

**Determinants of carbon emissions in a European emerging country:
Evidence from ARDL cointegration and Granger causality analysis**

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Hungary is one of the European Union's most dynamically developing countries in Central-Eastern Europe with a high income and increasing level of environmental degradation. The present study explores the dynamic relationship between economic growth, electricity consumption, carbon emissions and urbanization in Hungary for period 1974–2014 based on annual data. Using autoregressive distributed lag model, we found long run relationship among the variables in the presence of structural breaks and Toda–Yamamoto procedure were applied to test causality. The findings indicate that electricity consumption is positively linked with carbon emissions in the long run, which implies that the energy efficiency should be improved. Urbanization have also positive effect on carbon emissions meaning that the number of cities increases the emissions. Causality results suggest that Hungary is growing at the cost of the environment and the lack of the coordination of economic and environmental objectives to fulfill emission reduction targets can reduce economic growth. The reconsideration of the economic and energy policy is vital for ensuring sustainable development and stricter environmental policy is suggested. These results contribute not only to the expansion of the existing literature, but also improves the methodological background by employing a new variable to capture urbanization effect on carbon emissions.

Keywords: energy, economic growth, urbanization, Granger causality, Toda-Yamamoto approach, ARDL, conservation hypothesis, energy policy.

1. Introduction

With the acceleration of technological development and the improvement of economic mechanisms, the primary goal of policy makers since the Industrial Revolution has been to enhance the production. Although the energy-intensive production processes of the sectors of the national economy provide the basis of economic growth, but as a result our environment is at increased risk (Mazur et al. 2015). The role of energy is twofold in the relationship between economic growth and production. On one hand, energy is an

essential source of the basis for economic activities. On the other hand, energy production has a primary role in pollutant emissions (IEA 2017).

As we can see in the action plans of 2030 Agenda for Sustainable Development, there is a great emphasis on the promoting of sustainable consumption and production to protect the planet. As for the future to maintain sustainable development, it is important to reveal past energy transitions in the direction of energy-economic growth nexus (Caglayan and Oskonbaeva 2011) especially in countries where economic growth is closely linked to energy production activities. In recent years, development efforts have focused not only on growth, but rather on sustainable growth. Today, it is irrelevant to focus only on economic growth and prosperity, as conscious strategic planning requires sustainability - also in environmental terms. Reconciling economic and environmental goals is necessary to create a long-term sustainable economic and natural environment.

Due to the importance of the topic, studies (Sharma 2011; Shahbaz et al. 2014; Shahbaz et al. 2014; Dogan and Seker 2016; Saidi and Hammami 2016; Pata 2018; Jiang and Ma 2019; Zhou et al. 2019; Munoz et al. 2020; Acheampong et al. 2020) analyzed the relationship among economic growth and carbon emissions for different countries. Empirical literature is wide-ranging but often with inconsistent results due to the applying of different data source, time set and usage of different econometric modelling. Some studies founded evidence that economic growth enhance carbon emissions in Europe (Stolyarova 2010; Ozturk and Acaravci 2010b; Gardiner and Hajek 2019) and some studies proves only the nexus among economic growth and electricity consumption (Ciarreta and Zarraga 2010; Stjepanovic 2018), while some studies denied significant relationship among variables (Menegaki 2011; Piaggio and Padilla (2012).

However, we did not find any study examining the causal relationship between carbon emissions and economic growth in the case of Hungary.

The present study investigates the direction of causality between carbon emissions, economic growth and electricity consumption by taking into account urbanization as a potential determinant elements of the emission-growth nexus for Hungary. It worth to explore causal relationships in Hungary because with accelerating economic growth, the decline in carbon emissions has begun to stagnate despite efforts to protect the environment. This process could be effect economic growth because in emerging countries, the energy is the potential catalyst of economic growth and social development (Bergasse 2013; Wajahat et al. 2017; Ulutas and Caraca 2018; Liko 2019; Reilly 2015; Ulutas and Caraca 2018) where a reduction in energy production and pollutant emissions may cause decline in economic growth. Nowadays, Hungary is one of the fastest growing emerging economies in the European Union (Eurostat 2019) and at the same time Hungary has a high degree of air pollution (OECD 2018; WHO 2018; Eurostat 2019; IPSOS 2020).

Before 1990, Hungary was a socialist, plan-based economy. With the collapse of the Soviet Union and with the wave of regime change in 1989, a new period began in the economies of Central and Eastern European (CEE) countries as well as in Hungary. Hungary's transition differed from other CEE countries' process e.g. Bulgaria (Iorgulescu and Polimeni 2009, p. 342.) because the development of the open market system also brought a structural change in the energy sector as an important element of the economy (Gros and Steinherr 2004) and it will be the largest greenhouse gas emitting sector in Hungary (Hungarian Central Statistical Office 2015). However, the energy production has fallen sharply after the regime change, and the environmental indicators have shown noticeable improvement. After the 2008-2009 crisis, the services

sector strengthened, which may also have contributed to the reduction in emissions. However, the decline in emissions has slowed, stagnated, and begins to increase from 2013.

Urbanization has also increased in Hungary. In the 1970s, only 50 cities were registered in Hungary, representing 45% of the urban population. After the regime change, the number of cities jumped to 200, although urban population (65%) did not grow further to such an extent (Figure 1.). However, urbanization does not necessarily mean moving into a city or spreading an urban lifestyle. In Hungary, urbanization can be explained rather by the fact that the conditions for being declared a city have become more lax over time. For example, acquiring city status required only a population of 1–2 thousand people compared to the ten-fold population requirement before the regime change. Higher standard of living is also debatable because new cities are designed to boost economic recovery in lower-income areas (Szepesi 2008). Consequently, we measure the effect of urbanization on carbon emissions with the number of cities instead of the proportion of city dwellers as in the literature employs (Poumayong and Kaneko 2010; Taale and Kyeremeh 2016; Gupta and Gregg 2018; Yang et al. 2019). As we confirmed in our previous study, the relationship between energy consumption and the level of urbanization (Durkó et al 2016a; Durkó et al 2016b; Durkó et al 2016c), we assume that the phenomenon of urbanization may also have affected Hungary's carbon emissions.

Figure 1. The number of cities and the proportion of urban population in Hungary between 1974 and 2014

The primary aim of this paper is to fill a research gap by presenting a relationship between economic growth, carbon emissions, electricity consumption, and urbanization in Hungary. To the best of our knowledge, this is the first study that

examines Hungary exclusively and also the first one that examines the urbanization effect for Hungary. Second, the effect of urbanization is captured in the number of cities to find out real impact of the urban sprawl on carbon emissions. Third, in contrast to previous studies (Atici 2008; Mazur et al. 2015; Vavrek-Chovancova 2016; Lazar et al. 2019;) this study determines the causality relationships between energy-growth nexus and environmental protection. Exploring the causal relationships is especially important for political decision-makers to help them devise a proper energy strategy.

The paper is structured as follows. Section 2 provides a review of the relevant literature about economic growth and environmental degradation with special regard to the conditions in Hungary and Central and Eastern European emerging economies. Section 3 discusses the methodology. Section 4 presents the empirical results, after which Section 5 concludes by providing policy implications and further research objectives.

2. Review of literature

In the empirical literature, there are numerous studies currently investigating the challenges of energy management and its effect on economic growth. More than 15,000 studies have been published on this research topic since 1978 (Sanches-Pereira et al. 2016). However, classical energy–pollutant–growth relationship is less studied nowadays (Belke et al. 2011; Szép 2014; Caraianni et al. 2015) than in its earlier stages. In a globalized world, the focus is on a widespread model that eliminates extended carbon emissions by considering the economic and demographic impacts (Shahbaz et al. 2014; Ajmi et al. 2015; Dogan and Seker 2016; Saidi and Hammami 2016) and analyzing the interrelated effect of urbanization (Sharma 2011; Shahbaz et al. 2014; Saidi and Hammami 2016; Zhou et al. 2019; Munoz et al. 2020), financial development (Dogan and Seker 2016; Saidi and Hammami 2016; Pata 2018; Jiang and Ma 2019;

Acheampong et al. 2020), and trade openness (Shahzad et al. 2017; Shahbaz et al. 2019; Zmami and Salha 2020) to pollutant emissions.

Empirical results have also confirmed the responsibility of urbanization in increasing carbon emissions and energy consumption. Urbanization contributes to enhance economic growth and energy use (Larivière and Lafrance 1999; Poumayong and Kaneko 2010; Yang et al. 2019), increasing carbon emissions (Taale and Kyeremeh 2016; Gupta and Gregg 2018; Yang et al. 2019) by the trends of growing urban population and population density. Another group of empirical studies (Shammin et al. 2010; Poumayong and Kaneko 2010; Yang et al. 2019) justify the opposite with economies of scale, because cities show an improvement in per capita energy use and emissions compared to villages (Lenzen et al. 2004; Shammin et al. 2010; Ye et al. 2017). Thus, the urbanization sprawl in these emerging economies can also be identified as a key to enforce environmental protection.

Pablo-Romero and Sánchez-Braza (2017) observed that for the 28 Member States of the European Union, only four of them managed to decrease carbon emissions with increasing economic growth. All four countries are older founding countries of the European Union and produce higher GDP per capita than the other analyzed countries. Empirical evidence since the 1980s suggest that increase in economic growth results greater energy consumption because energy is the basis of economic growth, enhanced environmental pollution (Ciarreta and Zarraga, 2010). Carbon emissions are contributed to the increase in energy consumption (Ozturk - Acaravci, 2010) in Eastern-Europe (Stolyarova, 2010). However, economic growth can be a good tool for improving the environment, but only after reaching a higher level of income (Atici, 2008).

Overall, economic growth is significantly linked with increased emissions, with the exception of a few Central-Eastern European countries, where more intensive

economic growth has been achieved without significant environmental degradation between 1996 and 2015 (Lazar et al. 2019). Only a few studies examine the emerging countries in Central and Eastern Europe, and we can find even less results which mentioned Hungary (Table 1). The energy-growth results in connection with Hungary is mentioned as Hungary a member of the European Union (Ozturk and Acaravci 2010b; Karmellos et al. 2016; Gazi et al. 2016; Lazar et al. 2019), as an emerging economy (Ozturk and Acaravci 2010; Ronald et al. 2014), or a member state of Visegrad Group (V4 countries) (Streimikiene and Kasperowicz 2016; Vavrek and Chovancova 2016).

[Table 1 near here]

Table 1. Some recent selected studies

Note: GDP: economic growth, CO2: carbon emissions, POP: population, EC: electricity consumption, EP: energy prices, TO: trade openness, ENC: energy production, RES: renewable energy sources, GHG: greenhouse gases, UNEMP: unemployment, FDI: financial development. <-> means bidirectional causality, -> and -< means unidirectional causality

Table 1 shows that there are three types results for Hungary, that is, the bidirectional relationship between GDP and energy consumption in one case, no causal relationship between GDP and energy in the second case, and no long-run relationship between the variables in the third case. On the other hand, only conservation hypothesis was proven for Hungary (Narayan and Narayan 2010; Ronald et al. 2014; Caraianni et al. 2015). However, the role of emissions were not investigated.

As we have seen, many studies have investigated the energy-growth nexus, but only a few have examined Hungary and even less focused on emission and economic growth causal relationships. To the best of our knowledge, this paper is the first, which exclusively analyzes the causal relationship in an extended economic growth–energy nexus with urbanization employing ARDL cointegration framework in the Hungarian context.

3. Methodological framework

3.1 Data and empirical modeling

The study covers the time period of 1974–2014 in case of Hungary. Annual data on carbon emissions and population have been collected from the World Bank (2018) and World Bank (2018b). Electricity consumption data are obtained from the Hungarian Energy and Public Utility Regulatory Authority (MEKH). Urbanization data was derived from the Hungarian Statistical Office (KSH). Similar, to Galli (1998), Medlock and Soligo (2001), and Agovino et al. (2018), data for economic growth (real GDP) is sourced from Penn World Table from Groningen Growth and Development Centre (GGDC).

All series data have been translated to per capita values and in logarithmic form. Using the general form, the empirical equation is the following:

$$CO2_t = f(EC_t, GDP_t, URB_t) \quad (1)$$

where $CO2_t$ is the carbon emission per capita (metric kilotons), EC_t is the electricity consumption per capita (kt of oil equivalent), GDP_t is the real GDP per capita (2011; million US dollar) and URB_t shows the spread of urbanization (expressed in terms of the number of the cities).

3.2 The ARDL bounds testing of cointegration

In current study, the Autoregressive Distributed Lag (ARDL) methodology was employed for checking cointegration among carbon emissions, electricity consumption, economic growth, and urbanization in Hungary using annual time series data for the period of 1974 to 2014. The ARDL method was developed by Pesaran et al. (2001). The ARDL bounds test has several econometrics advantages over other cointegration tests.

It is applicable when variables have mixed stationarity properties (Pesaran et al. 2001) and suitable for small sample size data providing better estimates for small sample data (Haug 2002).

For the bounds test approach, we composed vector error correction model (VECM). The VECM has short run dynamics with long-term equilibrium, without losing any long-term information (Shahbaz et al. 2014). The empirical structure of the ARDL bounds testing to cointegration is expressed as the following (Begum et al. 2015; Rahman and Kashem 2017):

$$\Delta \ln CO2_t = \alpha_0 + \sum_{i=1}^p \beta_i \Delta \ln CO2_{t-i} + \sum_{j=1}^q \gamma_j \Delta \ln EC_{t-j} + \sum_{k=1}^q \delta_k \Delta \ln GDP_{t-k} + \sum_{l=1}^q \vartheta_l \Delta \ln URB_{t-l} + \alpha_1 \ln CO2_{t-1} + \alpha_2 \ln EC_{t-1} + \alpha_3 \ln GDP_{t-1} + \alpha_4 \ln URB_{t-1} + \varepsilon_t \quad (2)$$

where Δ is the first difference operator and $\varepsilon_t, \mu_t, \pi_t$ and ω_t are terms assumed to be normally distributed and white noise. The terms $\beta, \gamma, \delta, \vartheta$ in summation signs are short-run coefficients representing the dynamics for error correction in the short run, while α is the long-run multiplier. The next half of the equation corresponds to the long-run relationship.

After founding evidence for cointegration between variables, the next step is estimating the long run coefficient of the ARDL model using the following equation (Begum et al. 2015; Rahman and Kashem 2017):

$$\ln CO2_t = \alpha_0 + \sum_{i=1}^p \beta_i \ln CO2_{t-i} + \sum_{j=0}^{q1} \gamma_j \ln EC_{t-j} + \sum_{k=0}^{q2} \delta_k \ln GDP_{t-k} + \sum_{l=0}^{q3} \alpha_l \ln URB_{t-l} + \varepsilon_t \quad (3)$$

Having obtained the value of the long-run coefficient, the cointegrating vector of the ARDL model is reparametrized to form an error correction mechanism (ECM). The reparametrized result provides short-run dynamics (i.e., traditional ARDL) and the long-run relationship of the variables of a single model. A negative and significant value of

the error correction term (ECT) is expected to support long run relationship (Rahman and Mamun 2016; Shahbaz et al. 2013; Rahman and Kashem 2017).

3.3 Causality analysis

In the case of cointegration vector founding between the series, Granger causality is most likely to exist. However, the conventional Granger causality test based on ECM cannot eliminate bias and spurious results because most economic time series do not have the same stationarity properties, they have different integrated orders and might be mutually cointegrated or non-cointegrated. Toda and Yamamoto (1995) developed a test to reveal Granger causality regardless of the stationarity properies of the variables. The Toda–Yamamoto approach estimates causality between variables at levels under an augmented Vector Autoregression (VAR) framework. The VAR models are expressed as augmented Granger-causality (Faisal et al. 2016):

$$\ln CO2_t = \alpha_0 + \sum_{i=1}^k b_{1i} \ln CO2_{t-i} + \sum_{i=k+1}^{k+dmax} b_{2i} \ln CO2_{t-i} + \sum_{i=1}^k c_{1i} \ln EC_{t-i} + \sum_{i=k+1}^{k+dmax} c_{2i} \ln EC_{t-i} + \sum_{i=1}^k c_{1i} \ln GDP_{t-i} + \sum_{i=k+1}^{k+dmax} c_{2i} \ln GDP_{t-i} + \theta ECT_{t-i} + \sum_{i=1}^k c_{1i} \ln URB_{t-i} + \sum_{i=k+1}^{k+dmax} c_{2i} \ln URB_{t-i} + \varepsilon_{1t} \quad (4)$$

where $\ln CO2_t$ is the dependent variable, k is the number of lags, and $dmax$ is the number of augmented lags. The Toda–Yamamoto method is based on a Wald test in a VAR framework used regardless of the integrated order of the variables.

3.4 Diagnostic and stability tests

Diagnostic tests indicate the robustness of the estimated coefficients. Serial independence and normal distribution of error terms are both crucial assumptions in the ARDL Bounds testing methodology. This study employed the Breusch–Godfrey Serial Correlation LM test for testing serial independence, White test for testing heteroscedasticity, and the Jarque–Bera test for checking normality of the error terms in

the model equations. The stability of the model can be deduced from the long-run results based on the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMQ) in the graphical representation of the figures (Pesaran and Pesaran 1997; Brown et al. 1975).

4 Empirical results and analysis

4.1 Unit root testing

The prerequisite of the ARDL bounds testing is that time series should be integrated at level or after taking first difference. We applied not only traditional unit root tests such as the augmented Dickey-Fueller test (1979) but also the Zivot–Andrews test (Zivot-Andrews 1992) with a single unknown break to ascertain all the variables for meeting the stationarity requirements of the ARDL bounds test. We can see in Table 2 that series have mixed integrated properties but none of the variables is integrated at second order. Unit root test results permitted us to employ the ARDL model technique to test cointegration.

[Table 2 near here]

Table 2. Unit root tests results

Note: *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively. The [] contains the appropriate lags of the variables which were selected using the Akaike Information Criteria (AIC).

Time break points occurred in the years following the Hungarian regime change in cases of all time series in 1993, 1994, 1991 and 1989, respectively. These dates can clearly be linked to the regime shift in Hungary where industrial production began to decline and a new open economy began (Romsics 2015). The real information about structural break dates may help the policy makers to make appropriate and sustainable plans for energy and economic policy.

4.2 *ARDL bounds test and cointegration*

The ARDL bounds test revealed a long-run relationship between the variables. The long run relationship exists when the value of F-statistic exceeds the upper bound. Since we have a small sample, we use Narayan critical values to make a decision whether cointegration exist. The calculated F-statistic for the ARDL bounds test is 7.2591 for $k=3$ (k is the number of the independent variables) concluded that there is cointegration between carbon emissions, electricity consumption, economic growth and urbanization in Hungary. The null hypothesis of no cointegration can be rejected at the 1% level of significance in case of the $F_{\ln\text{CO}_2t}$, $F_{\ln\text{EC}_t}$, $F_{\ln\text{GDP}_t}$, and $F_{\ln\text{URB}_t}$ models. The calculated F-statistics were 7.2591, 7.0414, 6.6750, and 16.005 respectively, which are above the critical values not only from Narayan (2005) but also Pesaran (2001) as well as those from the statistical program. Results of critical values significantly suggest that all the models should be involve cointegration vectors (Table 3).

[Table 3 near here]

Table 3. Results of ARDL cointegration test and critical values from Pesaran et al. (2001) and Narayan (2005) for bounds testing

Note: *** denotes the significance at 1% level. Lag lengths were decided by evaluating Akaike Information Criterion. The diagnostics tests are the Breusch-Godfrey LM test for serial correlation and White test for heteroscedasticity. Lower and upper bonds are calculated with the statistical program.

The empirical models passed the three major diagnostic tests. The results of diagnostic tests indicated that the error terms is free from serial correlation, having normal distribution, and heteroscedasticity exists when the dependent variables are $\ln\text{CO}_2t$, $\ln\text{EC}_t$, $\ln\text{GDP}$ and $\ln\text{URB}_t$. The null hypothesis of ARCH, non-normality, and heteroscedasticity problems could not be rejected, leading us to the conclusion that the parameter stability of the model is ensured.

4.3 Long and short-run analysis

After identifying the existing of cointegration relationship, the next step is to reveal the long-run equilibrium relationship between the variables using the ARDL specification (2,1,5,5). We found that a 1% raise in electricity consumption is linked with 2.507% increase in carbon emissions in the long run. If 1% increase occurs in urbanization, carbon emissions are increased by 2.138% in the analyzed period (Table 4.). Only economic growth decreases carbon emissions, holding electricity consumption and urbanization constant. However, the impact is not significant, which can be explained by two reasons. First, Hungary's economy became an open economy and started to grow only after 1989 (Gros and Steinherr 2004; Iorgulescu and Polimeni 2009), in the middle of the sample period. Second, the new economy model was mostly based on the service sector (IEA 2018) requiring less energy production than before as an industry-driven economy (KSH 2015).

[Table 4 near here]

Table 4. Long-run and short-run analysis result (error correction representation)

Note: *,**,*** denote significance at 10%, 5% and 1% levels, respectively.

$$ecm = \ln CO_2 - 2.5068 * \ln EC + 0.076377 * \ln GDP - 2.1384 * \ln URB + 0.13202 * TREND + 19.0568 * INT$$

Similar to our results, Richmond and Kaufmann (2006) employed the OLS method in levels concluded that a significant relationship does not exist between economic growth and carbon emissions series. Piaggio and Padilla (2012) and Ozturk and Acaravci (2010)b also found no evidence of a long-run relationship for Hungary between economic growth and carbon emissions. The present results are partly the same as the results of Gazi et al. (2016). The findings regarding the urbanization effect on carbon emissions are in a line with those of Poumayong and Kaneko (2010) and contrary to those of Sadorsky (2014).

The coefficient of the lagged error correction term is negative and significant, validating the stable cointegrating relationship between the variables. The ECM measures the speed of adjustment of the endogenous variable in the case of a shock in the equilibrium. In this study, the ECM estimation suggested that short-run deviations in carbon emissions were corrected by 41.3% every year toward the long equilibrium (Table 4). Other words, in Hungarian conditions, carbon emissions return to its original equilibrium state in less than three years.

We can see the estimated effect of the electricity consumption on carbon emissions was positive, suggesting that an increase in electricity consumption results in increasing carbon emissions. Economic growth and carbon emissions were also found to be positively related meaning that an increase in economic growth enhances carbon emissions in short run. However, the direction of the effect of economic growth on carbon emissions was time varied. Therefore, it may be concluded that economic growth leads to environmental degradation only years later.

All other things being equal, all the lagged values of the coefficients in urbanization and carbon emissions were negatively linked at a 1% level of significance. Findings suggests that the spread of cities reduces carbon emissions in the short run. The more the number of cities, the less the damage to the environment. The effect of urbanization on carbon emission is time invariant.

4.4 Granger causality test

Engle and Granger (1987) suggest that if cointegration exists between the variables in the long run, then there must be either unidirectional or bidirectional Granger causality between variables. Finally, the causal relationship between carbon emissions and independent variables were tested using the Toda–Yamamoto Granger causality test. The result shows that carbon emissions were caused by all other variables in Hungary

(Table 5).

[Table 5 near here]

Table 5. Granger causality/block exogeneity Wald test

Note: *,** and *** denote significance at 10%, 5%, and 1% levels, respectively.

The null hypothesis of no causality should be rejected when carbon emissions are the dependent variable at a 1% significance level. We found that unidirectional causality running from electricity consumption, economic growth, and urbanization to carbon emissions. All the selected series Granger cause carbon emissions in the long run, but the inverse does not hold true, since the causality is not bi-directional. The results of Ajmi et al. (2015) were partially confirmed by the present study, meaning that economic growth and electricity consumption determine the carbon emissions. Similar to the studies of Stolyarova (2010) and Ozturk and Acaravci (2010b), the causal effect of economic growth and electricity consumption, respectively, on carbon emissions was corroborated by the present study.

Feedback hypothesis was partially proved between economic growth and energy consumption similar to Ozturk and Acaravci (2010) for Hungary. Unidirectional Granger causality exists from economic growth to electricity consumption, implying that the neutrality hypothesis does not hold for these variables unlike in the case of Piaggio and Padilla (2012), Ozturk and Acaravci (2010)b and Menegaki (2011). We failed to detect a causal relationship for urbanization with any variables. However, urbanization Granger causes carbon emissions (Figure 2.). The Granger causality of urbanization has not been tested on Hungarian data thus far, and therefore the obtained results regarding urbanization cannot be compared with the results of previous literature.

Figure 2. Causal Channels

Note: The line means 1% and the dotted line and the frame mean 10% level of significance.

4.5 Diagnostic and stability test

The results of diagnostic and stability tests indicate that the ARDL model is well fitted, as proved by the value of R^2 and the value of adjusted R^2 (0.841 and 0.691 respectively). The value of the Durbin–Watson test statistics is 1.85, which implies that spurious regression does not exist in the model. Diagnostic tests confirmed no problems with phenomena of either autocorrelation or heteroscedasticity and the model did not suffer from non-normality. The graphical representations of CUSUM and CUSUMSQ statistics are presented in Figure 3, respectively verifying the stability of the ARDL model.

Figure 3. Plot of the cumulative sum of recursive residuals and the Plot of the cumulative sum of squares of recursive residuals

5 Conclusions and policy recommendations

The study investigates the long-run and causal relationships between carbon emissions, electricity consumption, economic growth and urbanization in Hungary over the period of 1974–2014. The results of ARDL bounds testing method confirmed the dynamic relationship between the variables in the presence of structural breaks. The findings showed that electricity consumption and urbanization have a positive and significant effect on carbon emissions in the long run, while the impact of economic growth on carbon emission is negative and insignificant. We reveal that unidirectional causal relationship exist from electricity consumption, economic growth, and urbanization to carbon emissions, proving the validity of conservative hypothesis. Unidirectional Granger causality was found to run from economic growth to electricity consumption, unlike in the case of existing empirical evidence, the neutrality hypothesis does not

hold.

Policy recommendations are based on the causality relationship found between carbon emissions, electricity consumption, economic growth, and urbanization simultaneously. Since electricity consumption is responsible for the rise of carbon emissions, energy efficiency programs and improvements have been developed for reaching environmental and social benefits as well as for the improvement of economic actors and society. More importantly, both economic growth and electricity consumption cause emissions, and economic growth causes electricity consumption. Thus, the Hungarian economy can only grow sustainably by mitigating the pollution per unit of electricity consumption. Hungary is now lagging behind the European Union nations in terms of energy intensity per unit of GDP and energy efficiency (Eurostat 2019). It proposes to remove barriers by implementing energy efficiency support programs (Czakó 2012). Moreover, the feedback hypothesis is valid for the energy–economic growth nexus and electricity consumption is a good indicator of economic development. It is therefore not directly recommended to reduce electricity consumption, because economic growth may decline.

Considering the results reported above, the study suggests that in order to reduce carbon emissions in Hungary, measures need to be taken in all fields of energy and socio-economics. Regarding urbanization, the long-run and causality results emphasizes that urbanization cause and increase the pressure of carbon emissions on the environment. Based on this evidence, supporting rural life is proposed from an environmental point of view. Increasing rural employment opportunities and improving housing conditions can make the rural lifestyle more attractive to young couples, resulting in a good future direction. The 2019 government decree proposing support for the purchase of housing in villages (namely the village family housing benefit “csok”)

may also have environmental benefits. It provides a non-refundable grant for purchasing a family home for young families with children willing to settle with a maximum 5,000 inhabitants in the countryside (Kormány.hu 2020).

Towards this end, limitations need to be mentioned which can be covered by future research. As causal effect towards urbanization was not revealed, we suggest investigating the urbanization characteristic in a city-level framework. In order to better understand the relationship between environmental degradation and urbanization in Hungary, other important variables, such as urban density on a city level, should be considered to measure country-specific evidence with empirical analysis and thus present a reliable picture for policy and decision makers to help them revisit environmental and economic goals.

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Tables

Table 3. Some recent selected European studies and the Hungarian results

No	Study authors	Country	Time period	Methodology	Variables	Causality
<i>Evidences from groups of European countries</i>						
1	Stolyarova (2010)	Eastern European countries	1960–2008	WITHIN, SYS GMM	GDP, CO2, POP, EC, Region	GDP->CO2
2	Ciarreta and Zarraga (2010)	12 European countries	1970–2007	GMM, VECM	GDP, EC, Energy prices	EC-> GDP EP<->GDP EP<->EC
3	Atici (2008)	Central-Eastern Europe countries	1980–2002	RE, FE	GDP, CO2, EC, TO	-
4	Ozturk-Acaravci (2010)b	19 EU countries	1980–2006	ARDL, VECM	GDP, EC, ENC	GDP->ENC CO2->ENC
5	Gardiner-Hajek (2019)	EU-23	1990–2015	Granger causality	GDP, EC, CO2, FDI, EMP	GDP<->CO2 GDP<->EC EC<->CO2
6	Mazur et al. (2015)	EU-28	1992–2010	FE-RE OLS panel data	GDP, CO2	-
7	Sadorsky (2009)	18 emerging countries	1994–2003	panel cointegration	GDP, RES	GDP-> RES
8	Stjepanovic (2018)	30 European countries	1994–2016	panel regression	GDP, EC	EC-> GDP
9	Lazar et al. (2019)	EU-28	1995–2015	FMOLS	GDP, CO2	-
10	Menegaki (2011)	27 European countries	1997–2007	Granger causality	GDP, RES, UNEMP, GHG	no causality
<i>Hungary</i>						
1	Piaggio-Padilla (2012)	31 countries	1950–2006	NLLS, cointegration	CO2, GDP	no long run relationship GDP->ENC
2	Narayan-Narayan (2010)	30 OECD countries	1960–2002		GDP, EN	
3	Ozturk-Acaravci (2010)b	19 EU countries	1965–2005	ARDL, Granger causality	CO2, EN, GDP	no causality
4	Ozturk-Acaravci (2010)	Hungary, Albania, Bulgaria, Romania	1980–2006	ARDL, VEC, Granger- caus.	GDP, EN, ENC	GDP<>ENC
5	Caraiani et al. (2015)	Hungary, Bulgaria, Romania, Poland, Turkey	1980–2013	Granger caus.	GDP, EN	GDP->ENC
6	Gazi et al. (2016)	24 European countries	1980–2010	ARDL, GMM	CO2, GDP, Technology, Biomass	Biom.->CO2
7	Szép (2014)	V4 countries	1990–2009	panel OLS	GDP, EN	EN->GDP
8	Vavrek-Chovancova (2016)	V4 countries	1991–2012	decoupling	CO2, GDP	-
9	Ronald et al (2014)	Hungary, Albania, Bulgaria, Romania	1994–2009	ARDL TY non-caus.	GDP, capital, EC	GDP-> EC
10	Streimikiene-Kasperowicz (2016)	V4 and 14 old EU countries	1995–2012	FMOLS, DOLS	GDP, EC, Capital	-
11	Lazar et al. (2019)	EU-28	1995–2015	FMOLS	GDP, CO2	linear relationship
12	Zachariadis-Kouvaritakis (2003)	Central and Eastern countries	2000–2030	forecast	GDP, transport	-
13	Karmellos et al. (2016)	EU-28	2000–2012	decomposition analysis, LMDI	GDP, EC, EI, fuel mix, activity	-

Table 2. Unit root tests results

Augmented Dickey-Fueller test			Zivot-Andrews test			
Variables	Level	First diff.	Level		First diff.	
			T-stat.	Time break	T-stat.	Time break
lnCO2_t	-2.642 [3]	-6.405*** [0]	-3.419 [2]	2003	-5.234** [1]	1993
lnEC_t	-2.919 [2]	-2.667* [1]	-4.429 [1]	1990	-5.227** [0]	1994
lnGDP_t	-4.07 [2]	-3.203** [1]	-4.815* [1]	1991	-5.726*** [0]	1981
lnURB_t	-0.992 [2]	-5.85*** [1]	-8.324*** [0]	1989	-9.435*** [0]	1991

Table 3. Results of ARDL cointegration test and critical values from Pesaran et al. (2001) and Narayan (2005) for bounds testing

ARDL estimates			diagnostic test		
Dependent variable	optimal lag	F-stat.	serial corr.	normality	heteroskeda.
lnCO2 _t	2,1,5,5	7.2591***	0.4863 [0.486]	0.6454 [0.724]	0.0320 [0.858]
lnEC _t	3,3,5,5	7.0414***	0.6688 [0.413]	0.6688 [0.413]	0.0266 [0.870]
lnGDP _t	4,0,2,3	6.6750***	2.2956 [0.130]	0.94443 [0.624]	0.0129 [0.909]
lnURB _t	5,2,2,5	16.0050***	3.5859 [0.158]	1.5053 [0.471]	0.0129 [0.909]
Critical values	Pesaran*		Narayan*		
	Lower bound I(0) I(1)	Upper bond	Lower bound I(0) I(1)	Upper bond	
1%	4.29	5.61	5.258	6.526	
5%	3.23	4.35	3.850	4.782	
10%	2.72	3.77	3.260	4.094	

Table 4. Long-run and short-run analysis result (error correction representation)

Dependent variable: lnCO_{2t}			
Long-run result			
Variable	Coefficient	T-statistics	Probability
lnEC _t	2.507***	3.698	0.002
lnGDP _t	-0.076	-0.123	0.903
lnURB _t	2.138**	2.523	0.021
C	-19.057**	-2.306	0.033
Short-run result			
d.lnCO21	-0.6464***	-3.940	0.001
d.lnEC	1.668***	5.474	0.000
d.lnGDP	0.051	0.246	0.808
d.lnGDP1	0.026	0.131	0.897
d.lnGDP2	-0.172	-1.065	0.299
d.lnGDP3	0.403***	2.919	0.008
d.lnGDP4	0.185	1.206	0.241
d.lnURB	-0.324**	-2.321	0.030
d.lnURB1	-1.178***	-3.605	0.001
d.lnURB2	-0.981***	-3.131	0.005
d.lnURB3	-0.865***	-3.633	0.002
d.lnURB4	-0.478**	-2.577	0.018
ecm(-1)	-0.413**	-2.280	0.033
R ²	0.841		
Adj. R ²	0.691		
F-statistic	6.810		
DW test	1.824		

Table 5. Granger causality/block exogeneity Wald test

Dependent variable: $\ln\text{CO2}_t$				Decision
Excluded	Chi-sq	df	Prob.	
$\ln\text{EC}$	18.30241	5	0.0026***	Reject H_0
$\ln\text{GDP}$	29.88723	5	0.0000***	Reject H_0
$\ln\text{URB}$	16.13513	5	0.0065***	Reject H_0
All	36.68907	15	0.0014***	Reject H_0
Dependent variable: $\ln\text{EC}_t$				
Excluded	Chi-sq	df	Prob.	
$\ln\text{CO2}$	1.400771	5	0.9242	Do not reject H_0
$\ln\text{GDP}$	9.014018	5	0.1085*	Reject H_0
$\ln\text{URB}$	4.686348	5	0.4553	Do not reject H_0
All	17.92080	15	0.2669	Do not reject H_0
Dependent variable: $\ln\text{GDP}_t$				
Excluded	Chi-sq	df	Prob.	
$\ln\text{CO2}$	8.010204	5	0.1557	Do not reject H_0
$\ln\text{EC}$	4.470790	5	0.4838	Do not reject H_0
$\ln\text{URB}$	8.481431	5	0.1316	Do not reject H_0
All	22.87863	15	0.0868*	Reject H_0
Dependent variable: $\ln\text{URB}_t$				
Excluded	Chi-sq	df	Prob.	
$\ln\text{CO2}$	2.035025	5	0.8443	Do not reject H_0
$\ln\text{ECP}$	4.699540	5	0.4536	Do not reject H_0
$\ln\text{GDP}$	6.930296	5	0.2259	Do not reject H_0
All	20.09699	15	0.1682	Do not reject H_0

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Figure 1. The number of cities and the proportion of urban population in Hungary between 1974 and 2014

Figure 2. Causal Channels

Figure 3. Plot of the cumulative sum of recursive residuals and the plot of the cumulative sum of squares of recursive residuals