



# Are economic growth and environmental pollution a dilemma?

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## Abstract

For the first time, this study introduces-proposes using the Armeey curve hypothesis (ACH) for testing the environmental Kuznets curve hypothesis (EKCH) in the relevant literature. The rationale for this new proposed methodology is that both hypotheses are expected to have similar inverted U-shaped curves. Hence, we combine the aforementioned hypotheses to obtain a single composite model. This single model may allow us to calculate a maximum (optimum) level of government expenditures that will increase or decrease CO<sub>2</sub> emissions for USMCA (the USA-Mexico-Canada Agreement) countries. To this end, our study employs an augmented mean group (AMG) estimator. The results demonstrate that the EKCH is verified by way of the AC model only for Mexico. Additionally, with the advantage of this approach, we calculated the optimal government spending level, which will increase both per capita real GDP (RGDPPC) and CO<sub>2</sub> emissions in this country by around 26.4% of RGDPPC. This level of spending will be a kind of threshold point for the Mexican government's policymakers. Hence, they will know that if they continue to spend more than this level, both the RGDPPC and CO<sub>2</sub> emissions will decrease, implying either a lower RGDPPC or a cleaner environment. The primary purpose of the proposed methodology in this study is to reveal the possible effects of the government's economic growth-oriented increased public expenditures on the environment in a single composite model. In other words, the relationship between economic growth and the environment is approached from the perspective of public spending, and it is reminded that governments should have harmonious and sustainable public spending policies for both economic growth and a cleaner environment.

**Keywords** Armeey curve hypothesis · Environmental Kuznets curve hypothesis · CO<sub>2</sub> emissions · Augmented mean group estimator

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## Introduction

Previously, the role of government in economic growth has been debated by several researchers (for instance, Azam 2022; Emara and Said 2021; Alhassan et al. 2020; Thanh et al. 2020; Dzhumashev 2014). Furthermore, in the theoretical discussion, Wagner, (1863); Smith, (1937); Solow's (1956) neoclassical growth model asserts that fiscal policies involving taxes and government expenditures can affect economic growth, while the endogenous growth model, developed by Romer (1986), Lucas (1988), and Barro (1990), posits that government can

influence economic growth since transition and steady-state growth rates and government are considered endogenous. This indicates that governments have a significant impact on the economy. In light of the above discussion regarding the significance of the government in an economy, our study sheds light on one of the most discussed questions is "How big should the government sector be in an economy?" Armeey (1995) argues that economic growth and government expenditures must be non-linear. Figure 1 depicts this expected correlation between economic growth and government expenditures, which is similar to an inverted U-shaped relationship proposed by Armeey (1995) shown with a curve below, known as the Armeey curve hypothesis (ACH).

Economic growth as measured by RGDPPC will increase with the expansion of the government sector until a turning point, but it will decrease with the extension of the government

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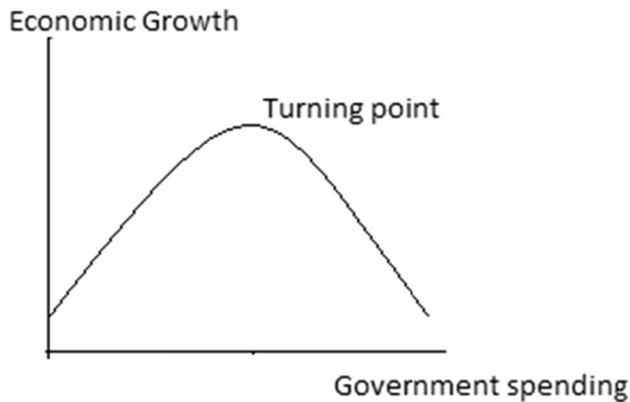


Fig. 1 Armeey curve

sector's size after that point (Amin and Dogan 2021). Briefly, the AC curve demonstrates that the positive relationships between the level of government expenditures and economic growth, which stem from the law of increasing returns, will go up until a certain point and then come down with the law of decreasing returns. Here, the concept of government spending, in general, represents the sum of the elements that constitute the cost of all the work the governments do to fulfill the functions they take on (Vedder and Gallaway 1998; Chen and Lee 2005; Herath 2012; Vasilev 2020). While production scale increases with an increase in economic growth, which is influenced by government spending, the environmental factor comes into prominence along with sectoral diversity (Dogru et al. 2019, 2020; Radulescu and Sandra 2019; Oktavilia et al. 2021; Abbsass et al. 2022a, b; Ahmad et al. 2021a, b; Makiyan and Amareh 2021; Pata and Işık 2021; Turna and Özcan 2021; Alsanusi et al. 2022; Asif et al. 2022; Avci and Sarıgül 2022). Production effectiveness is secured by using fewer inputs that cause pollution per output when technological developments and other factors are constant (Mutascu and Milos 2009; Ichinose et al. 2015; Aydın and Esen 2019; Wang and Wang 2020; Dogan et al. 2022a; Fatima et al. 2022; Hussain et al. 2022; Taskin et al. 2022; Yasir et al. 2022; Singh et al. 2023). The process of emission-specific change results in less pollution per input, which causes potential pollution (Akan et al. 2007, 2010; Bulut 2017; Ongan et al. 2017, 2018, 2022; Rafindadi and Ozturk 2017; Rafindadi et al. 2018; Su and Cen 2018; Schmidt and Wigerstedt 2019). Thus, factors are influenced by environmental regulations or innovation policies, which are built on different foundations (Wang and Wang 2020; Chen et al. 2020; Shahid et al. 2021; Rehman et al. 2021a, b, c, 2022a, b, 2023a, b; Turna and Özcan 2021; Abbass et al. 2022a, b, c, d; Ahmad et al. 2022, 2023; Alvarado et al. 2021a, b, 2022a, b, c; Avci and Sarıgül 2022; Azam 2022; Baig et al. 2022; Deng et al. 2022; Dogan et al. 2022b; Işık 2010, 2013; Işık and Radulescu 2017; Işık et al. 2017, 2018, 2020a, b, 2021a, 2022; Kartal et al. 2022; Çetin et al. 2023).

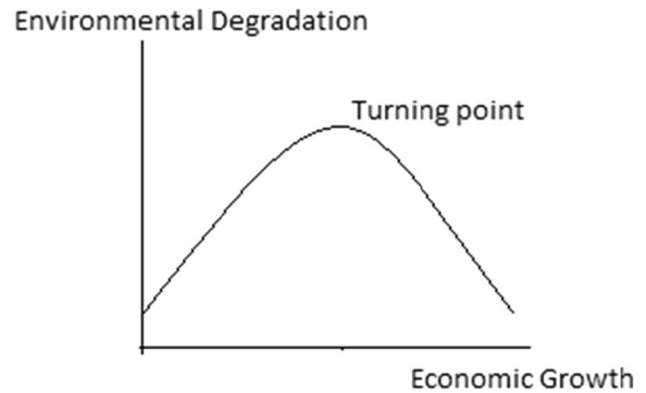


Fig. 2 EKC

The directionally causal transmission mechanism mentioned above from the level of government expenditures and economic growth, based on the AC, to an environmental pollution issue similar to another inverted U-shaped curve refers to the EKC, initially projected by Grossman and Krueger (1991). EKCH explains that an upward trend in economic growth initially leads to a decrease in environmental quality until a turning point, but eventually, it leads to a decrease in such degradation with the increase in growth after that point. Many factors can result in this non-linear linkage between economic growth and environmental deterioration (Stern 2004). In the environmental literature, there is no discussion about whether or not the EKC hypothesis is true and for what types of countries, but most studies have looked at economic growth as a whole without taking into account how different countries' economies are set up. For instance, following Grossman and Krueger (1991), the studies of Beckerman (1992) and Panayotou (1993) concluded that economic growth caused environmental deterioration, while Stern et al. (1996) researched the pollution concentrations and improvements of economic activities. McConnell (1997) concludes that pollution originates from consuming goods instead of from the production process. Magnani (2001) argues against government policy, and Andreoni and Levinson (2001) claim the adequacy of the EKC. The USMCA countries aim to mitigate emissions by an average of 11.8% at the end of the Kyoto Protocol's first commitment period. Meanwhile, the USMCA countries projected a reduction in emissions of up to 60% by 2030. On the basis of these projections, it is essential to understand the determinants of emissions, and the validity of the EKC hypothesis for USMCA economies. Figure 2 depicts the nexus between growth (RGDP) and environmental deterioration (for instance, CO<sub>2</sub> emissions), which resembles an inverted U-shaped curve.

In summary, the two inverted U-shaped curves can be differentiated as the ACH investigates how government expenditures affect per capita growth, while the EKCH analyzes the effects of per capita GDP growth on CO<sub>2</sub> emissions. Even though, at first sight, the difference seems to be that these are

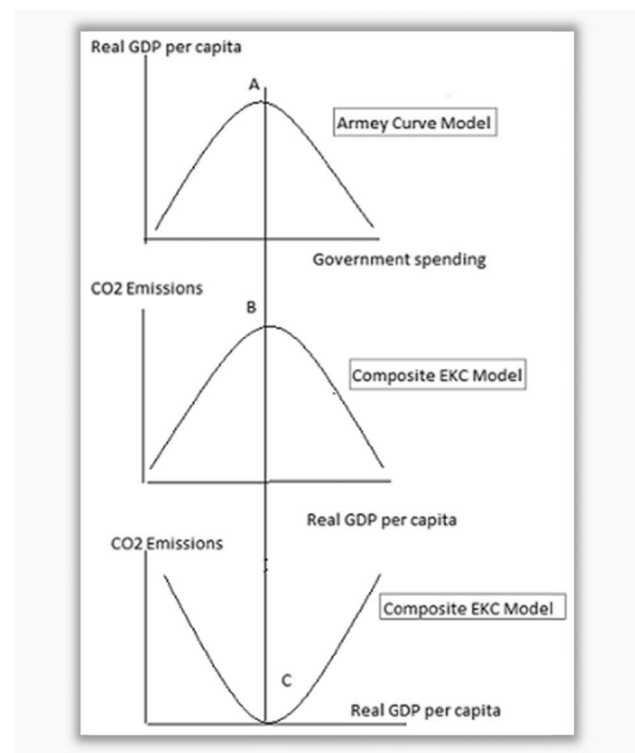


**Fig. 3** Transmission from the Arme y curve to the EKC

two separate issues because regress and regressors of these two hypotheses differ, it becomes apparent on looking more closely that all those variables have a direct causal association. It seems that an increase in government expenditures causes RGDPPC to rise, and thereby, increases in RGDPPC cause environmental degradation, i.e., CO<sub>2</sub> emissions. Furthermore, the mathematical postulates that both curves have been built on expected non-linear relationships plotted with two inverted U-shaped curves. This causal, variable-based relationship from the ACH to the EKCH can be seen in the following Fig. 3.

This possible transmission mechanism described above may enable us to test the EKCH by way of the ACH (model) in a new, single composite model. Because the dependent variable (GDP growth) of the Arme y curve model is also a causally independent variable of the EKC model. It should be noted that government spending was used in some empirical studies for EKCH testing (Amadou 2014; Dogan and Turkekul 2016; Rafindadi 2016a, b; Gnonlonfin et al. 2017; Nguyen et al. 2019; İşık et al. 2019a, b; 2020a, 2021b; Rafindadi and Usman 2019; Amin et al. 2020a, b; Dogan and Inglesi-Lotz 2020; Murshed et al. 2021; Othman and Bekhet 2021; Abdulqadir 2021, 2022). However, in all these previous studies in the related literature, government spending is used as a single independent variable in the EKC models, and scholars explained how government spendings affect environmental pollution (e.g., CO<sub>2</sub>). The methodology in our study is very different. Thus, government spending is not an independent variable of our EKC model but an independent variable of the AC model. For this reason, this study has two research questions, in line with the contributions of the methodology applied, as listed below, and depending on shape of the curve in the composite model. The first question, in the case of the composite model depicts a U-shaped curve, is: can we calculate (set) a maximum level of government expenditure that will minimize CO<sub>2</sub> emissions? Second question, if this curve is an inverted U-shape, can we calculate or set a maximum level of government expenditure that will maximize CO<sub>2</sub> emissions? Therefore, the answers to these two research questions will fill in the gaps in the related literature. We seek answers to these questions by integrating two different hypotheses into a single composite model. While doing this, we are also questioning whether environmental and economic policies work in harmony with each other. In a sense, this can also be considered a third side research question of this study. This study, with its proposed methodological approach mentioned above, makes the

following several contributions. (i) It will synthesize, for the first time, the causal and expected non-linear relationships of the EKC and Arme y curve hypotheses (models) in a single composite model. The methodological approach recommended here is combined as the “composite economic model (CEM),” which is composed of seemingly two different but strongly interrelated models, and it is re-interpreted. (ii) The benefit of such a method is that the composite model may allow us to calculate the optimum government spending level (through a maximum RGDPPC level) that minimizes or maximizes the CO<sub>2</sub> emission level. If the composite model’s curve demonstrates an inverted U-shape (as obvious in Fig. 4B below), this optimum level of government spending will provide an increasing CO<sub>2</sub> emission level. The maximum point of the inverted U-shaped letter (∩) will correspond to the maximum level of CO<sub>2</sub> emissions. If the curve of the mentioned model is U-shaped (U) (demonstrates by Fig. 4C below), then this maximum (optimal) spending level will provide a minimum CO<sub>2</sub> emission level. The lower part of the letter U will correspond to the decreasing level of CO<sub>2</sub> emissions. Therefore, policymakers may easily increase their economic growth and design environmental policies proactively at this optimal level. Because they will know their sustainable-optimal government spending and RGDPPC levels (their limits), there will be no increase in environmental degradation. To calculate the maximum



**Fig. 4** Different shapes of the Arme y curve model and composite EKC model

(optimal) government expenditure level that will increase or decrease CO<sub>2</sub> emissions, the maximization formula we developed and used will be presented and explained in Section 3. (iii) Our composite model will show how RGDPPC, government expenditures, and CO<sub>2</sub> emissions interact with each other. (iv) The study, thanks to CEM, will also use, for the first time, a new, non-linear, mathematical approach in EKC literature. (v) The possible transmission mechanism from the ACH to the EKCH, shown in Fig. 3, can be, to some degree, interpreted as another transmission mechanism from economic policy to energy policy. As interpreted in this transmission mechanism, while we regard government spending-based economic growth policy through ACH, we interpret the economic growth-bases energy policy through the EKCH. This information may, therefore, provide the government with significant information about how their energy and economic policies interact, or, to some degree, whether both of the aforementioned policies work in harmony with one another. The U-shaped curve of this composite model (Fig. 4C) explains that both economic and energy policies *concurrently* interact with one another since CO<sub>2</sub> emissions fall during economic growth and rise during declines in the economy. If this is an inverted U-shaped curve (Fig. 4B), it can be assumed that there is a slow interaction between both policies because CO<sub>2</sub> emissions decline when there arise a turning point in economic growth.

However, to be able to test the EKCH by way of the ACH model for a specific country, we, first, must verify the ACH for this country. This means that the verified ACH and inverted U-shaped curve of a composite EKC model will verify the EKCH by way of the ACH (model) for a specific country. If the curve is U-shaped, this will mean that the composite model does not verify the EKCH. However, this does not mean that we cannot test the EKCH way of the ACH unless the composite model is insignificant. The shape of our composite model curve can be U-shaped, or an inverted U-shaped.

All of the empirical studies testing the EKC hypothesis in the relevant literature have been conducted within the framework of the classical EKC model, which is directly based on the expected impact of the increase in national income on the environment (inverted U-shaped curve). However, this study differs from all previous studies with its methodology, as explained above. This methodology aims to reveal the possible effects of the government's increased public spending on economic growth on the environment in a single composite model. In other words, the relationship between economic growth and the environment is approached from the perspective of public spending, and it is reminded that governments should have harmonious and sustainable public spending policies for both economic growth and a cleaner environment. This means that

governments should have compatible economic growth and environmental policies. It should be noted that the methodology introduced-proposed in this study takes a different methodological approach from the different econometric methodologies used in previous studies. Therefore, it will not be possible to technically compare the empirical results of this study with the previous ones in this direction.

In this study, we will use our proposed composite model to test the EKCH by way of the ACH (model) for the USMCA countries, namely, the USA, Canada, and Mexico. The rationale for selecting the largest trading bloc countries is that they have different government spending levels, RGDPPC, and CO<sub>2</sub> emissions. Therefore, this study's empirical findings may provide important and critical information to these countries' policymakers about how government spending, RGDPPC, and CO<sub>2</sub> emissions interact with one another since they can introduce some effective energy policies to achieve a more sustainable environment considering they have common borders. Moreover, since these are cross-border countries, any environmental problem in principle will be a problem not only for that country but also for the other two countries. Therefore, it will be required that these countries' economic and environmental policies be compatible and coordinated with each other. Therefore, these countries can be considered suitable sample countries.

Figure 4 is created to clearly show the relationships between the AC model and our potential composite EKC models (CEMs).

## Literature review

Adolph Wagner is the economist who argued that the relative volume of the government sector would grow bigger in parallel to the increase in income per person, which is also known as Wagner's law in the literature. Later, after Wagner, Peacock, and Wiseman (1961) found that the increase in the level of government expenditures during the period between 1890 and 1960 resulted in progress in England's economy. Consequently, Rostow (1961) and Musgrave (1969) demonstrated that economic development and growth were influential in government spending and that government investment spending was higher than total investment spending in the current period. Barro (1990) analyzed the case in 98 countries between 1970 and 1985 and exhibited negative relationships between growth rates in national income per person and the share of governments' consumption expenditures in a country's overall income. In the empirical verification of the ACH, Karras (1997) determined the verification of the ACH at the level of 16% optimal threshold government spending for 20 European countries by using the neoclassical production function. By employing the

threshold regression approach for Taiwan, the findings of Chen and Lee (2005) confirmed this hypothesis by 11–25%. Chobanov and Mladenova (2009) used the Scully model and verified this hypothesis for 81 countries (10.04%). De Witte and Moesen (2010) confirmed this hypothesis (3.7%) for 23 OECD countries using nonparametric data envelopment analysis. Mutaşcu and Miloş (2009) used the non-linear regression approach and supported ACH for 27 EU countries (27.4%). Altunc and Aydin (2013) used the autoregressive distributed lag (ARDL) approach and confirmed this for Romania, Bulgaria, and Turkey, at 20, 22, and 25 percentage rates, respectively. Ferris and Voia (2015) used nonparametric analysis and supported the ACH for Canada (8.9%). Mendonça and Cacicedo (2015), on the other hand, used the generalized moments method (GMM) and the ordinary least squares (OLS) method. They confirmed this hypothesis for Brazil (22%). García (2019) used the cointegration analysis to determine the validity of this hypothesis for Spain at the level of a 40.07% optimal threshold for government spending. By employing the threshold autoregressive (TAR) approach, the findings of Aydin and Esen (2019) confirmed the significance of the ACH for 26 transition countries (11.67–17.54%). Kim et al. (2020) use the Granger causality approach: their analysis proved this hypothesis for South Korea (28.67%). Yet, for the OECD countries, Afonso and Furceri (2010) employed the panel regression technique, and they were unable to prove this hypothesis. Ghose and Das (2013) could not confirm the hypothesis for 19 rising economies by using the cointegration approach. Concerning the EKCH, several scholars have tested it using different methods for different countries after Grossman and Krueger (1991). Apergis and Payne (2009) used the panel vector error-correction approach, but their findings did not support the EKCH for six central USA economies. Acaravcı and Ozturk (2010) used the ARDL approach for 19 European countries but could not confirm this hypothesis. Heidari et al. (2015) employed the panel smooth transition regression for five ASEAN countries, but their findings could not prove the EKCH. For 106 economies, Antonakakis et al. (2017) used the panel vector auto-regression approach; however, their findings did not provide support in favor of the EKCH for those countries. Bekhet et al. (2018) used the vector error-correction model (VECM), Granger causality, the CUSUM, and the CUSUMSQ tests and could support the EKCH for Malaysia. Hu et al. (2018) could not confirm this hypothesis for 25 developing countries using the fully modified ordinary least squares (FMOLS), and dynamic (DOLS) estimators. However, Ichinose et al. (2015) used the OLS model for Japan and supported the EKCH. Apergis (2016) applied both panel-based and time-series-based cointegration and found that the time-varying cointegration approach supports the EKCH for 12 out of the 15 countries. Bilgili

et al. (2016) used the panel FMOLS, and DOLS models and confirmed this hypothesis for 17 OECD countries. Arbulu et al. (2015) used the pooled OLS and supported the EKCH for 25 European economies. Kim et al. (2018) confirmed the EKCH for China by using the geographically weighted regression. Su and Chen (2018) employed OLS for Taiwan, and confirmed this hypothesis. Madden et al. (2019) used the pooled OLS and the GTWR models for Australia and supported the hypothesis. Barnes (2019) applied the OLS model for 151 countries and found evidence for the EKCH. Cheng et al. (2020), using the difference in difference (DID) model for China, supported this EKCH. Dogan et al. (2020) used panel data analysis and could not confirm the EKCH for the BRIC countries. Ongan et al. (2021) used the decomposition process, and their results support this hypothesis for the USA. Işık et al. (2021) used the same decomposition methodology for eight OECD countries. They found that the undecomposed model supports the EKCH for 4 out of eight countries. However, the results of all the studies above do not give a clear picture of the validity of the EKCH in relevant literature like the ACH.

## Data, model, and econometric technique

### Model

The composite economic model (CEM) employed for the first time in this study was derived from the AC and the EKCH models by following the stages described below. The AC model with natural logarithmic form is given as follows:

$$\ln Y_{it} = \alpha + \beta \ln PS_{it} + \gamma \ln PS_{it}^2 + \varepsilon_{it} \quad (1)$$

where  $\gamma < 0$ ;  $Y$  is RGDP (local currencies);  $PS$  and  $PS^2$  are government spending and the square of government spending values, respectively;  $\varepsilon$  represents error term. The ACH will be verified for a USMCA country if  $\beta$  and  $\gamma$  represent increasing (+) and decreasing (–) signs, respectively. The yearly data of all variables utilized in this study was acquired from the World Bank (WB 2020). The study's sample period is between 1971 and 2016. Following the AC model in Eq. (1), the EKC model is defined as follows:

$$\ln CO2_{it} = a + b \ln Y_{it} + c \ln Y_{it}^2 + \varepsilon_{it} \quad (2)$$

where  $c < 0$ ;  $CO_2$  is carbon emission (metric million tons);  $Y$  and  $Y^2$  are RGDP and square of RGDP, respectively; and  $\varepsilon$  represents error term. The EKCH will be verified for a USMCA country if  $b$  and  $c$  demonstrate increasing (+) and decreasing (–) signs, respectively. The yearly data of variables was obtained from the World Bank (WB 2020).

It is obvious from the models of AC and EKC in Eqs. (1) and (2), we obtain our composite EKC model (CEM) in Eq. 3:

$$\ln \text{CO}_{2it} = a + b \left( \underbrace{\alpha + \beta \ln PS_{it} + \gamma \ln PS_{it}^2}_Y \right) + c \left( \underbrace{\alpha + \beta \ln PS_{it} + \gamma \ln PS_{it}^2}_{Y^2} \right) \dots \varepsilon_{it} \quad (3)$$

In this equation, the EKC model can be *rewritten* through the AC model since the EKC model's independent variables ( $Y$  and  $Y^2$ ) will be represented by the AC model's independent variables in parentheses ( $PS$  and  $PS^2$ ). This means that we will be able to test the EKCH by way of the ACH model. This can be interpreted as EKCH being estimated by using the transmission mechanism of the AC model. Hence, the verification of EKCH will be confirmed if  $b$  and  $c$  (which corresponds to  $Y$  and  $Y^2$  in the model) demonstrate an increasing (+) and decreasing (−) trend, respectively.

To calculate the optimum level of government expenditure that will increase (Fig. 4B) or decrease (Fig. 4C)  $\text{CO}_2$  emissions, we develop and use the following procedure:

By utilizing the first-order optimization ( $d \ln Y / d \ln PS$ ) to Eq. (1), we get the level of government expenditures as,

$$\ln PS = -\frac{\beta}{2\gamma} \quad (4)$$

The sufficient condition for the maximization is  $d^2 \ln Y / d \ln PS^2 = 2\gamma < 0$ , so  $\gamma$  is predicted to be less than zero. Because the data depicts  $PS_{it}$  is greater than 1,  $\ln PS$  is positive; thus,  $\beta$  is predicted to be greater than zero.

Equation (3) demonstrates the optimal level for our composite model, which is attained from the first-order condition  $d\text{CO}_2/dPS$ :

$$\ln PS_1 = -\frac{\beta}{2\gamma}$$

$$\ln PS_{2,3} = \frac{-\beta \pm \sqrt{\beta^2 - 2\left(\frac{b}{c}\right)\gamma - 4\alpha\gamma}}{2\gamma} \quad (5)$$

The value of  $\ln PS = -\frac{\beta}{2\gamma}$  in Eq. (4) will depict the optimum level of carbon emissions for Eq. (3). When we add the value of  $\ln PS = -\frac{\beta}{2\gamma}$  into  $d^2 \text{CO}_2 / d \ln PS^2 = 2b\gamma + 2c(\beta + 2\gamma \ln PS)^2 + 4c\gamma(\alpha + \beta \ln PS + \gamma \ln PS^2)$ , we obtain the following formula:

$$\frac{d^2 \text{CO}_2}{d \ln PS^2} (\ln PS_1) = -c\beta^2 + 2b\gamma + 4c\alpha\gamma \quad (6)$$

if  $\gamma < 0$  and  $-c\beta^2 + 2b\gamma + 4c\alpha\gamma > 0$ , this will mean that the AC has an inverted U-shaped, while the composite EKC is U-shaped. If  $\gamma < 0$  and  $-c\beta^2 + 2b\gamma + 4c\alpha\gamma < 0$ , this will mean that both the AC and the composite EKC (CEM) are inverted U-shaped.

## Estimation process

For the estimation process, we will proceed with the following steps in the following order and with the following sub-titles.

## Cross-sectional dependence and heterogeneity tests

To determine whether a shock in USMCA countries influence the other two economies, we test cross-sectional dependence and slope heterogeneity. To this end, we apply the Lagrange multiplier (LM) test propounded by Breusch and Pagan (1980), the CD and  $CD_{LM}$  tests introduced by Pesaran (2004), and the  $LM_{adj}$  test developed by Pesaran et al. (2008). Concerning the test of the null hypothesis ( $H_0$ ) of slope homogeneity, we employed  $\tilde{\Delta}$  and  $\Delta_{adj}$  tests by Pesaran and Yamagata (2008). The CD and LM tests are constructed in the following forms:

$$y_{it} = \alpha_i + \beta_{it}x_{it} + \varepsilon_{it}, \text{ cov}(\varepsilon_{it}, \varepsilon_{it'}) \neq 0 \quad (7)$$

$$LM_{BP} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \rho_{ij}^2 \quad (8)$$

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \left( \frac{(T-k)\rho_{ij}^2 - \mu T_{ij}}{v_{Tij}^2} \right); \quad dn(0, 1) \quad (9)$$

## Pesaran (2007) panel unit root test

To overcome the issue of spurious regression, we must be sure that the variables used in the panel unit root test must be stationary. For this purpose, we employ the cross-sectionally augmented Dickey-Fuller (CADF) test initially developed by Pesaran (2007) in the following forms:

$$\Delta y_{it} = a_i + g_{it} + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^p d_{ij} \Delta \bar{y}_{t-j} + \sum_{j=0}^p \delta_{ij} \Delta y_{i,t-j} + e_{it} \quad (10)$$

$$CIPS(N, T) = N^{-1} \sum_{i=1}^N CADF_i \quad (11)$$

## Westerlund (2007) panel cointegration test

Westerlund (2007) suggests four errors-correction-based panel cointegration tests that consider cross-sectional dependence, whereas panel statistics, such as  $P_t$  and  $P_a$ , associate with the error-correction information and group mean statistics, such as  $G_t$  and  $G_a$ , avoid utilizing this

statistics. For all the tests, the null hypothesis (Ho) of no cointegration is checked against the alternate hypothesis (Ha) of cointegration. Westerlund (2007) takes into account the following panel regression model:

$$\Delta Y_{it} = \delta_i' d_t + \lambda_i' \Delta X_{it} + \gamma_i Y_{it-1} + \varphi_i X_{it-1} + \varepsilon_{it} \tag{12}$$

The Ho of no cointegration, such as  $H_0: p_i = 0$  for all  $i$ , is checked against the Ha of cointegration, for instance,  $H_1: p_i < 0$  for all  $i$ , that is tested for  $P_a$  and  $P_t$  tests. The following test statistics are computed as below:

$$P_a = \left( \sum_{i=1}^N L_{i11} \right)^{-1} \sum_{i=1}^N L_{i12} \tag{13}$$

$$P_t = \hat{\sigma}^{-1} \left( \sum_{i=1}^N L_{i11} \right)^{-1/2} \sum_{i=1}^N L_{i12} \tag{14}$$

The Ho of no cointegration is checked against the Ha of cointegration for  $i$ , which is analyzed for  $G_a$  and  $G_t$  tests. These test statistics are computed as follows:

$$G_a = \sum_{i=1}^N L_{i11}^2 L_{i12} \tag{15}$$

$$G_t = \sum_{i=1}^N \hat{\sigma}_i^{-1} L_{i11}^{-1/2} L_{i12} \tag{16}$$

**AMG estimator**

To evaluate the long-run relationship between variables, Eberhardt and Teal (2010) produced a two-stage estimator described as:

$$\Delta y_{it} = b' \Delta x_{it} + \sum_{t=2}^T c_t D_t + e_{it} \rightarrow \hat{c}_t = \hat{\mu}_t^\circ \tag{17}$$

$$y_{it} = a_i + b_i' x_{it} + c_i t + d_i \hat{\mu}_t^\circ + e_{it} \rightarrow \hat{b}_{AMG} = N^{-1} \sum_{i=1}^N \hat{b}_i \tag{18}$$

Firstly, a standard pooled of first-order regression was estimated comprising  $T - 1$  dummies, such as  $\hat{\mu}_t^\circ$ . This variable is then included in the  $N$  unit regressions. The long-run coefficients of these variables are presented by  $\hat{b}_{AMG}$  for the panel.

**Empirical outcome**

Table 1 represents the outcomes of the cross-sectional and slope heterogeneity tests for the AC, the EKC, and the composite economic models (CEM).

**Table 1** Cross-sectional dependence and heterogeneity tests

<b>Armey curve model</b> $\ln Y = F(\ln PS, (\ln PS)^2)$	Test statistic	<i>p</i> -value
Cross-sectional dependence tests		
LM	26.883*	0.000
CD <sub>LM</sub>	9.750*	0.000
CD	4.887*	0.000
LM <sub>adj</sub>	7.027*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	292.561*	0.000
$\tilde{\Delta}_{adj}$	7.797*	0.000
<b>EKC model</b> $\ln CO_2 = F(\ln Y, (\ln Y)^2)$	Test statistic	<i>p</i> -value
Cross-sectional dependence tests		
LM	25.900*	0.000
CD <sub>LM</sub>	9.349*	0.000
CD	3.885*	0.000
LM <sub>adj</sub>	8.743*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	4408.600*	0.000
$\tilde{\Delta}_{adj}$	7.653*	0.000
<b>CEM</b> $\ln CO_2 = F[(\ln PS + (\ln PS)^2), (\ln PS + (\ln PS)^2)^2]$	Test statistic	<i>p</i> -value
Cross-sectional dependence tests		
LM	31.833*	0.000
CD <sub>LM</sub>	11.771*	0.000
CD	5.066*	0.000
LM <sub>adj</sub>	11.873*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	108.020*	0.000
$\tilde{\Delta}_{adj}$	11.664*	0.000

\*1% statistical significance

**Table 2** CADF unit root test

Variable	Test statistic	
	Level	First difference
ln Y	-1.732	-3.322*
ln PS	-1.644	-2.981*
(ln PS) <sup>2</sup>	-1.692	-2.946*
ln CO <sub>2</sub>	-2.187	-2.647*
(ln Y) <sup>2</sup>	-1.697	-3.252*
(ln PS + (ln PS) <sup>2</sup> )	-1.691	-2.946*
(ln PS + (ln PS) <sup>2</sup> ) <sup>2</sup>	-1.759	-2.884*

\*1% statistical significance

Table 1 indicates that the Ho of no cross-sectional dependence can be rejected by all test statistics for all models, implying that if there is a shock in one of the USMCA countries, it will affect the other USMCA countries as well. Besides, both tests can reject the Ho of slope homogeneity for all the models, meaning USMCA countries have particular properties for ACH and the EKCH. The findings of the covariate-augmented Dickey-Fuller (CADF) unit root test are presented in Table 2.

For all the variables under consideration, the null hypothesis of a unit root can be rejected at the first difference, but not at level. Hence, the CADF test explores that all variables used in the study are integrated at first difference  $I(1)$ , which implies that further Westerlund (2007) panel cointegration approach will be utilized to explore the cointegration relationships of all models.

Table 3 indicates the findings of Westerlund’s (2007) panel cointegration approach. Accordingly, (i) two statistics indicate the existence of cointegration in the AC model, (ii) one statistic implies that cointegration occurs in the EKC model, and (iii) one statistic reveals that there is a cointegration relationship in the CM. Overall, the Westerlund (2007)

**Table 3** Westerlund (2007) panel cointegration test

	$G_t$	$G_a$	$P_t$	$P_a$
Arme y curve model $\ln Y = F(\ln PS, (\ln PS)^2)$	-3.613*	-14.032***	-3.494	-8.591
EKC model $\ln CO_2 = F(\ln Y, (\ln Y)^2)$	-2.268	-8.939	-4.341***	-7.860
CEM $\ln CO_2 = F[(\ln PS + (\ln PS)^2), (\ln PS + (\ln PS)^2)^2]$	-3.868*	-6.866	-2.422	-3.655

Note: \*, \*\*, and \*\*\* indicate 1%, 5%, and 10% statistical significances, respectively.

panel cointegration approach indicates the existence of a cointegration relationship among all specified models and that the long-run parameters in the models can be examined through the AMG estimator.

The results of Table 4 signify the significant composite EKC model (CEM) verifies the EKCH by way of the AC model only for Mexico, since the ACH has been verified and the curve of the CEM is also inverted U-shaped. However, our proposed composite model does not support EKCH for the USA and Canada. This is because the composite models of these two countries are not significant, although the ACH has been verified for the USA. Table 5 demonstrates the curve shapes for the models of the ACH, EKCH, and CEM.

To confirm the curve shapes of the Arme y and the composite EKC (CEM) models above and calculate the maximum (optimal) government spending level for Mexico, we run the function in Eq. 6. and found  $\gamma < 0$  and  $-c\beta^2 + 2b\gamma + 4c\alpha\gamma < 0$ . This result confirms that both curves are inverted U-shaped. Furthermore, we calculated the maximum (optimal) level of government expenditures that will maximize CO<sub>2</sub> emissions, at around 26.4% of Mexican RGDP. This means that additional government spending by the Mexican government exceeding this threshold level will decrease RGDP but also CO<sub>2</sub> emissions.

**Table 5** The curve shapes of the ARMEY, EKC, and CEM models

	Arme y curve model	EKC model	CEM
Canada	U	U	Insignificant
Mexico	∩	∩	∩
USA	∩	U	Insignificant

Curve shapes were obtained from Table 4

**Table 4** AMG estimator results

Variable	Canada	Mexico	USA
<b>Arme y curve model</b> $\ln Y = F(\ln PS, (\ln PS)^2)$			
$\ln PS$	-8.372* (0.005)	3.653** (0.042)	14.462* (0.000)
$(\ln PS)^2$	0.171* (0.002)	-0.069*** (0.057)	-0.242* (0.000)
<b>EKC model</b> $\ln CO_2 = F(\ln Y, (\ln Y)^2)$			
$\ln Y$	-6.807* (0.004)	32.490* (0.000)	-4.600*** (0.053)
$(\ln Y)^2$	0.337* (0.003)	-1.752* (0.000)	0.222*** (0.051)
<b>CEM</b> $\ln CO_2 = F[(\ln PS + (\ln PS)^2), (\ln PS + (\ln PS)^2)^2]$			
$(\ln PS + (\ln PS)^2)$	-0.033 (0.239)	0.104* (0.000)	0.042 (0.487)
$(\ln PS + (\ln PS)^2)^2$	0.00 (0.221)	-0.001* (0.000)	-0.001 (0.468)

Prob. values are shown in parentheses. \*, \*\*, and \*\*\* indicate 1%, 5%, and 10% statistical significances, respectively

## Conclusion

This study aims to test the EKCH with a new methodological approach that has never been used before in the relevant literature. To this aim, we employ the ACH (model) since both hypotheses have been constructed on the non-linear manner functions with inverted U-shaped curves, namely, the AC and the EKC. Besides these same functional-mathematical propositions, these two hypotheses have variable-based directional causal relationships. This implies that a surge in government expenditures through the ACH significantly contributes to stimulate RGDPPC and, thereby, rises in RGDPPC by way of the EKCH cause increased environmental deterioration (i.e., CO<sub>2</sub> emissions). Hence, all these can make testing the EKCH by way of the AC model mathematically-economically possible in a single composite model, derived from both hypotheses (models). The main advantages of this proposed methodology can be explained in two ways. First, this single composite model may allow us to calculate a single maximum (optimal) level of government expenditures (through a maximum RGDPPC level) that will maximize CO<sub>2</sub> emissions in case the curve of a this composite model is inverted U-shaped. Second, alternatively, if the curve of this composite model is U-shaped, this composite model may allow us to calculate a maximum government spending level that will minimize CO<sub>2</sub> emissions. Hence, the policymakers may anticipate the level of maximum (optimal) government spending and, thereby, the level of maximum RGDPPC (their upper limits) that will not cause an increase in CO<sub>2</sub> emissions if this curve is inverted U-shaped. To mitigate CO<sub>2</sub> emissions, policymakers may slow down their spending, if this curve is U-shaped. Second, this study shows readers that policymakers can choose between higher economic growth and a consequently dirtier environment, or a lower rate of growth and a cleaner environment, thanks to the proposed methodology.

Empirical findings indicate that the EKCH, by way of the AC model, was verified only for Mexico, and the threshold maximum (optimal) government spending level was calculated at 24.6% of RGDPPC for this country. This means that this level of spending maximizes both RGDPPC and CO<sub>2</sub> emissions, since the AC and the EKC are both inverted U-shaped. From the Mexican government's policymakers' perspective, if they exceed this level of government spending, they will know that both RGDPPC and CO<sub>2</sub> emissions will be reduced. This simultaneous dual result will create a kind of dilemma for this country's policymakers between a lower RGDPPC and a cleaner environment reflected in lower CO<sub>2</sub> emissions. In addition to this, the same threshold spending level will also show the government that the AC-hypothesized economic policy, based on increasing government spending, does not pollute the environment in the long run

in this country. From this point of view, this threshold level of government spending implicitly depicts another threshold between the economic and energy policies through the ACH and the EKCH for this country's policymakers, if we can regard the ACH and the EKCH as economic and energy policies, respectively. All in all, the empirical findings of this study with its proposed new methodology may provide Mexican government policymakers with crucial information about how government spending, economic growth, and CO<sub>2</sub> emissions simultaneously interact with one another in the economy. This may ensure that they have enabled more sustainable and counterpoised economic and energy policies that work in harmony without polluting the environment, as energy policy is a subset of economic policy and vice versa. The most important advantage of the proposed methodology in this study is that it reveals the possible effects of the government's increased public spending on economic growth on the environment. In other words, the study approaches the relationship between economic growth and the environment from the perspective of public spending. Hence, it reminds governments to have harmonious and sustainable public expenditure policies for economic growth and a cleaner environment.

The findings of present study show the need for further empirical works that will try to combine and analyze different theories and economic models in a single composite model as we did here for the ACH and the EKCH. To support the related literature, these future studies should be done for different countries. In this study, we introduce and propose this methodology for USMCA countries only. These types of methodological approaches may help scholars and governments examine economic issues, variables, and their causal relationships from a broader perspective and holistic picture to accommodate more proactive and sustainable economic and energy policies. The methodology used in this study is based on a composite model derived from Arney and EKC hypotheses and obtained as a result of maximization. Therefore, the study should be considered a mathematical model in this respect. However, each mathematical model can be criticized, falsified, or verified. Therefore, the results obtained from forthcoming studies and the results of this study can be discussed.

**Authors' contributions** Conceptualization: S. O., C. I., and U. B.; methodology: U. B. and C. I.; software: U. B.; investigation, writing—original draft preparation: U. B., S. O., and C. I.; writing—review and editing: U. B., A. A., S. O., S. K., C. I., R. A., A. R., and M. A.; supervision: S. O., C. I., and S. K. All authors have read and agreed to the published version of the manuscript.

**Data availability** The datasets generated and analyzed during the current study are available in the World Bank Indicator, World Intellectual Property Organization repository, <http://data.worldbank.org>.

## Declarations

**Ethics approval and consent to participate** Not applicable.

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