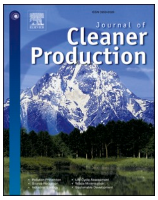
Journal of Cleaner Production 314 (2021) 127865

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro



An overview of greenhouse gases emissions in Hungary

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ARTICLE INFO

Handling editor: Bin Chen

Keywords:
GHGs
Energy consumption
Land use changes
EKC
Hungary

ABSTRACT

In Hungary, successive steps have been taken toward adjusting GHG emissions from all sectors on a national scale. However, few studies were carried out to analyze the environmental dimensions of GHG emissions from an economic point of view. In this research, the contemporary changes of GHG emissions between 1985 and 2018 were analyzed using the Mann-Kendall test (M-K test); along with the interaction between GHG emissions and economic growth by applying the environmental Kuznets curve (EKC). Results showed that the industrial sector has been the main source of CO_2-emitting, and contributed 72% of the total emissions. Meanwhile, the biggest CH_4-emitting sector was the waste sector (44%), followed by the agricultural sector (39%). Nonetheless, the agricultural sector was responsible for more than 65% of N_2O emissions over Hungary. The M-K test results showed that total CO_2 emissions were reduced significantly ($p < 0.05$) by -1001 thousand tonnes/year. Similarly, the total N_2O emissions were subject to a significant decrease ($p < 0.05$) of -0.31 thousand tonnes/year. Interestingly, the long-run positive significant coefficient on income growth (GDP), and negative significance on $(GDP)^2$ indicate EKC's existence for CO_2 emission, CH_4, and N_2O in Hungary, revealing that GHG emissions will increase at a decreasing rate with economic growth in Hungary. The output of this research is useful for decision-makers to consider the environmental dimensions of GHG emissions and set priorities for minimizing emissions by sectors.

1. Introduction

In recent years, the world's population has increased rapidly and is expected to increase from 7.2B to 9.6–12.3B people in 2100 (Gerland et al., 2014). On the other hand, expanding anthropogenic activities due to rapid civilizational development has led to a tremendous increase in emissions of greenhouse gases (GHGs). Moreover, the concentration of carbon dioxide (CO_2) rose from 280 ppm in the 1760s, to 410.6 ppm in Feb. 2019 (Zhang et al., 2019). Ultimately, an accelerated increase in the earth's surface temperature (EST) was recorded as the direct consequence of uncontrolled and unsustainable use of the earth's resources. However, the CO_2 concentration is expected to reach 590 ppm by the end of the 21st century (Li et al., 2014), and the average global EST will be increased by 1–3.5 °C , which imposes a great challenge for humanity to sustain life on earth. These changes in the CO_2 concentration have led to anthropogenic climate change, which alters ecosystems (Walther et al., 2002), agricultural (Huang et al., 2020), non-human species (Stewart et al., 2020), and threatens human health(Leal Filho et al., 2018).

GHGs are essentially formed of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are rapidly increasing in the atmosphere, causing global climate change (Yang et al., 2014; Mei et al.,

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https://doi.org/10.1016/j.jclepro.2021.127865
Received 24 February 2021; Received in revised form 3 May 2021; Accepted 4 June 2021

2018). In this sense, CH_4 concentration increased by 150%, while, CO_2 increased by 40% from 1750 to 2011 (Mei et al., 2018). GHG emissions have increased rapidly since the industrial revolution in 1750 (Ayalon et al., 2000) due to dramatic increases in fuel consumption and the expansion of anthropogenic activities in different sectors such as the economy, energy, coal mining, and agriculture. Based on the work of Herzog (2009), the global GHG emissions can be divided into 31.6% from the industrial sector, 13.8% from the agricultural sector (AgS), 12.2% from land-use changes, 14.3% from transportation, 24.9% from electricity and heating, and 3.2% from waste; final GHG emissions are made up of 77% CO_2, 15% CH_4 and 7% N_2O.

Globally, many actions have been taken to minimize or stabilize GHG emissions, such as the United Nations Framework Convention on Climate Change 1992 (i.e. UNFCC-1992), the Kyoto Protocol in 2002, and the Paris agreement in 2015. Some countries, for instance, China and India, are still facing difficulties in reducing their emissions. Interestingly, the EU-28 reduced their share of emissions from 18.9% to 10.49% between 1990 and 2013; Russia and the USA also reduced their emissions by 5.4% and 7%, respectively (1990–2013) (Kijewska and Bluszcz, 2016). Globally, many researchers have tried to track and characterize GHG emissions. Pradhan et al. (2019) highlighted that one-fourth of global GHG emissions originated from the Agriculture, Forestry and Other Land Use (AFOLU) category, while the cement industry and consumption of fossil fuel released 33.4 Pg of CO_2 annually (Oertel et al., 2016). Tilman et al. (2011) predicted that emissions of CO_2 equivalent GHGs in 2050 of 3 Gt/y would be necessary to meet human needs.

In Europe, successive steps towards reducing GHG emissions were carried out by the European Union (Oberthür and Groen, 2018). In this context, the European Union succeeded in reducing GHG emissions by 1B.t of CO_2-equivalent between 1990 (5.6B.t) and 2013 (4.6B.t). Even though between 1990 and 2012, the EU-28 witnessed an increase in energy consumption of +1%, associated with an increase in the population of +6% and an increase in GDP of +44%, the EU-28 achieved great success in reducing GHG emissions by 19%. Within this context, the EU-28 implemented a roadmap towards an 80% reduction of GHGs from different sectors by 2050 (European Climate Foundation, 2010; European Commission, 2011). Even though many projects have been undertaken to indicate the relationship between climate change and GHGs, as well as recent trends in GHG emissions all over the world, few studies have been carried out in Eastern Europe. Moreover, most of them have been local, focusing on only one aspect, such as agriculture, energy, or transport such as those in Romania (Bălan and Vasile, 2013), Bulgaria (Yarnal, 1996) the Czech Republic (Jursová et al., 2018), and Hungary (Talamon et al., 2019; Deák et al., 2018).

In Hungary, monitoring CO_2 started in 1981, and in the 1990s many projects were launched to monitor the GHGs budget in different ecosystems (Haszpra, 2011). Successive steps have been taken toward the adjustment of GHG emissions in all sectors. According to the EU-28 road map, Hungary is required to reduce GHG emissions by 10% by 2020 compared to 2005 levels (the baseline) (Talamon et al., 2019). Recently, Hungary published the main points of a new framework for the energy sector, which placed the greatest emphasis on low carbon emissions from all sectors, such as the supply and consumption chains, heat production methods, the electrical sector, and transportation (Fogarassy and Kovacs, 2016). Interestingly, under the Hungarian National Energy Strategy 2030, renewable energy sources were listed in second place in sustainable energy in terms of climate policy (Szlavik and Csete, 2012). To the best of the authors' knowledge, many studies have reported GHG emissions in Hungary. Some of them were on a local scale (i.e. Titov et al., 2021; Tóth et al., 2010), while others were on a national scale (i.e. Molnár et al., 1996; Szlavik and Csete, 2012). On the other hand, some deal with the AgS only (i.e. Brinkman et al., 2017; Somogyi, 2000; Tóth et al., 2005), while others deal with the energy and transport sectors (i.e. Török, 2009; Szlavik and Csete, 2012; Titov et al., 2021). However, few of them have discussed this topic from several relevant perspectives on a national scale. Thus, the main aims of this research are to: (I) report comprehensively on the contemporary changes of GHGs emission from different sectors in Hungary between 1985 and 2018; and (II) highlight the interaction between Hungarian income and the GHG emissions (CO_{2t}, $CH_{4t,}$ and N_2O_t) by employing for the first time the environmental Kuznets curve (EKC) in Hungary. Overall, the research goals will answer the following questions: (I) Is there a negative trend in GHG emissions from different sectors in Hungary? and (II) has Hungry been successful in turning the EKC for GHGs?

2. Materials and methods

2.1. Data collection

For tracking GHG emissions from different sectors in Hungary, the CO_2, CH_4, N_2O emission data [thousand tonnes] was obtained from the Hungarian Central Statistical Office (1985–2018) (https://www.ksh.hu/docs/eng/xstadat/xstadat_annual/i_ua002a.html). Other available data about air pollutants which include: 1) hydrofluorocarbon (HFC), 2) perfluorocarbon (PFC), 3) sulphur hexafluoride (SF6), 4) nitrogen oxides (NO_X), 5) sulphur oxides (SO_X), 6) ammonia (NH_3), 7) non-methane volatile organic compounds (NMVOC), 8) carbon monoxide (CO), 9) particulate matter with a diameter of 10 μm or less (PM10), and 11) particulate matter with a diameter of 2,5 μm or less (PM2,5) were, also, obtained from the Hungarian Central Statistical Office [thousand tonnes]. Data normality and homogeneity were checked before conducting any further analysis, however, results showed that all data follow the normal distribution. The Hungarian gross domestic product (GDP) per capita (current US$) and energy consumption (EC) data from 1990 to 2016 was collected from the database of world bank: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD.

2.2. Data analysis

2.2.1. M-K test

The M-K test is a nonparametric one, aims to determine if the data exhibit a positive or negative trend (Pathak and Dodamani, 2020), based on the correlation rank and order of time series (Hamed, 2008). However, $\boldsymbol{H_0}$ refers to no trend, while $\boldsymbol{H_1}$ refers to a clear trend over time. The M-K test is calculated as follow:

$$\boldsymbol{S} = \boldsymbol{M} - \boldsymbol{K} = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \boldsymbol{sgn}\left(\boldsymbol{x}_j - \boldsymbol{x}_k\right) : (\boldsymbol{j} > \boldsymbol{k}) \qquad 2$$

x_j, x_k annual values for R in years j and k, n: years of observation, $sgn(x_j - x_k)$: sign function:

$$\boldsymbol{sgn}\left(\boldsymbol{x}_j - \boldsymbol{x}_k\right) = \begin{cases} +1 \left(if \left(\boldsymbol{x}_j - \boldsymbol{x}_k\right) > 0\right) \\ 0 \left(if \left(\boldsymbol{x}_j - \boldsymbol{x}_k\right) = 0\right) \\ -1 \left(if \left(\boldsymbol{x}_j - \boldsymbol{x}_k\right) < 0\right) \end{cases}$$

According to Kendall (1975), the variance ($Var(S) = \nabla$) and Z static is calculated as follow:

$$\nabla(\boldsymbol{S}) = \frac{\boldsymbol{n}.(\boldsymbol{n} - 1)(2\boldsymbol{n} + 5) - \sum_{i=1}^{m} \boldsymbol{t}_i(\boldsymbol{t}_i - 1)(2\boldsymbol{t}_i + 5)}{18} \qquad 3$$

$$\boldsymbol{Z} = \begin{cases} \dfrac{\boldsymbol{S} - 1}{\sqrt{\nabla(\boldsymbol{S})}} (S > 0) \\ 0 \quad (S = 0) \\ \dfrac{\boldsymbol{S} + 1}{\sqrt{\nabla(\boldsymbol{S})}} \ (S < 0) \end{cases} \qquad 4$$

where: n: number of tied groups (t_i) (i.e. sample data with the same value), m: number of tied data.

However, the negative or positive value of Z indicates the trend of the time series (upward, downward). The p-value of Z can be estimated at different significant levels (0.01, 0.05,0.01), in this research, significant level $\boldsymbol{\alpha} = 0.05$ was.

Also, Sen's slope method (Sen, 1968) was applied to estimate the magnitude of trend (i.e. slope), which calculated as follow:

$$\varepsilon_i = \frac{\boldsymbol{x_j - x_k}}{\boldsymbol{j - k}} \; \boldsymbol{for\, i} = 1, 2, 3 \ldots \boldsymbol{n} \qquad 5$$

The median of n values is estimated as Sen's slope which is computed as follow:

$$\varepsilon_{med} = \begin{cases} \varepsilon_{\frac{(n+1)}{2}} & n \text{ is odd} \\ \frac{1}{2}\left(\varepsilon_{\frac{n}{2}} + \varepsilon_{\frac{(n+2)}{2}}\right) & n \text{ is even} \end{cases} \qquad 6$$

Ultimately, $\varepsilon_{med}$is computed with a two-sided test, then Sen's slope is estimated by the non-parametric test (Güner Bacanli, 2017; Mahajan and Dodamani, 2015).

2.2.2. Environmental Kuznets curve (EKC)

To examine the relation between GHG emissions as a source for environmental pollution and the GDP of Hungary, we applied the Environmental Kuznets Curve (EKC) framework. The EKC represents a nonlinear relationship between any type of pollutant (e.g. in our case were CO_{2t}, $CH_{4t,}$ and N_2O_t) and economic growth. The common shape of EKC is an inverted U-shape which reveals that expanding economic activities will firstly harm the environment (early stages), then in the later stage, the economic growth enhances the environmental quality (Gill et al., 2018).

The regression model (Eq. (7)) for estimating the EKC relationship between environmental pollutants and income growth (Shafik, 1994; Grossman and Krueger, 1995):

$$\boldsymbol{Env_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 Z_t + u_t} \qquad (7)$$

Here, Env_t is environmental degradation, Y_t is capita GDP, Z_t are other determinants of environmental degradation and u_t is an error term that captures the variation of Env_t that is not captured by the model. Based on the EKC theory, β_1 is anticipated to be positive significant and β_2 negative significant. In the context of Hungary, the current study employs following the EKC model (Eq. (8)) taking energy consumption (EC) as a control variable:

$$\boldsymbol{Env_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 EC_t + u_t} \qquad (8)$$

The EKC turning point, where a positive environmental improvement with income growth could be noticed, can be illustrated as:

$$\textbf{EKC turning point} = \frac{\beta_1}{2\beta_2} \qquad (9)$$

As the aim of this research is to examine the EKC between income and three environmental pollutants: CO_{2t}, $CH_{4t,}$ and $N_2O_{t,}$ therefore, the current study has employed the following three equations taking these pollutants as dependent variables:

$$\boldsymbol{CO_{2t} = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 EC_t + u_t} \qquad (10)$$

$$\boldsymbol{CH_{4t} = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 EC_t + u_t} \qquad (11)$$

$$\boldsymbol{N_2O_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 EC_t + u_t} \qquad (12)$$

In this research, the (Autoregressive Distributed Lag) ARDL was employed for identifying the long-run cointegration relationship between time series variables, when the variables have different integration order. However, other three main cointegration tests could be applied: 1) Engle and Granger (2015) test which is based on the residual of the model, 2) Phillips and Hansen (1990) test is based on modified OLS, and 3) Johansen (1995) test employs multiple systems of equations. All these three tests require that time-series of investigated variables must have the same cointegration order. Nonetheless, the ARDL captures the long-run as well as short-run dynamics in the cointegration relationship. Moreover, Pesaran and Shin (1998) assert that ARDL coefficients are corrected for serial correlation and endogeneity, therefore, are claimed to be robust.

Thus, the present study employs the Autoregressive Distributed Lag (ARDL) method (Pesaran and Shin (1998) to gauge the EKC relationship between GDP and GHG emissions. The general ARDL (p, q, r) for Equation (8) can be modelled as in Equation (13):

$$\boldsymbol{\Delta Env_t = \alpha_0 + \alpha_1 t + \sum_{i-1}^{p} \beta_{1i} \Delta Env_{t-i} + \sum_{i-1}^{q} \beta_{2i} \Delta Y_{t-i} + \sum_{i-1}^{r} \beta_{3i} \Delta Y^2{}_{t-i}} \\ \boldsymbol{+ \sum_{i-1}^{v} \beta_{4i} \Delta EC_{t-i} + \beta_5 CO_{2t-i} + \beta_6 Y_{t-i} + \beta_7 Y_{t-i}^2 + \beta_8 EC_{t-i} + \varepsilon_t} \qquad (13)$$

where: (p, q, r): the lag order, βi : short-run, γ_i : long-run estimates for ARDL co-integration. Notably, the lag order of the ARDL model is determined using the Schwarz Criterion (SC) or Akaike Information Criterion (AIC). The bound test procedure is applied to confirm the long-run co-integration relationship between the studied variables. The bound test procedure involves the following hypothesizes:

Null hypothesis ($\boldsymbol{H_0}$): $\beta_5 = \beta_6 = \beta 7 = \beta 8 = 0$ (non cointegration)

Alternate hypothesis ($\boldsymbol{H1}$): $\beta_5 = \beta_6 = \beta 7 = \beta 8 \neq 0$ (cointegration)

If the F-test statistics exceed the critical values of the upper bound, the H_0 is rejected in favour of alternative hypotheses that assert a long-run cointegration relationship among the variables of the model.

After determining the cointegration relation among the variables, ARDL procedure estimates short-run and long-run coefficients of the model. The short-run dynamics also include an error-correction mechanism and concluded in the following way:

$$\boldsymbol{Env_t = \delta_0 + \sum_{i-1}^{p} \delta_{1i} \Delta CO_{2t-i} + \sum_{i-1}^{q} \delta_{2i} \Delta Y_{t-i} + \sum_{i-1}^{r} \delta_{3i} Y_{t-i}^2 + \sum_{i-1}^{m} \beta_{6i} \Delta EC_{t-i}} \\ \boldsymbol{+ \lambda ECT_{t-1} + \varepsilon_t} \qquad (14)$$

The negative significant error correction term ECT_{t-1} is another prove of long-run cointegration relation among dependant and independent variables of the model. Its coefficient implies how much short-run disequilibrium is adjusted towards its long-run equilibrium.

As present study aims to examine the EKC relationship in Hungary for the period 1990–2019. The ARDL estimation procedure is therefore employed due to its above-mentioned advantages over other cointegration tests.

3. Results

3.1. Distribution of GHG emissions from different sectors

Until recently, the biggest CO_2-emitting sector was the energy sector (34%), followed by the industrial sector (22%), household (18%), the transportation sector (16%), and biomass including agriculture (10%) of the total CO_2-emissions in 2016. In other words, we can say that the industrial sector has been the main source of CO_2-emitting, and contributed 72% of the total emissions. Meanwhile, the biggest CH_4-emitting sector in 2016 was the waste sector (44%), followed by the AgS (39%), and then the other different sectors (17%). Interestingly, more than 65% of N_2O emissions in 2016 originated from the AgS, while the other sectors account for 35%, as can be seen in Fig. 1.

3.2. GHG emissions trends between 1985 and 2018 in Hungary

By employing the M-K test, results showed that most sectors witnessed a significant reduction in CO_2 emissions between 1985 and 2018, except for biomass emissions (i.e. agriculture and other related sector) and the transportation sector. In detail, emissions from the biomass sector increased significantly by +355.98 thousand tons/year ($p <$

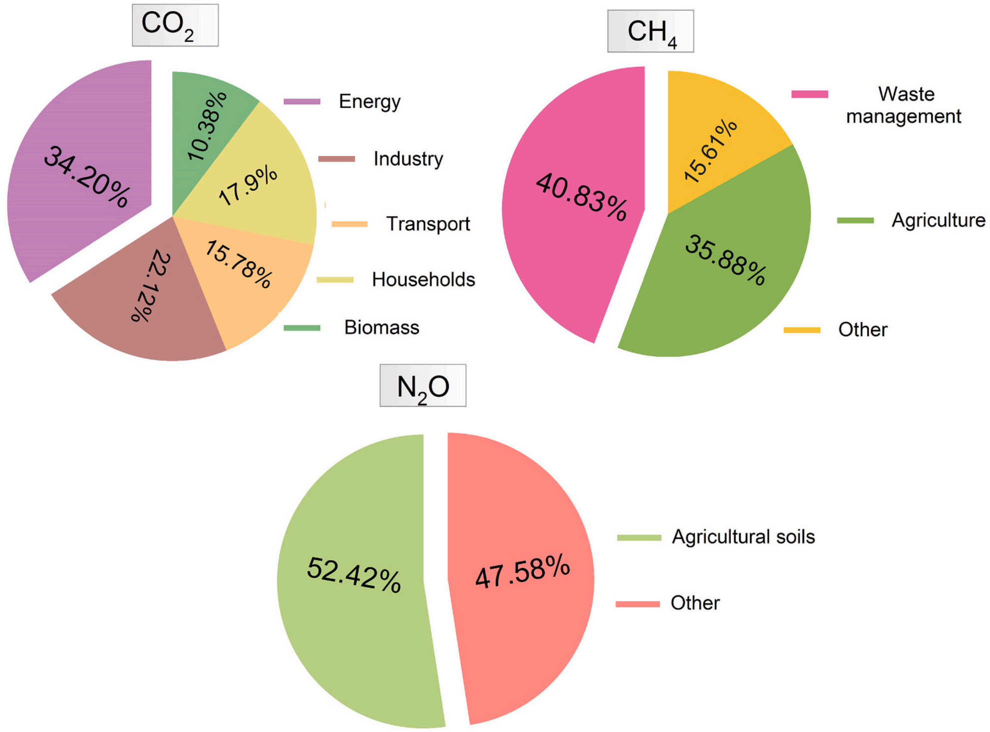

Fig. 1. Sources of GHG emissions in Hungary.

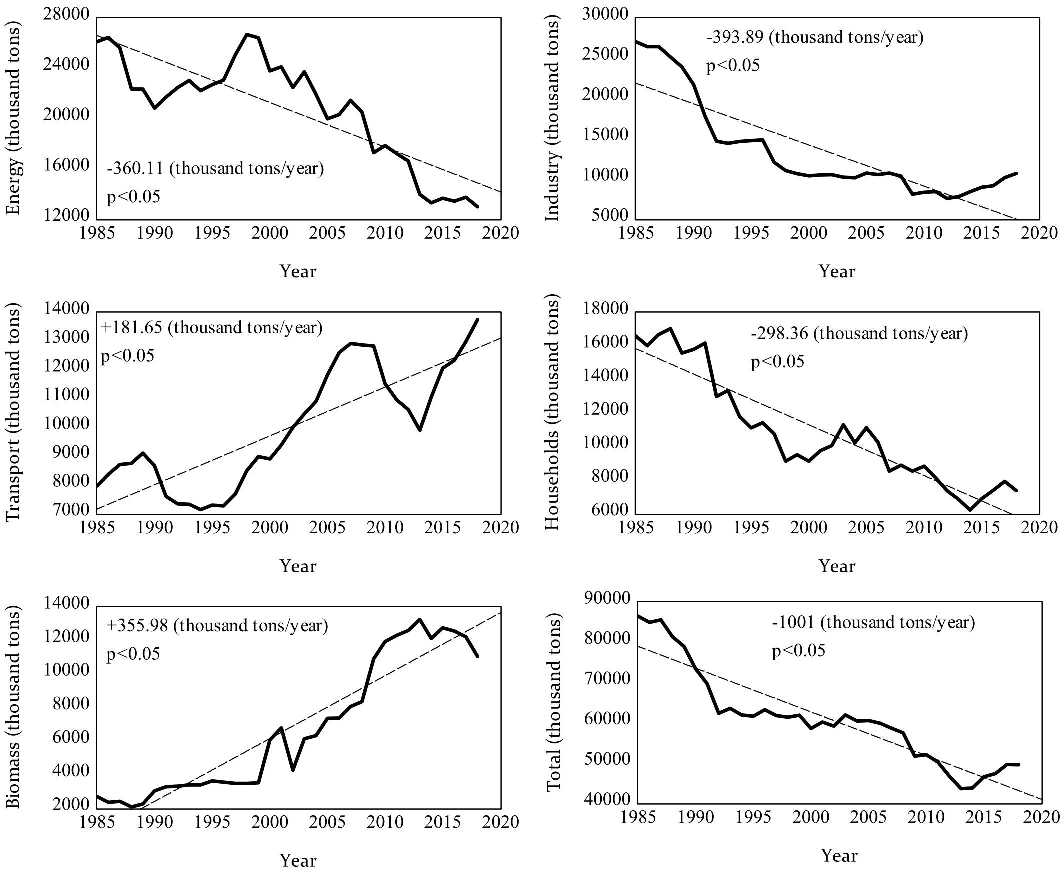

Fig. 2. Trends in CO_2 emissions by different sectors in Hungary between 1985 and 2018.

0.05), while emissions from the transportation sector also increased significantly, by +181.65 thousand tons/year ($p < 0.05$). The highest reduction was recorded in the industrial sector (−393.89 thousand tons/year, $p < 0.05$), followed by the energy sector (−360.11 thousand tons/year, $p < 0.05$), then the household sector (−298.36 thousand tons/year, $p < 0.05$). Interestingly, the total CO_2 emissions in Hungary recorded a significant reduction between 1985 and 2018, by −1001 thousand tons/year ($p < 0.05$) (Fig. 2).

Fig. 3 shows a significant reduction trend of the total CH_4 emissions from different sectors by −4.46 thousand tons/year ($p < 0.05$). However, a significant increase in CH_4 emissions from waste management by +0.63 thousand tons/year was recorded. In contrast, a significant decrease by −2.03 and −4.46 thousand tons/year ($p < 0.05$) were recorded from the AgS and other sectors, respectively (Fig. 3). The total N_2O emissions were subject to a significant decrease by −0.31 thousand tons/year ($p < 0.05$), as shown in Fig. 4. Nevertheless, N_2O emissions from soils in Hungary increased by +0.07 thousand tons/year ($p > 0.05$).

3.3. Emission of other air pollutants from different sectors in Hungary

An overview of emissions of other air pollutants (i.e. PFC, NO_x, So_x, CO, ….etc.) from different sectors in Hungary indicates negative trends from most of them, as shown in the Fig. 5. In details, a negative significant trend was recorded in PFC (−11.73 thousand tons/year, $p < 0.05$), NO_x (−3.66 thousand tons/year, $p < 0.05$), So_x (−32.81 thousand tons/year, $p < 0.05$), NH_3 (−0.43 thousand tons/year, $p < 0.05$), NMVOC (−4.44 thousand tons/year, $p < 0.05$), and CO (−27.23 thousand tons/year, $p < 0.05$). A non-significant decrease of $PM_{2.5}$ emission was also recorded. However, positive significant emissions of HFC (+60.22 thousand tons/year, $p < 0.05$), and SF_6 (+3.49 thousand tons/year, $p < 0.05$) were captured over Hungary, along with positive but not significant trend of PM_{10} emissions (+0.40 thousand tons/year, $p > 0.05$). As the main air pollutants in Hungary are CO_2, CH_4, and N_2O, this study mainly focused on them, while the other pollutants were neglected.

3.4. Environmental Kuznets Curve (EKC)

The EKC estimation procedure starts by calculating the descriptive statistics shown in Table 1. These statistics reveal the degree of variation and reliability of the data. The regression model assumes that variables under investigation must have substantial variations and are normally distributed. Descriptive statistics are employed to verify these assumptions of the regression models. The high difference between the maximum and minimum values and the high value of standard deviation relative to the mean of all variables in Table 1 indicate substantial variations in the time series variables. Moreover, the Jarque-Bera (JB) statistics fail to reject the hypothesis of normality. It is, therefore, concluded that all the variables have substantial variation and are normally distributed.

It is the prerequisite of regression analysis to determine the unite root properties of the time series variables. For this purpose, the Augmented Dickey-Fuller test (ADF) (Dickey and Fuller, 1981), and Phillips–Perron (PP) test (Kwiatkowski et al., 1992) have been applied. Further, the Akaike Information Criterion (AIC) test has been employed to assign the lag structure to these unit root tests. According to the results given in Table 2 and Table 3, both PP and ADF the null hypothesis was rejected (i. e. $\boldsymbol{H_0}$: that the time series variables have unit root (non-stationary)) for LCO_2, LCH_4, and LN_2O, while for LY (GDP), LY^2 (square GDP), and LEC (energy consumption) test statistics do not reject the $\boldsymbol{H_0}$. However, at the first difference, $\boldsymbol{H_0}$ is rejected for all variables. Hence, both ADF and PP unit root tests conclude that LCO_2, LCH_4, and LNO_2 are stationary at the level: integrated order of $\boldsymbol{I(0)}$, while LY, LY^2, and LEC are stationary at the first difference: integrated order of $\boldsymbol{I(1)}$. As variables have different integrated order, ARDL is the most appropriate estimation method.

To carry out ARDL analysis, the selection of optimum lag structure of dependent and independent variables is necessarily required. The Akaike Information Criterion (AIC) statistics recommend optimal lag order for Equations (10)–(12) are (1,0,0,4, 2, 0), (1,0,0,4, 2, 3), and (1,0,0,0).

The next step in the ARDL procedure is to establish the presence of a cointegration relationship among the variables. The F- statistics are given in Table-4 for equations (10)–(12) underpin the decision. Regarding the present study, its value exceeds the upper critical bound value in all equations. The $\boldsymbol{H_0}$ is therefore rejected, which indicate the existence of cointegration among the variables in equations (10)–(12). This result specifies that CO_2, CH_4, and N_2O emissions have long-run cointegration relation with economic growth (GDP), $(GDP)^2$, and energy consumption (EC) in Hungary.

After establishing the co-integrated equilibrium relationship in all equations, we report short-run and long-run co-efficient on independent variables in Table 5 and Table 6. The long-run positive coefficient on

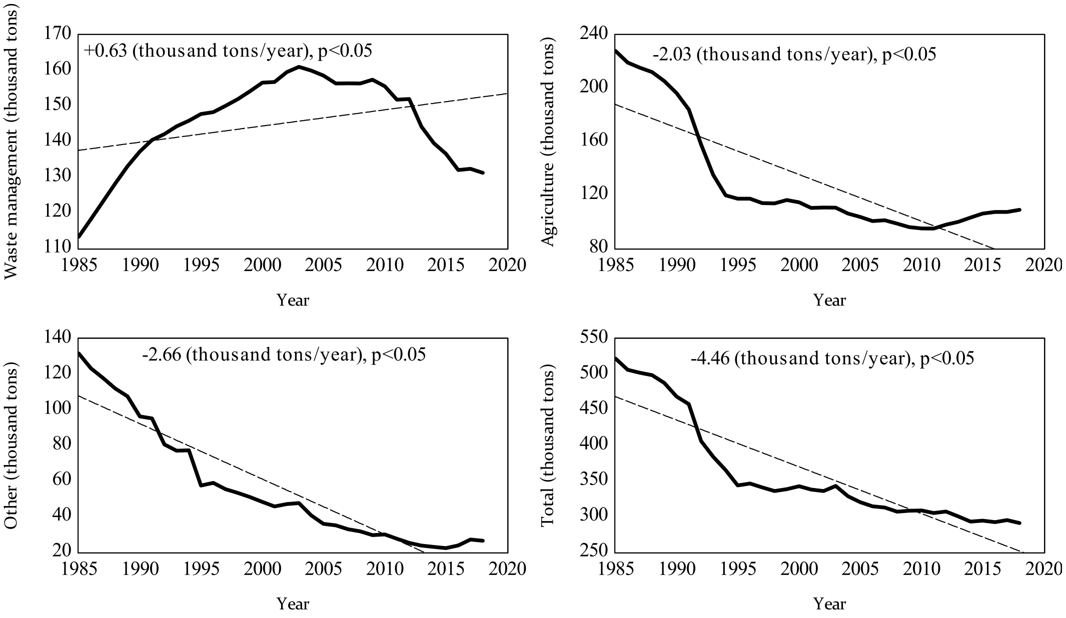

Fig. 3. Trends in CH_4 emissions by different sectors in Hungary between 1985 and 2018.

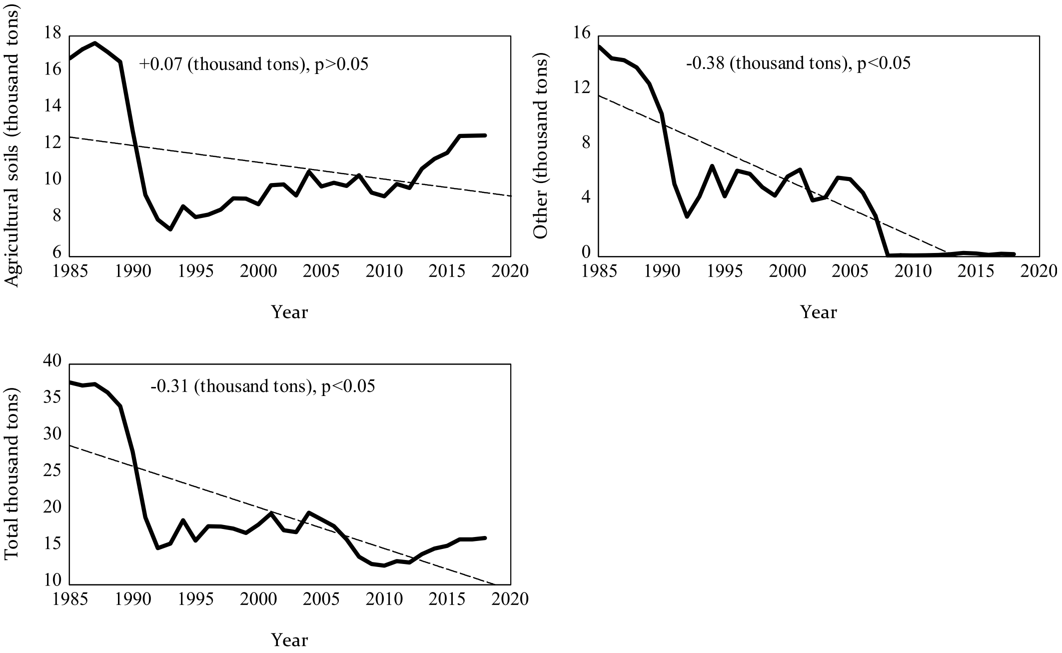

Fig. 4. Trends in N_2O emissions by different sectors in Hungary between 1985 and 2018.

income growth (GDP), and negative coefficient on (GDP)^2 for equations (10)–(12) indicate the existence of relationship between EKC and the emissions of CO_2, CH_4, and N_2O in Hungary. This relation implies that GHG emissions in Hungary will increase at a decreasing rate with economic growth (GDP).

Notably, the three models (equation (10), (11), and (12)) also have passed through the diagnostic tests of serial correlation, heteroscedasticity, and model-specifications given at the end of Table 6. The D-W statistics close to two for all three models, which led to accepting the $\boldsymbol{H_0}$ ($\boldsymbol{H_0}$: no serial correlation). Similarly, the Chi-square values for the LM test do not reject the $\boldsymbol{H_0}$ ($\boldsymbol{H_0}$: no higher-order serial correlation). The probability value of the Breeusch-Pagon test of heteroscedasticity also exceeds 10% for all three models, indicating constant variance of the error term. Similarly, RMSE and JB test statistics do not reject the alternate hypothesis of models are correctly specified and residuals are normally distributed. It is, therefore, safely concluded that models are correctly specified for the data. Moreover, R^2 is significantly high for all three models, implying models are explaining a high proportion of variations in the pollutants.

4. Discussion

Hungary, which is located in the central part of Europe rapidly affected by climate change (Alsafadi et al., 2020; Mohammed et al., 2020). Although climate change cannot be explained at the level of one country like Hungary, it is an essential part of what the world, particularly the European continental, is exposed to, where anthropogenic activities (i.e. GHG emissions) are the driving forces for such phenomena. Our results indicate a significant reduction of GHG emissions from different sectors. In this sense, two distinct periods had a remarkable impact on the reduction of GHG emissions in Hungary. The first one was between 1990 and 1995, especially in the industrial and energy sectors (Fig. 2), due to collapse of the Soviet Union (Soviets left Hungary starting in 1990 through 1991). While the second period was from 2008 to 2009 due to the world economic crisis, as can be seen in Figs. 2-4s.. However, our results reveal that total emissions dropped remarkably by 81.5%, 69%, and 145.6% for CO_2, CH_4, N_2O, respectively. As a member of the EU, Hungary was committed to reducing GHG emissions by 20% compared with the base year; thus, successive steps toward achieving this goal were undertaken (e.g. renewable energy, energy upgrades), which significantly contributed to total reduction (Molnár, 2014).

Several studies have been carried out to track CO_2 emissions in Hungary; Major et al. (2018) reported an increase of 11 ppm of annual mean CO_2 mole fractions between 2008 and 2014 in the Hegyhátsál station (W-Hungary). Similarly, Haszpra et al. (2008) highlighted the increase in the CO_2 mixing ratio from 343 to 390 ppm between 1981 and 2007 in Hungary (Hegyhátsál station), where the CO_2 growth rate was 2.1 ppm/year in the last five years. Interestingly, GHG emissions in Hungary were 15% lower in 1990 compared to 1985–1987 (the base period) (Molnár et al., 1996).

4.1. GHG emissions from the energy and industry sector in Hungary

In 2002, Hungary was one of the major countries that ratified the Kyoto Protocol and its emissions targets which aim to reduce their GHG emissions by 20–30% compared to 1990 levels (UNFCCC, 2015). Based on the energy strategies, Hungary has accomplished an extraordinary reduction in GHG emissions in different sectors (Szlávik et al., 2000). GHG emissions went down slightly in Hungary with a reduction of 35.6% in 2007; moreover, a 10% reduction in CO_2 intensity during the period 1996–2007 was recorded (Tolón-Becerra et al., 2010). This result coincides with the results shown in Fig. 2.

Generally, the energy sector is characterized as a traditional one and is dominated by coal (Radics and Bartholy, 2008), besides more than 30% of its electricity is imported from other countries (Antal, 2019). Furthermore, renewable energy (RE) strategies have been planned, such as the Hungarian Sustainable Energy Strategy which was outlined by the Hungarian non-governmental organization Energy Club, and another which was developed by Greenpeace International, Greenpeace Hungary, and the European Renewable Energy Council (EREC). These strategies highlight the possibility of shifting towered renewable-based energy by 2050 for almost 75% of systems in Hungary (Sáfián, 2014). Yet Hungary has the lowest share of RE in terms of electricity production among EU-28 countries (Antal and Karhunmaa, 2018), and the government is expanding the lifetime of the currently operating nuclear power plant, and planning to build a new plant. However, the current goals of Hungarian energy policy and strategies aim to (1) raise the renewable energy share of total energy production and consumption

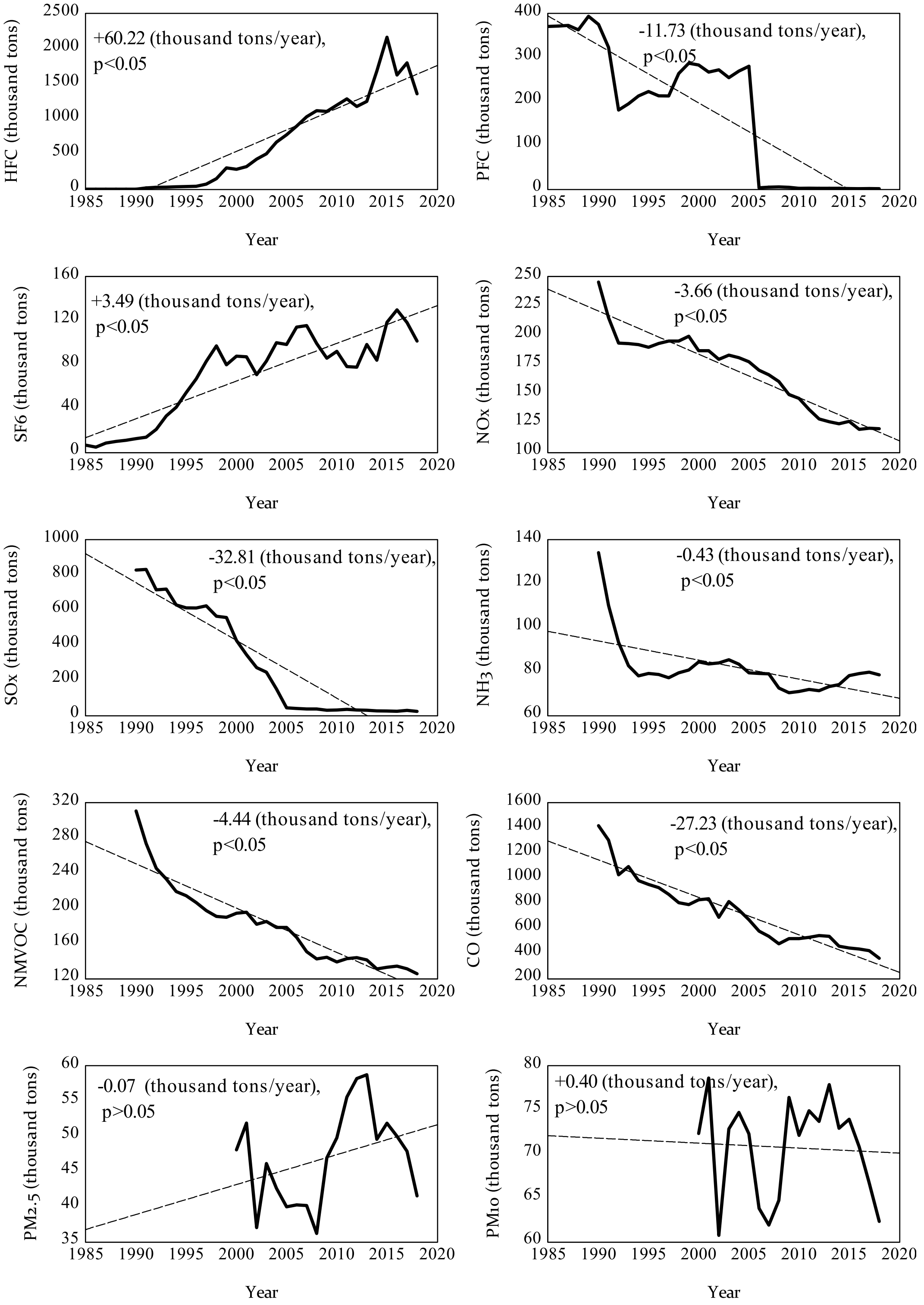

Fig. 5. Emissions trend of other air pollutants from different sectors in Hungary.

(Mathiesen et al., 2011; Schmidt et al., 2010, Hernández et al., 2004; Fuss and Szolgayová, 2010), (2) enhance power efficiency and lessen energy consumption (Lean and Smyth, 2010; Mathiesen et al., 2011; Kannan, 2009), and (3) promote nuclear energy (Lean and Smyth, 2010; Besmann, 2010). Nonetheless, the nuclear power plant generates 52% of Hungarian electricity, while 7% is produced from RE (Tóth et al., 2018).

4.2. GHG emissions from the AgS in Hungary

Agricultural land covers more than 50% of Hungarian territory, thus GHG emissions from the AgS should be addressed carefully (Barcza et al., 2011). Even though our results reveal that GHG emissions from the AgS increased gradually, Jambor and Sirone Varadi (2014) claim that GHG emissions decreased in Hungary, and also in some other EU countries (i.e. Slovakia, Slovenia, and the Czech Republic). Similarly, Molnar et al. (2011) tracked a reduction of GHG emissions from the

Table 1
Descriptive Statistics of studied variables.

	LY	LCO_2	LCH_4	LN_2O	LEC
Mean	5.11	8.71	5.85	2.81	18.16
Median	5.14	8.74	5.86	2.83	18.18
Maximum	5.58	9.49	6.15	3.32	18.40
Minimum	4.64	8.02	5.71	2.55	17.95
Std. Dev.	1.2	1.54	0.91	0.47	2.11
Jarque-Bera	2.62	2.62	7.86	4.19	1.4
Probability	0.27	0.27	0.21	0.23	0.17
Observations	26	26	26	26	26

Table 2
ADF and PP tests.

	ADF		PP	
	Test	*P*	Test	*p*
LCO_2	−3.30	(0.08) **	-.319	(0.10) **
LCH_4	−3.52	(.05) **	−3.58	(.05) **
LN_2O	−3.38	(.08) **	−3.38	(.10) **
LY	−1.60	(.76)	−2.71	(.24)
LY^2	0.41	(.98)	.171	(.96)
LEC	−2.35	(.94)	−2.49	(.32)

(***H_0***: variable is non-stationary),* MacKinnon (2010), Kwiatkowski et al. (1992): 1% significance, ** MacKinnon (2010), Kwiatkowski et al. (1992): 5% significance.

Table 3
ADF and PP tests at first difference.

	ADF		PP	
	Test	*P*	Test	*p*
LCO_2	−5.10	(0.01) *	−9.17	(0.00) *
LCH_4	−3.91	(0.03) *	−3.99	(0.02) *
LN_2O	−4.96	(0.01) *	−7.39	(0.00) *
LY	−4.60	(0.01) *	−4.60	(0.01) *
LY^2	−4.61	(0.001) *	−4.61	(0.001) *
LEC	−4.14	(0.01) *	−4.07	(0.01) *

(***H_0***: variable is non-stationary),* MacKinnon (2010), Kwiatkowski et al. (1992): 1% significance, ** MacKinnon (2010), Kwiatkowski et al. (1992): 5% significance.

Hungarian AgS between 1990 and 2006, along with a slight decrease in agricultural production. Nonetheless, among EU28-countries, emissions from the AgS in Hungary were reported to be the lowest (Dace and Blumberga, 2016).

On a national and sub-national scale, rare studies measured carbon flux (i.e. net ecosystem exchange (NEE), and net biome production (NBP)). Barcza et al. (2011) reveal that arable land in the western part of Hungary was a net carbon sink (average-NEE = -170 gC m^{-2} $year^{-1}$, average-NBP = -30 gC m^{-2} $year^{-1}$) due to the implementation of climate-smart agriculture strategies (CSAs) (i.e. agro-climate technology; crop management), and the direct impact of climate change. Fogarassy and Nábrádi (2015) argued that the implementation of climate-friendly farming projects (CFFs) will not be possible in Hungary, due to the complexity of the AgS and its interaction with other sectors (food, energy, commercial, etc.).

Some actions, such as changing the production system and closing fertilizer treatment facilities, could significantly decrease emissions from the AgS, but these actions are not sustainable for achieving a long-term reduction in comparison to other sectors, due to many production limitations, and the instability of the food chain in Hungary (Bai et al., 2017). On the contrary, many scholars have emphasized the important role of mitigation policies within agricultural sectors which can bridge the period until other mitigations or adaptation plans are implemented in other sectors (energy, industry) (Freibauer et al., 2004; Smith et al.,

Table 5
Short-run ARDL coefficients.

LCO_2		LCH_4		LN_2O	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
D(LY)	18.91 (.55)	D(LY)	2.32 (.62)	D(LY)	34.14 (.10)
D(LY^2)	−8.97 (.57)	D(LY^2)	−1.18 (.61)	D(LY(-2))	2.17 (.04)
D(LEC)	−1.05 (.06) **	D(LEC)	0.17 (.07) **	D(LY^2)	−16.49 (.11)
Coint.Eq. ($^{-1}$)	−0.74 (.01) *	Coint.Eq. (-1)	−0.35 (.08) **	D(LEC (-2))	−0.92 (.10)
				D(LEC (-3))	0.93 (.09)
				Coint.Eq. (-1)	−1.47 (.020) *

D: represent the first difference operator, while log represents a natural log. Cintiq (-1) is error correction term; R^2 is the coefficient of determination; * and ** specify the rejection of the null hypothesis at 1% and 5% respectively.

Table 6
Long-run ARDL coefficients.

LCO_2		LCH_4		LN_2O	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
LY	25.47 (.05) **	LY	6.49 (.02) *	LY	50.33 (.06) **
LY^2	−12.09 (.06) **	LY^2	−3.29 (.06) **	LY^2	−25.24 (.03) *
LEC	1.42 (.02) *	LEC	0.478 (.01) *	LEC	0.41 (.26)
C	27.92 (.02) *	C	−2.38 (.52)	C	−3.99 (.54)
R^2	.83	R^2	.85	R^2	.87
DW	1.97	DW	1.87	DW	1.89
JB	.52 (.76)	JB	.81 (.66)	JB	.27 (.87)
LM	.54 (.52)	LM	.19 (.44)	LM	13.60 (33)
Arch	1.20 (.72)	Arch	4.52 (.24)	Arch	.27 (.86)
Ramsey RESET	1.48 (.27)	Ramsey RESET	1.15 (.37)	Ramsey RESET	.98 (.44)

C: constant of all models, DW: Durbin Watson test of autocorrelation, JB: Jarque-Bera test of normality LM: Lagrange multiplier test of serial correlation, Arch: Autoregressive conditional heteroskedasticity test of heteroskedasticity, Ramsey RESET: is a test of model misspecification.

Table 4
ARDL bounds test for the equation (10) (11) and (12).

ARDL [*]	Eq. 10		Eq. 11		Eq. 12	
	Value	K	Value	K	Value	K
F-statistic	4.82	3	5.98	3	4.88	3
Critical value						
Sig.	I (0) Bound	I (1) Bound	I (0) Bound	I (1) Bound	I (0) Bound	I (1) Bound
10%	2.26	2.72	3.77	3.35	3.72	3.77
5%	2.62	3.23	4.35	3.79	3.23	4.35
1%	3.41	4.29	5.61	4.68	4.10	4.78

[*] ***H_0***: no existence of long-run relationships.

2007). These could include converting land to grass or woodland, effective and sustainable animal manure management, the implementation of conservation agriculture instead of the traditional form, and effective fertilization management (Smith et al., 2008; Bakam et al., 2012).

In the foreseeable future, for Hungary, implementation of such techniques is still in the early stage, thus our projection reveals that GHG emissions will continue to increase in the future from the AgS. Notably, on the European Union scale (EU-27), Mohammed et al. (2019) reported a reduction in GHG emissions from the AgS. However, the share of the AgS in total EU GHG emissions increased by 1.5 pp between 2007 and 2016 (Piwowar, 2020). It is important to mention here that any restriction or limitation on the AgS could have negative consequences for food production, sustainability, and security (Barry et al., 2010). Climate policies must therefore deal carefully with the AgS, especially that more than 58.809 billion € of EU funds were made available for "sustainable growth" in agriculture in 2015.

Eventually, CH_4 is produced by livestock (ruminants), while N_2O is released from manure decomposition and other agricultural activities, and 18% of global GHG emissions originate from the livestock sector (Lesschen et al., 2011). In Hungary, CH_4 emissions have decreased, while emissions of N_2O from the soil fluctuated with a positive trend (Fig. 4). This result could be explained by the intensive use of fertilization. A similar result was obtained by Molnar et al. (2011) where the average fertilization was higher than half of the amount between 1980 and 1985. Also, an increase in N_2O emissions in Hungary was reported by Haszpra et al. (2018). However, Lesschen et al. (2011) reported that emissions from organic soil were as high as in some other EU-27 countries.

Despite the positive significant trend of CH_4 emissions from the waste sector. Many factors, such as Europeanisation trends in Hungary, subsidies from the EU, and interaction between the host local community and multinational companies have enhanced the development of the waste management system. Obstacles to developing waste management sectors are the governance model (centralization), stakeholders' attitudes, and a lack of community participation in environmental policy-making (Mezei et al., 2018). Nonetheless, total CH_4 emissions have decreased significantly by 2.47 thousand tons/year.

4.3. GHG emissions from households' sector in Hungary

The Hungarian government declared that Nearly Zero-Energy Building (NZEB) will be started after 2020, and a decrease in CO_2 emissions from the building sector (households) was detected in the current situation (Fig. 3). This could be mainly attributed to the fact that a wide range of actions could enhance energy saving and CO_2 mitigation, such as (1) passive energy design; (2) thermal envelope improvement, (3) low carbon heating systems; and (4) shifting toward more efficient and energy-saving equipment (lights; electric appliances) (Novikova and Ürge-Vorsatz, 2007). However, the Nearly Zero-Energy Building seems far from being achieved in Hungary. Similarly, Fogarassy et al. (2015) emphasized the potential of the building sector in any GHG mitigation policies due to the implementation of new emissions-saving technology. Nonetheless, the Hungarian building sector is one of the pioneer sectors, where climate mitigation plans could be applied efficiently, in comparison to other sectors (Fogarassy and Horvath, 2015).

Notably, Hungarian commercial services are mainly divided into wholesale, transportation, accommodation, information, and communication, among them the accommodation services sector has the highest GHG emissions. However, the GHG emissions from this sector were characterized as stable and moderate (Dombi, 2019).

4.4. GHG emissions from the transportation sector in Hungary

The Hungarian transportation sector has contributed remarkably to energy consumption (Torok, and Zoldy, 2010). Along with the AgS, current and future projected CO_2 emissions from the transportation sector have shown a gradual increase, due to rapid increases in (1) passengers and cars, (2) road networks, and (3) fossil fuel consumption (Szendro et al., 2014). This was consistent with the findings of Torok and Zoldy (2010) who noted a reduction in all energy consumption sectors except for the transport sector, and recommended some action to minimize emissions, so that the transportation sector could significantly contribute to the reduction in the carbon footprint. Such actions will cost money but are affordable to achieve more climate-friendly roads.

4.5. EKC in Hungary

The long-run coefficient on energy consumption (EC) is positive and significant for CO_2 emission and CH_4; while it is insignificant for N_2O (Table 6). The EC appears negatively significant with appropriate signs in three equations (Table 5). It also confirms the long-run co-integrating relationship between the variables. The adjustment coefficient -0.74 for equation (10) suggests that 74% deviation in CO_2 is corrected every year towards its long-run equilibrium path (Table 5). A similar explanation can be extended to the EC term for CH_4 (35%) and N_2O (147%). According to Pesaran et al. (2001), the significant negative sign on EC in short-run dynamics is a stable measure of long-run equilibrium association among the variables.

Also, the stability of cointegrating relation is concerned, Pesaran et al. (2001) indicated that cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) do not have significant power as stability tests. The current study, therefore, considers EC term to gauge the stability of three models. The negative significant coefficient on EC term in all three models indicates that models are stable over the sample period of the study. Moreover, the current study employs Hansen (2002) parametric stability test to gauge any instability in the sample period. The results are reported in Table 7.

The probity values of LC statistics reject the hypothesis of parameter instability in favour of long-run parameter stability. Thus, the good fit and diagnostic tests conclude that models have desired econometric probabilities and can be utilized for policy implications on environmental issues.

The positive significant coefficient on income growth and negative significance on $(GDP)^2$ in the long-run, showed an EKC transition in Hungary. Credit goes to environmental policies such as a decrease in energy consumption (Yan et al., 2017); the economic transition in Hungary (Molnár, 2014), public interest in and awareness of climate change issues (Zemankovics, 2012), and local initiatives for promoting a climate strategy (Szirmai et al., 2008). These findings are in line with recent findings of Dogan and Inglesi-Lotz (2020), and Neagu (2019) which confirm the existence of the EKC in European countries for GHGs.

Despite the overall negative trend of overall emission of main GHGs, this study is based on the official data published by the Hungarian Central Statistical Office. Maybe some emission sources were not counted, due to some national policies, or were estimated based on some mathematical approaches, which could be considered as one of the limitations in this research. Nonetheless, the output of this work provides an important step towered analysing estimating trends of GHG emissions and their environmental impact on a national scale.

Table 7
Hansen test for parameter stability for Equations (10)–(12).

Dependent Variables	LC Test Statistics	Probability value
CO_2	.085	.25
CH_4	.094	.24
N_2O	.12	.21

5. Conclusion

Until recently, Policies in many countries were driven by economic growth; meanwhile, few plans were drawn out to mitigate environmental degradation, including minimizing GHG emissions. Within this context; the main aim of this research was to track changes in GHG emissions in Hungary between 1985 and 2018, and to find out if there is any turning point for the EKC. In this study the key findings could be summarized:

- Total emissions dropped remarkably between 1985 and 2018 by 81.5%, 69%, and 145.6% for CO_2, CH_4, N_2O, respectively.
- A positive significant increase in CO_2 emissions was recorded in both biomass and transportation sectors. However, CO_2 emissions from the industrial sector, energy sector household sector were dropped significantly ($p < 0.05$).
- Similar to CO_2, CH_4 and N_2O emissions were decreased significantly ($p < 0.05$) from most relevant sectors, except for soil in terms of N_2O emissions.
- The long-run positive effect on income growth and negative effect on income square indicate the existence of EKC relationship for CO_2 emission, $CH_{4,}$ and N_2O in Hungary implying that the economic growth in the future would lead to environmental improvement.

The implementation of environmental policies in Hungary has a positive impact on terms of environmental mitigation. However, an urgent plan for GHGs mitigation in the AgS is needed to minimize CO_2 and N_2O emissions.

CRediT authorship contribution statement

Safwan Mohammed: Conceptualization, Methodology, Writing – original draft. **Abid Rashid Gill:** Data curation, (EKC), Writing – original draft. **Karam Alsafadi:** Visualization, Investigation, Writing – review & editing. **Omar Hijazi:** Visualization, Investigation, Writing – review & editing. **Krishna Kumar Yadav:** Visualization, Investigation, Writing – review & editing. **Afzal Husain Khan:** Visualization, Investigation, Writing – review & editing. **Saiful Islam:** Visualization, Investigation, Writing – review & editing. **Marina M.S. Cabral-Pinto:** Visualization, Investigation, Writing – review & editing. **Endre Harsanyi:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors grateful for Debrecen University for supporting open access, The Islamia University of Bahawalpur, and the Hungarian Central Statistical Office for their unlimited support. The authors thankfully acknowledge the Deanship of Scientific Research, King Khalid University, Abha, Saudi Arabia , for funding the Project Grant No. RGP.1/174/42. The Debrecen University, the Islamia University of Bahawalapur and the Hungarian Central Statical Office for their unlimited support is also acknowledged.

References

Alsafadi, K., Mohammed, S.A., Ayugi, B., Sharaf, M., Harsányi, E., 2020. Spatial–Temporal evolution of drought characteristics over Hungary between 1961 and 2010. Pure Appl. Geophys. 177, 3961–3978. https://doi.org/10.1007/s00024-020-02449-5.

Antal, M., 2019. How the regime hampered a transition to renewable electricity in Hungary. Environ. Innov. Soc. Trans. 33, 162–182. https://doi.org/10.1016/j.eist.2019.04.004.

Antal, M., Karhunmaa, K., 2018. The German energy transition in the British, Finnish and Hungarian news media. Nat. Energy 3, 994–1001. https://doi.org/10.1038/s41560-018-0248-3.

Ayalon, O., Avnimelech, Y., Shechter, M., 2000. Alternative MSW treatment options to reduce global greenhouse gases emissions - the Israeli example. Waste Manag. Res. 18, 538–544. https://doi.org/10.1034/j.1399-3070.2000.00158.x.

Bai, A., Popp, J., Pető, K., Szőke, I., Harangi-Rákos, M., Gabnai, Z., 2017. The significance of forests and algae in CO2 balance: a Hungarian case study. Sustain. Times 9. https://doi.org/10.3390/su9050857.

Bakam, I., Balana, B.B., Matthews, R., 2012. Cost-effectiveness analysis of policy instruments for greenhouse gas emission mitigation in the agricultural sector. J. Environ. Manag. 112, 33–44. https://doi.org/10.1016/j.jenvman.2012.07.001.

Bălan, M., Vasile, V., 2013. Measures to reduce transportation greenhouse gas emissions in Romania. Qual. - Access Success 14, 306–310.

Barcza, Z., Bondeau, A., Churkina, G., Ciais, P., Czóbel, S., Gelybó, G., Grosz, B., Haszpra, L., Hidy, D., Horváth, L., Machon, A., Pásztor, L., Somogyi, Z., Van Oost, K., 2011. Model-based biospheric greenhouse gas balance of Hungary. In: Atmospheric Greenhouse Gases: the Hungarian Perspective, pp. 295–330. https://doi.org/10.1007/978-90-481-9950-1_13.

Barry, F., King, M., Matthews, A., 2010. Policy coherence for development: five challenges. Ir. Stud. Int. Aff. https://doi.org/10.3318/ISIA.2010.21.207.

Besmann, T.M., 2010. Projections of US GHG reductions from nuclear power new capacity based on historic levels of investment. Energy Pol. 38, 2431–2437. https://doi.org/10.1016/j.enpol.2009.12.036.

Brinkman, M.L.J., Wicke, B., Faaij, A.P.C., 2017. Low-ILUC-risk ethanol from Hungarian maize. Biomass Bioenergy 99, 57–68. https://doi.org/10.1016/j.biombioe.2017.02.006.

Dace, E., Blumberga, D., 2016. How do 28 European Union Member States perform in agricultural greenhouse gas emissions? It depends on what we look at: application of the multi-criteria analysis. Ecol. Indicat. 71, 352–358. https://doi.org/10.1016/j.ecolind.2016.07.016.

Deák, C., Palotás, Á.B., Mizsey, P., Viskolcz, B., 2018. Carbon-dioxide management network in Hungary. Chem. Eng. Trans. 70, 2143–2148. https://doi.org/10.3303/CET1870358.

Dickey, D.A., Fuller, W.A., 1981. Likelihood ratio statistics for autoregressive time series with a unit root. Econometrica 49, 1057. https://doi.org/10.2307/1912517.

Dogan, E., Inglesi-Lotz, R., 2020. The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries. Environ. Sci. Pollut. Res. 27, 12717–12724. https://doi.org/10.1007/s11356-020-07878-2.

Dombi, M., 2019. The service-stock trap: analysis of the environmental impacts and productivity of the service sector in Hungary. Environ. Res. Lett. 14 https://doi.org/10.1088/1748-9326/ab15be.

Engle, R.F., Granger, C.W.J., 2015. Co-integration and error correction: representation, estimation, and testing. Appl. Econ. 39, 107–135. https://doi.org/10.2307/1913236.

European Climate Foundation, 2010. Roadmap 2050: A Practical Guide to a Prosperous, Low Carbon Future. European Climate Foundation, The Hague, The Netherlands.

European Commission, 2011. A Roadmap for Moving to a Competitive Low Carbon Economy in 2050. COM, pp. 1–34, 2011.

Fogarassy, C., Horvath, B., 2015. Low-carbon building innovation trends and policy pespectives in Hungary between 2020 and 2030. YBL J. Built Environ. 3, 42–54. https://doi.org/10.1515/jbe-2015-0005.

Fogarassy, C., Horváth, B., Kovács, A., 2015. Cross-sector analysis of the Hungarian sectors covered by the Effort Sharing Decision – climate policy perspectives for the Hungarian agriculture within the 2021-2030 EU programming period. Appl. Stud. Agribus. Commer. 9, 17–24. https://doi.org/10.19041/apstract/2015/4/2.

Fogarassy, C., Kovacs, A., 2016. The cost-benefit relations of the future environmental related developments strategies in the Hungarian energy sector. YBL J. Built Environ. 4, 33–48. https://doi.org/10.1515/jbe-2016-0004.

Fogarassy, C., Nábrádi, A., 2015. Proposals for low-carbon agriculture production strategies between 2020 and 2030 in Hungary. Appl. Stud. Agribus. Commer. 9, 5–15. https://doi.org/10.19041/apstract/2015/4/1.

Freibauer, A., Rounsevell, M.D.A., Smith, P., Verhagen, J., 2004. Carbon sequestration in the agricultural soils of Europe. Geoderma. https://doi.org/10.1016/j.geoderma.2004.01.021.

Fuss, S., Szolgayová, J., 2010. Fuel price and technological uncertainty in a real options model for electricity planning. Appl. Energy 87, 2938–2944. https://doi.org/10.1016/j.apenergy.2009.05.020.

Gerland, P., Raftery, A.E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B.K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G.K., Wilmoth, J., 2014. World population stabilization unlikely this century. Science 84 346, 234–237. https://doi.org/10.1126/science.1257469.

Gill, A.R., Viswanathan, K.K., Hassan, S., 2018. A test of environmental Kuznets curve (EKC) for carbon emission and potential of renewable energy to reduce green house gases (GHG) in Malaysia. Environ. Dev. Sustain. 20, 1103–1114. https://doi.org/10.1007/s10668-017-9929-5.

Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. Q. J. Econ. 110, 353–377. https://doi.org/10.2307/2118443.

Güner Bacanli, Ü., 2017. Trend analysis of precipitation and drought in the Aegean region. Turkey. Meteorol. Appl. 24, 239–249. https://doi.org/10.1002/met.1622.

Hamed, K.H., 2008. Trend detection in hydrologic data: the Mann-Kendall trend test under the scaling hypothesis. J. Hydrol. 349, 350–363. https://doi.org/10.1016/j.jhydrol.2007.11.009.

Hansen, B.E., 2002. Tests for parameter instability in regreessions with I(1) processes. J. Bus. Econ. Stat. 20, 45–59. https://doi.org/10.1198/073500102753410381.

Haszpra, L., 2011. Atmospheric greenhouse gases: the Hungarian perspective, atmospheric greenhouse gases: the Hungarian perspective. https://doi.org/10.1007/978-90-481-9950-1.

Haszpra, L., Barcza, Z., Hidy, D., Szilágyi, I., Dlugokencky, E., Tans, P., 2008. Trends and temporal variations of major greenhouse gases at a rural site in Central Europe. Atmos. Environ. 42, 8707–8716. https://doi.org/10.1016/j.atmosenv.2008.09.012.

Haszpra, L., Hidy, D., Taligás, T., Barcza, Z., 2018. First results of tall tower based nitrous oxide flux monitoring over an agricultural region in Central Europe. Atmos. Environ. 176, 240–251. https://doi.org/10.1016/j.atmosenv.2017.12.035.

Hernández, F., Gual, M.Á., Del Río, P., Caparrós, A., 2004. Energy sustainability and global warming in Spain. Energy Pol. 32, 383–394. https://doi.org/10.1016/S0301-4215(02)00308-7.

Herzog, T., 2009. World Greenhouse Gas Emissions in 2005. World Resources Institute, Washington.

Huang, C., Li, N., Zhang, Z., Liu, Y., Chen, X., Wang, F., 2020. Assessment of the economic cascading effect on future climate change in China: evidence from agricultural direct damage. J. Clean. Prod. 276 https://doi.org/10.1016/j.jclepro.2020.123951.

Jambor, A., Sirone Varadi, J., 2014. 10 years of EU membership: winners and losers in the agri-food sector of the new member states (No. 727-2016-50485).

Johansen, S., 1995. *Likelihood-based inference in cointegrated vector autoregressive models.* Oxford University Press on Demand, Oxford, UK.

Jursová, S., Burchart-Korol, D., Pustějovská, P., Korol, J., Blaut, A., 2018. Greenhouse gas emission assessment from electricity production in the Czech Republic. Environ. - MDPI 5, 1–10. https://doi.org/10.3390/environments5010017.

Kannan, R., 2009. Uncertainties in key low carbon power generation technologies - implication for UK decarbonisation targets. Appl. Energy 86, 1873–1886. https://doi.org/10.1016/j.apenergy.2009.02.014.

Kendall, M.G., 1975. Rank Correlation Methods, fourth ed. Charles Griffin, San Francisco, CA.

Kijewska, A., Bluszcz, A., 2016. Research of varying levels of greenhouse gas emissions in European countries using the k-means method. Atmos. Pollut. Res. 7, 935–944. https://doi.org/10.1016/j.apr.2016.05.010.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., Shin, Y., 1992. Testing the null hypothesis of stationarity against the alternative of a unit root. How sure are we that economic time series have a unit root? J. Econom. 54, 159–178. https://doi.org/10.1016/0304-4076(92)90104-Y.

Leal Filho, W., Bönecke, J., Spielmann, H., Azeiteiro, U.M., Alves, F., Lopes de Carvalho, M., Nagy, G.J., 2018. Climate change and health: an analysis of causal relations on the spread of vector-borne diseases in Brazil. J. Clean. Prod. 177, 589–596. https://doi.org/10.1016/j.jclepro.2017.12.144.

Lean, H.H., Smyth, R., 2010. CO2 emissions, electricity consumption and output in ASEAN. Appl. Energy 87, 1858–1864. https://doi.org/10.1016/j.apenergy.2010.02.003.

Lesschen, J.P., van den Berg, M., Westhoek, H.J., Witzke, H.P., Oenema, O., 2011. Greenhouse gas emission profiles of European livestock sectors. Anim. Feed Sci. Technol. 166–167, 16–28. https://doi.org/10.1016/j.anifeedsci.2011.04.058.

Li, K., An, X., Park, K.H., Khraisheh, M., Tang, J., 2014. A critical review of CO2 photoconversion: catalysts and reactors. Catal. Today 224, 3–12. https://doi.org/10.1016/j.cattod.2013.12.006.

MacKinnon, J., 2010. Critical Values for Cointegration Tests (No. 1227). Queen's Economics Department Working Paper, Ontario. https://doi.org/10.22004/ag.econ.273723.

Mahajan, D.R., Dodamani, B.M., 2015. Trend analysis of drought events over upper krishna basin in Maharashtra. Aquat. Procedia 4, 1250–1257. https://doi.org/10.1016/j.aqpro.2015.02.163.

Major, I., Haszpra, L., Rinyu, L., Futó, I., Bihari, Á., Hammer, S., Jull, A.J.T., Molnár, M., 2018. Temporal variation of atmospheric fossil and modern CO2 Excess at a central european rural tower station between 2008 and 2014. Radiocarbon 1285–1299. https://doi.org/10.1017/RDC.2018.79.

Mathiesen, B.V., Lund, H., Karlsson, K., 2011. 100% Renewable energy systems, climate mitigation and economic growth. Appl. Energy 88, 488–501. https://doi.org/10.1016/j.apenergy.2010.03.001.

Mei, B., Yue, H., Zheng, X., McDowell, W.H., Zhao, Q., Zhou, Z., Yao, Z., 2018. Effects of grazing pattern on ecosystem respiration and methane flux in a sown pasture in Inner Mongolia, China. Atmosphere 10. https://doi.org/10.3390/atmos10010005.

Mezei, C., Kovács, S.Z., Trenyik, T., Nagy, I., 2018. Energy potential of waste: case study of the Hungarian waste management system. In: 16. Skup O Prirodnom Plinu, Toplini I Vodi= 16th Natural Gas, Heat and Water Conference: 9. Međunarodni Skup O Prirodnom Plinu, Toplini I Vodi= 9th International Natural Gas, Heat and Water Conference. Osijek, Horvátország, pp. 189–198, 2018.09. 26-2018.09. 28.

Mohammed, S., Alsafadi, K., Daher, H., Gombos, B., Mahmood, S., Harsányi, E., 2020. Precipitation pattern changes and response of vegetation to drought variability in the eastern Hungary. Bull. Natl. Res. Cent. 44, 1–10. https://doi.org/10.1186/s42269-020-00306-y.

Mohammed, S., Alsafadi, K., Takács, I., Harsányi, E., 2019. Contemporary changes of greenhouse gases emission from the agricultural sector in the EU-27. Geol. Ecol. Landscapes 4, 282–287. https://doi.org/10.1080/24749508.2019.1694129.

Molnár, M., 2014. Opportunities for Hungary under the stability reserve of the EU ETS. J. Central European Green Innov. 2 (1063–2016-86172), 105–114.

Molnar, S., Molnar, M., Csabragi, A., 2011. Impact assessment of mitigation strategies in the Hungarian agriculture. J. Agric. Informatics 2. https://doi.org/10.17700/jai.2011.2.1.43.

Molnár, S., Takács, T., Pálvölgyi, T., Faragó, T., Tajthy, T., 1996. Greenhouse gas emissions and removals in Hungary. In: Braatz, B.V., Jallow, B.P., Molnár, S., Murdiyarso, D., Perdomo, M., Fitzgerald, F.J. (Eds.), Greenhouse Gas Emission Inventories. Springer, Dordrecht, pp. 275–287. https://doi.org/10.1007/978-94-017-1722-9_17.

Neagu, O., 2019. The link between economic complexity and carbon emissions in the European Union countries: a model based on the Environmental Kuznets Curve (EKC) approach. Sustain. Times 11. https://doi.org/10.3390/su11174753.

Novikova, A., Ürge-Vorsatz, D., 2007. Carbon dioxide mitigation potential in the Hungarian residential sector. In: Report on Behalf of the Ministry of Environment and Water of the Republic of Hungary. CEU-3CSEP, Budapest, Hungary.

Oberthür, S., Groen, L., 2018. Explaining goal achievement in international negotiations: the EU and the Paris Agreement on climate change. J. Eur. Publ. Pol. 25, 708–727. https://doi.org/10.1080/13501763.2017.1291708.

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., Erasmi, S., 2016. Greenhouse gas emissions from soils—a review. Chem. Erde. https://doi.org/10.1016/j.chemer.2016.04.002.

Pathak, A.A., Dodamani, B.M., 2020. Trend analysis of rainfall, rainy days and drought: a case study of Ghataprabha River Basin, India. Model. Earth Syst. Environ. 6, 1357–1372. https://doi.org/10.1007/s40808-020-00798-7.

Pesaran, M.H., Shin, Y., 1998. An autoregressive distributed-lag modelling approach to cointegration analysis. Econom. Soc. Monogr. 31, 371–413.

Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econom. 16, 289–326. https://doi.org/10.1002/jae.616.

Phillips, P.C.B., Hansen, B.E., 1990. Statistical inference in instrumental variables regression with i(1) processes. Rev. Econ. Stud. 57, 99–125. https://doi.org/10.2307/2297545.

Piwowar, A., 2020. Challenges associated with environmental protection in rural areas of Poland: empirical studies' results. Econ. Soc. 13, 217–229. https://doi.org/10.14254/2071-789X.2020/13-1/14.

Pradhan, B.B., Chaichaloempreecha, A., Limmeechokchai, B., 2019. GHG mitigation in agriculture, forestry and other land use (AFOLU) sector in Thailand. Carbon Bal. Manag. 14 https://doi.org/10.1186/s13021-019-0119-7.

Radics, K., Bartholy, J., 2008. Estimating and modelling the wind resource of Hungary. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2006.10.009.

Sáfián, F., 2014. Modelling the Hungarian energy system - the first step towards sustainable energy planning. Energy 69, 58–66. https://doi.org/10.1016/j.energy.2014.02.067.

Schmidt, J., Leduc, S., Dotzauer, E., Kindermann, G., Schmid, E., 2010. Cost-effective CO2 emission reduction through heat, power and biofuel production from woody biomass: a spatially explicit comparison of conversion technologies. Appl. Energy 87, 2128–2141. https://doi.org/10.1016/j.apenergy.2009.11.007.

Sen, P.K., 1968. Estimates of the regression coefficient based on kendall's tau. J. Am. Stat. Assoc. 63, 1379–1389. https://doi.org/10.1080/01621459.1968.10480934.

Shafik, N., 1994. Economic development and environmental quality: an econometric analysis. Oxf. Econ. Pap. 46, 757–773. https://doi.org/10.1093/oep/46.Supplement_1.757.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric. Ecosyst. Environ. https://doi.org/10.1016/j.agee.2006.06.006.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, J., 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. B Biol. Sci. https://doi.org/10.1098/rstb.2007.2184.

Somogyi, Z., 2000. Possibilities for carbon sequestration by the forestry sector in Hungary. Biotechnol. Agron. Soc. Environ. 4, 296–299.

Stewart, B.M., Turner, S.E., Matthews, H.D., 2020. Climate change impacts on potential future ranges of non-human primate species. Climatic Change 162, 2301–2318. https://doi.org/10.1007/s10584-020-02776-5.

Szendro, G., Csete, M., Török, Á., 2014. The sectoral adaptive capacity index of Hungarian road transport. Periodica Polytech. Soc. Manag. Sci. 22, 99–106. https://doi.org/10.3311/PPso.7377.

Szirmai, V., Molnár, B., Szépvölgyi, Á., Schuchmann, J., Váradi, Z., 2008. A klímaváltozás térbeli hatásai a budapesti társadalomban (Regional effects of climate change in the society of Budapest). Klíma-21 füzetek, 54,, 51–71.

Szlavik, J., Csete, M., 2012. Climate and energy policy in Hungary. Energies 5, 494–517. https://doi.org/10.3390/en5020494.

Szlávik, J., Pálvölgyi, T., Füle, M., Ürge-Vorsatz, D., 2000. Carbon mitigation in Hungary: challenges for a sustainable national energy policy. Periodica Polytech. Soc. Manag. Sci. 8, 103–120.

Talamon, A., Papp, R.V., Vokony, I., Hartmann, B., 2019. Global solar energy trends and potential of building sector in Hungary. Interdiscip. Descr. Complex Syst. 17, 51–57. https://doi.org/10.7906/indecs.17.1.7.

Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. U. S. A 108, 20260–20264. https://doi.org/10.1073/pnas.1116437108.

Titov, A., Kövér, G., Tóth, K., Gelencsér, G., Horváthné Kovács, B., 2021. Acceptance and potential of renewable energy sources based on biomass in rural areas of Hungary. Sustain. Times 13, 1–19. https://doi.org/10.3390/su13042294.

Tolón-Becerra, A., Lastra-Bravo, X., Bienvenido-Bárcena, F., 2010. Methodology proposal for territorial distribution of greenhouse gas reduction percentages in the EU according to the strategic energy policy goal. Appl. Energy 87, 3552–3564. https://doi.org/10.1016/j.apenergy.2010.06.016.

Török, Á., 2009. Greenhouse gas emission of Hungarian transport sector. Period. Polytech. Transp. Eng. 37, 65–69. https://doi.org/10.3311/pp.tr.2009-1-2.11.

Torok, A., Zoldy, M., 2010. Energetic and economical investigation of greenhouse gas emission of Hungarian road transport sector. Pollack Period. 5, 123–132. https://doi.org/10.1556/Pollack.5.2010.3.10.

Tóth, E., Farkas, C., Koós, S., Németh, T., 2010. Effect of tillage on soil carbon dioxide emission I. Testing a laboratory method on undisturbed soil columns. Agrokémia és Talajt. 58, 215–226. https://doi.org/10.1556/agrokem.58.2009.2.4.

Tóth, E., Koós, S., Farkas, C., Németh, T., 2005. Carbon-dioxide emission from calcareous chernozem soil. Cereal Research Communications, pp. 129–132. https://doi.org/10.1556/CRC.33.2005.1.31.

Tóth, J.C., Hollósy, Z., Poór, J., 2018. Energy and renewable energy use in EU28 and Hungary on the basis of statistics. Analecta Tech. Szeged. 12, 51–56. https://doi.org/10.14232/analecta.2018.2.51-56.

UNFCCC, 2015. Greenhouse Gas Inventory Data. Greenh. Gas Invent. Data, 2014.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O., Bairlein, F., 2002. Ecological responses to recent climate change. Nature. https://doi.org/10.1038/416389a.

Yan, Q., Yin, J., Baležentis, T., Makutėnienė, D., Štreimikienė, D., 2017. Energy-related GHG emission in agriculture of the European countries: an application of the Generalized Divisia Index. J. Clean. Prod. 164, 686–694. https://doi.org/10.1016/j.jclepro.2017.07.010.

Yang, L., Lu, F., Zhou, X., Wang, X., Duan, X., Sun, B., 2014. Progress in the studies on the greenhouse gas emissions from reservoirs. Acta Ecol. Sin. 34, 204–212. https://doi.org/10.1016/j.chnaes.2013.05.011.

Yarnal, B., 1996. Socioeconomic transition and greenhouse-gas emissions from Bulgaria. Geogr. Rev. 86, 42–58. https://doi.org/10.2307/215140.

Zemankovics, M.H., 2012. Mitigation and adaptation to climate change in Hungary. J. Cent. Eur. Agric. https://doi.org/10.5513/JCEA01/13.1.1015.

Zhang, C., Zeng, G., Huang, D., Lai, C., Chen, M., Cheng, M., Tang, W., Tang, L., Dong, H., Huang, B., Tan, X., Wang, R., 2019. Biochar for environmental management: mitigating greenhouse gas emissions, contaminant treatment, and potential negative impacts. Chem. Eng. J. https://doi.org/10.1016/j.cej.2019.05.139.