construction on the Budapest-Belgrade railway line, Hungary signed a Memorandum of Understanding with China in June 2015, marking the inaugural European nation to endorse the BRI (Rencz, 2019). Concurrently, the nation failed to seize the chance to become the inaugural member of the Asian Infrastructure Investment Bank (AIIB). However, in the absence of a formal China strategy, there is also no BRI scheme. Hungary, in conclusion, could be among the initial beneficiaries of a BRI-labelled initiative; however, greater effort from the government is required to maximize all viable facets.

Hungary's capacity to collaborate with Chinese allies on a much larger scale is constrained by its size and the number of its businesses, but the development of a national China policy could aid in articulating Hungarian interests in relation to China and the BRI initiative. In the interim, because of rising domestic wages, Chinese businesses have considered transferring a portion of their production or corporate capacities overseas, while the central government strives to restructure the economy and realign its foreign trade

relationships. CEE, including Hungary, is a geographic area that could potentially garner Chinese investment of this nature; the construction of new transportation routes as part of the BRI may provide a favourable opportunity to do so. Nonetheless, there are risks, as specific Western member states of the Union and EU entities harbour concerns regarding both the BRI and the 16+1 cooperation. In response to concerns raised by Western nations, Beijing initiated the promotion of "third country cooperation" to present prospects for Western enterprises as well. However, if the West continues to view Chinese construction firms as rivals in CEE nations or seeks an opportunity to collaborate with them in the development of fresh transportation networks in the region remains a significant unknown. Beijing is inclined to offer financial assistance to construction endeavours, whereas in the future years, EU finances will be reallocated from CEE to nations throughout Southern Europe.

Furthermore, recent research by the Organisation for Economic Co-operation and Development (OECD, 2023) emphasizes Hungary's need for sustainable energy policies in line with EU climate targets. Additionally, the International Energy Agency (IEA, 2022) highlights the emerging role of renewable energy in Eastern European economies, including Hungary, underlining its transformative potential.

3. RESEARCH METHODOLOGY

3.1. Data

This study also aims to explore the impact of economic growth on carbon emissions in Hungary. As the countries are aiming to become technologically advanced countries and to achieve speedy industrialization (Aysan et al., 2020; Kayani & Gan, 2022). We are applying the autoregressive distributed lag (ARDL) Bounds test over the data for the period of 1990–2020, and the data has been extracted from World Development Indicators (WDI). Table 1 below comprises the details about the dependent and independent variables.

Table 1. List of variables.

Variables	Symbols	Description and measurement scale	Data source
Carbon emissions	CO_2	Metric tons per capita	WDI
Economic growth	GDP	GDP growth (annual %)	WDI
Renewable energy consumption	REW	Renewable energy consumption (% of total final energy consumption)	WDI

Source: Authors' elaboration.

GDP growth represents economic expansion, CO_2 emissions reflect environmental outcomes of such growth, and *REW* consumption indicates sustainable energy practices. Together, these variables capture the growth-environment nexus in Hungary.

3.2. Methods

To examine the effect of economic growth on carbon emissions, we used the ARDL Bounds test for analysis. The ARDL model is particularly suited for assessing both stationary and non-stationary data series, allowing robust analysis of the dynamic relationship between variables. Moreover, compared to other bilateral initiatives, such as Poland-China, Hungary's approach remains unique in its focus on infrastructure-led investments under BRI.

REW serves as both an economic growth stimulant and an environmental safeguard by reducing fossil fuel dependence. Carbon emissions, while an indicator of environmental degradation, are not directly reflective of governance but of industrial activity and energy policy efficiency.

Furthermore, we utilized Eq. (1) to check the relationship among the variables. Representation in regression form is provided in Eq. (2).

$$CO_2 = f(GDP, REW) \tag{1}$$

$$Y(CO_2) = \alpha + \beta_1(GDP) + \beta_2(REW) + \varepsilon \tag{2}$$

where, β_1 and β_2 refer to the coefficients of the respective independent variables, α is the intercept of the regression model, *GDP* is the gross domestic product growth, *REW* is renewable energy consumption, and e reflects the residuals.

To check the stationarity of variables, we employ the augmented Dickey-Fuller (ADF) test. The mathematical illustration of the ADF test is shared below in Eq. (3).

$$\Delta x_t = \varphi x_{t-1} + \sum_{i=1}^{m} \delta \Delta x_{t-1} + \varepsilon_t \tag{3}$$

where, Δ is the difference operator, *t* refers to time, φ is the symbol of the coefficient showing the process root, δ refers to the time trend coefficient, *m* shows the number of lags autoregressive model, and ε_t is the random error term.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Descriptive statistics

Initially, we ran the descriptive statistics, and the results are reported below in Table 2. The data is normal and has no issues with outliers.

Table 2. Summary statistics for the selected variables.

Variables	Mean	Median	Maximum value	Minimum value	Standard deviation
CO_2	5.232721	5.473181	6.499044	4.117502	0.582217
GDP	1.437062	2.947155	5.362348	-11.89204	3.919825
REW	9.193548	7.300000	17.200000	3.900000	4.734901

Source: Authors' elaboration.

The descriptive statistics have been presented in Table 2 above. The mean value of CO_2 is 5.23, with a maximum value of 6.49 and a minimum value of 4.11. *GDP* has a mean value of 1.43, with a maximum value of 5.36 and a minimum value of -11.89. *REW* has a mean value of 9.19 with a maximum value of 17.20 and a minimum value of 3.90.

4.2. Augmented Dickey-Fuller unit root test

The augmented Dickey-Fuller test is a statistical test used to determine whether a time series has a unit root, which implies non-stationarity. A unit root in a time series indicates that the series tends to drift over time and lacks a constant mean and variance. This is a key concept in time series analysis as non-stationary series can complicate modelling and forecasting. For gauging the stationarity of the variables, the ADF unit root test is applied as was proposed by Dickey and Fuller (1979). We found that our variables are stationary at the level $I(0)$ and $I(1)$, thus an ideal situation for applying the ARDL Bounds test. The ADF unit root test results are shared below in Table 3.

Table 3. ADF unit root test for stationarity

Variables	ADF (Level)	ADF (1st difference)
CO_2	Non-Stationary	Stationary
GDP	Stationary	N/A
REW	Non-Stationary	Stationary

Source: Authors' elaboration.

4.3. ARDL Bounds test

The ARDL Bounds test is a statistical method used to test the existence of a long-run relationship between variables in a time series context, particularly when the variables involved are of different orders of integration (i.e., some may be stationary, and others may be non-stationary but integrated of order. One of the main advantages of the ARDL Bounds test is that it can be applied whether the variables are integrated of order 0 (stationary) or order 1 (non-stationary). It does not require all variables to be integrated in the same order. The ARDL Bounds test results are shared below in Table 4. It can be noted that the F-statistic value is greater than the lower as well as the upper bound value, so clearly co-integration exists in the model.

Table 4. ARDL Bounds test results

Test statistic	Value	K
F-statistics	9.597546	2
Critical value bounds		
Significance level	$I(0)$	$I(1)$
10%	3.17	4.14
5%	3.79	4.85
2.5%	4.41	5.52
1%	5.15	6.36

Source: Authors' elaboration.

4.4. ARDL long-run estimates

Developing countries are facing a two-faceted challenge; on one side, the needs of billions of people regarding basic energy services are to be met, and on the other side, they must participate in the global transition towards clean energies (Kayani, 2021). The long-run coefficients can be interpreted as the impact of a one-unit change in an explanatory variable on the dependent variable, assuming that the system is in a steady state or long-run equilibrium. Table 5 below shows that *GDP* has an insignificant positive impact on carbon emissions, whereas *REW* has a significant negative impact on carbon emissions.

**Table 5.** ARDL long-run estimate results

| Variables	Coefficient	Standard error	T-statistics	P-value
Dependent variable = CO_2				
GDP	0.008472	0.019798	0.427920	0.6722
REW	-0.106831	0.011207	-9.532547	0.0000

Source: Authors' elaboration.

4.5. Stability diagnostic test

For determining the stability of long-run coefficients, we used the cumulative sum and the cumulative sum of squares test of recursive residuals. From Figures 1 and 2, we can see that the coefficients are stable at a 5% confidence interval.

Figure 1. Cumulative sum of recursive residuals
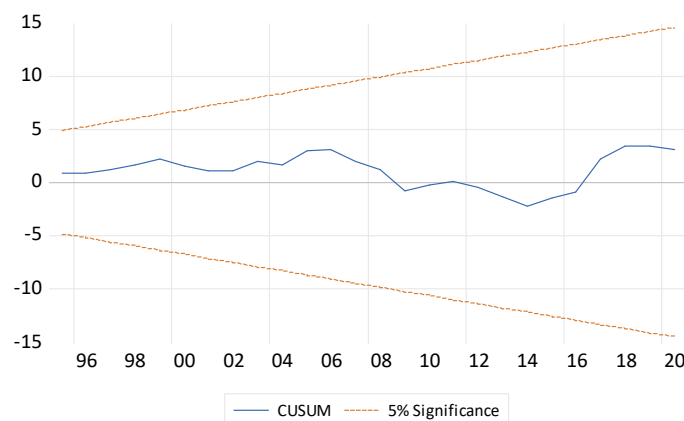
Source: Authors' elaboration.

Figure 2. Cumulative sum of squares of recursive residuals
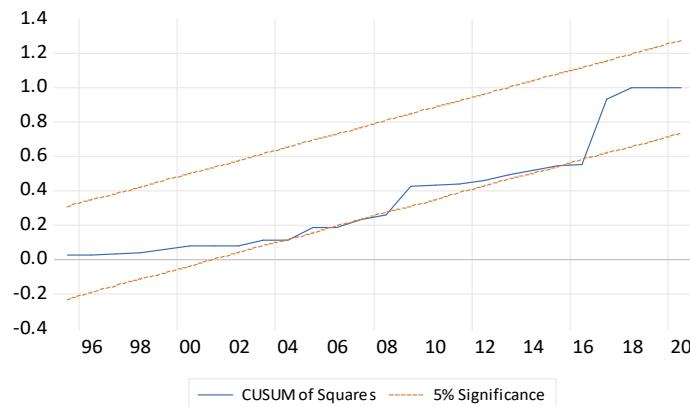
4.6. Granger causality test

The Granger causality test is a statistical hypothesis test used to determine whether one time series can predict another. Specifically, it tests whether past values of one time series can help predict future values of another. For gauging the direction of causality, we used the Granger causality test; the relationship between the variables can be unidirectional, bidirectional, or non-causal. Unidirectional causality occurs when there is a one-way relationship, meaning either GDP Granger-causes FDI or FDI Granger-causes GDP. Bidirectional causality arises when there is a two-way relationship, where both GDP Granger-causes FDI and FDI Granger-causes GDP. In contrast, no causality exists when neither GDP Granger-causes FDI nor FDI Granger-causes GDP. In Table 6 below, we found that *REW* is unidirectionally causing CO_2.

Table 6. Granger causality test results

Variables	F-statistic	P-value	Causality
GDP-CO_2	3.93027	0.0577	No
CO_2-GDP	1.32425	0.2599	No
REW-CO_2	9.34506	0.0050	Yes
CO_2-REW	0.16965	0.6832	No
REW-GDP	0.08175	0.7771	No
GDP-REW	0.34106	0.5641	No

These findings align with prior studies (Kayani et al., 2024; Aysan et al., 2020), which also emphasize renewable energy's negative relationship with emissions. Similar outcomes in EU countries suggest a regional trend towards decoupling economic growth from carbon emissions (OECD, 2023).

5. CONCLUSION

Hungary has ambitious targets of achieving economic development; it has also adopted the policy of looking towards the East, especially towards China. China is the most important trade partner of Hungary after the EU. The existing investment links remained robust, China's primary focus is on infrastructural and government-funded projects, whilst the Hungarian side is particularly keen on attracting investments that would generate new employment opportunities and manufacturing. In the coming years, Hungary is aiming to develop a well-defined policy towards China to take advantage of its favourable position at the intersection of EU-China, 16+1, and BRI ties. Hungary could potentially enhance its standing in specific sectors, most notably the tourism industry. Budapest has a distinct opportunity to substantially increase the influx of Chinese visitors to the country. Keeping in view the industrialization ambitions of Hungary, we also examined the long-run relationship between economic growth & carbon emissions in the case of Hungary. We employed the ARDL Bounds test for the period ranging from 1990 to 2020. The empirical results revealed the existence of a long-run relationship between the variables of our model. We found that renewable energy has a significant negative impact on carbon emissions; furthermore, renewable energy is also unidirectionally causing CO_2.

To encourage the use of renewable energy, Hungary must also focus on raising awareness and educating the public about its benefits. By taking this approach, Hungary can cultivate a well-informed and engaged society, which will help accelerate the transition towards a more sustainable and environmentally friendly future. Additionally, offering preferential treatment to investors who adopt green technologies and sustainable production methods is recommended. Lastly, it is crucial for the developed economies within the EU to share their technological expertise to help Hungary and the other Eastern European countries produce high-quality and cost-effective clean technologies.

Although ARDL Bounds testing was applied, future studies should include additional diagnostic tests, such as Breusch-Godfrey serial correlation Lagrange multiplier test and White's test for heteroscedasticity, to further confirm model robustness. Furthermore, ARDL was chosen for its flexibility with mixed integration orders; alternative methods like the vector error correction model, fully modified ordinary least squares, or dynamic ordinary least squares could provide complementary insights, particularly when dealing with cointegrated variables. Future research could integrate environmental, social, and governance indicators and alignment with UN Sustainable Development Goals (SDGs), such as SDG 7 (affordable and clean energy) and SDG 13 (climate action), to provide a multidimensional perspective on Hungary's sustainable development.

These insights provide important guidance for policymakers looking to promote economic growth, highlighting the need to support renewable energy consumption for a healthier environment and encourage private sector involvement in renewable

energy production. The only limitation of this study is that it is restricted only to the economy of Hungary while examining the relationship between economic growth and carbon emissions; future studies can consider the other Eastern European economies as well.

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