Environmental Science and Pollution Research (2021) 28:32648–32659
https://doi.org/10.1007/s11356-021-12993-9

RESEARCH ARTICLE

Convergence analysis of the ecological footprint: theory and empirical evidence from the USMCA countries

Cem Işık[1] · Munir Ahmad[2] · Serdar Ongan[3] · Dilek Ozdemir[4] · Muhammad Irfan[5] · Rafael Alvarado[6]

Received: 17 December 2020 / Accepted: 11 February 2021 / Published online: 24 February 2021

Abstract

The lower ecological footprint (EF) is the *sine qua non* condition of cleaner energy. The purpose of this study is to investigate the convergence of per capita ecological footprint for the USMCA (The North American Free Trade Agreement) countries, involving the USA, Canada, and Mexico, over the 1961 to 2016. To this aim, the *TAR* (threshold autoregressive) *panel unit* root *test* is applied. Empirical findings indicate that convergence of the EF exists in the second regime, which represents 48.08 percent of the sample, and divergence in the first. Canada is the transition country between two regimes. These results signify common environmental policies-actions among the USMCA countries to mitigate-stop their environmental degradation. Additionally, detected convergence and divergence also might help the policymakers of the USMCA countries to understand which strategies-policies-actions converge or diverge them in the case of EF.

Keywords Ecological footprint · Convergence · *TAR Panel Unit* Root · USMCA Countries

JEL codes Q40 · Q54

Introduction

The concept of sustainability in which economic, social, political, and environmental issues are discussed more intensely through the phenomenon of globalization is built upon meeting today's needs without eliminating next generations' capacity to meet their needs. The fundamental purpose of sustainability is to meet human needs and demands through economic activities and thus to raise the welfare of society. Human activities, such as farming, industry, fishery, and international trade, cause increasing pressure over the ecological system despite the fact that the ecological system has strengthened humans' welfare for centuries. Certain countries that do activities to increase their income are likely to ignore environmental destruction, climate change, and global warming. Sustainability of development becomes questionable in

Responsible Editor: Ilhan Ozturk

✉ Cem Işık
cemisik@anadolu.edu.tr

Munir Ahmad
munirahmad@zju.edu.cn

Serdar Ongan
songan@smcm.edu

Dilek Ozdemir
pdilek@atauni.edu.tr

Muhammad Irfan
irfan@ncepu.edu.cn

Rafael Alvarado
jose.r.alvarado@unl.edu.ec

1 Faculty of Tourism, Anadolu University, Eskişehir, Turkey

2 School of Economics, Zhejiang University, Hangzhou 310058, China

3 Department of Economics, St. Mary's College of Maryland, St. Mary's City, MD 20686, USA

4 Department of Economics, Atatürk University, 25240 Erzurum, Turkey

5 School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

6 Carrera de Economía, Universidad Nacional de Loja, 110150 Loja, Ecuador

countries that adopt policies based on manufacturing and increasing their income since such countries do not take environmental problems into consideration very much. Such problems as global warming, climate change, and environmental pollution caused the environment to become the focus of attention when the environment was regarded as economic and scarce. While the negative effects of global warming and of climate change attracted interest all over the world, the goal of reducing CO_2 emission to struggle with climate change was secured by Kyoto Protocol in 1997, in Katowice in 2018, and by the Paris agreement, which was strengthened recently.

One of the most important environmental issues analyzed is the greenhouse effect, which is caused by CO_2 emission release. The main reason for the increase in greenhouse gases in the atmosphere is economic growth and burning fossil fuels such as coal, petrol, and natural gas. Therefore, researchers focus on the correlations between the economy (production processes in particular) and environmental events.

CO_2 is used as the criterion for environmental pollution in the literature of environmental economy due to ease in obtaining large datasets and due to its effects on creating greenhouse gases (Ahmed et al. 2019; Isik et al. 2019a, 2019b, 2020, 2021; Dogru et al. 2020; Koçak et al. 2020; Le and Ozturk 2020; Ongan et al. 2020; Sarkodie and Ozturk 2020; Ahmad et al. 2021). A small number of studies also use other ecological indicators such as sulfur dioxide and suspended particulate matter. Yet, it is not rational to take only one indicator (or only one type of pollution) into consideration in analyzing environmental pollution. Thus, a method of measuring called EF was created by Rees (1992), Wackernagel (1994), and Rees et al. (1996). The method considers deterioration in standards in the soil, forests, and mines (Ulucak and Lin 2017; Bilgili and Ulucak 2018; Ulucak and Apergis 2018; Dogan et al. 2020; Ulucak and Khan 2020). EF consists of six components labelled as farming land footprint, grassland footprint, forest products footprint, fishing areas footprint, construction sites footprint, and carbon release footprint. Political inferences made on the basis of EF are more effective than the inferences made on the basis of only one indicator of pollution since EF focuses on several stocks of the resource.

The network of global footprint follows the extent to which humans need biologically fertile lands to meet their competing demands in calculating EF. The demands include lands for food production, absorbing CO_2 release caused by fossil fuels, and building the necessary infrastructure. A country's ecological consumption is calculated by adding imports to its national production and subtracting exports. All commodities need prolific lands and seas to manufacture them and to store the wastes emerging in producing them. Thus, international trade can be defined as the buried flows of EF. EF employs primary product efficiency from cultivated lands, forests, grasslands, and from fishing to support a certain activity. Considering biological capacity, current technology, and managerial practices, EF is measured by calculating the amount of biologically fertile land and sea areas available for providing the resources that the population consumes and for absorbing the wastes. Areas are adjusted in proportion to their biological prolificacy to make the biological capacity comparable over time. Those corrected areas are called global hectare (gha).

Discussion on convergence was started with neo-classical growth theory developed by Solow (1956). One of the most critical assumptions of Solow growth model is the existence of diminishing profits, which means that the marginal product of capital is big when capital stock is small and—considering Inada (1963)—it is small when capital stock is big.

Studies on convergence have attracted much interest in many areas of macroeconomic theory, especially since the seminal work of Barro and Sala-i-Martin (1992). There are several convergence results that make use of various empirical methodologies such as time series, cross section, and panel data. The common ground in those studies is convergence regression by means of economic growth equation in the context of neo-classical growth theory developed by Solow (1956). The studies range from commodity prices to medical, military, educational, scale, and financial variables and to public expenditures related to foreign trade, tourism, and energy consumption. However, studies that focus on serious threats to the world such as global warming, climate change and/or environmental convergence attract interest largely.

In the light of all evaluations done so far, we investigate the convergence of per capita ecological footprint for the USMCA countries. The potential results of this study will help the policymakers of these countries to find-understand which specific strategies-policies-actions converge or diverge them in the case of EF. Therefore, they will be finding more sustainable-effective common policies that converge them for a habitable environment for themselves. The rationale of focusing on these countries is that a group of countries such as USMCA can fulfill their specific potential common actions more easily-quickly than the global scale. Furthermore, these countries have large EFs and decreasing BIOs as well. All these make the USMCA countries unique sample countries to test the convergence analysis. The existence of convergence would allow these countries to implement collective strategies to overcome environmental degradation both domestically and internally. This is valid for all other groups of countries, such as the European Union (EU) and Asia-Pacific Economic Cooperation (APEC).

The convergence analysis

Rising e*nvironmental degradation* introduces and brings to our agenda new concepts such as eco-city, ecological energy, green certificate, and eco tag. EF, as one of these concepts introduced by Rees et al. (1996), may be more critical for the people than others since the EF measures how much we use the nature that we have. This measure was mainly based on the following equation by Borucke et al. (2013):

$$EF = D/Y \tag{1}$$

where D and Y are annual demand and yield (in global hectares) of the same product, respectively. Then, Eq. (1) can be transformed into the following most used formula to calculate the EF numerically for a country (Ewing et al. 2010):

$$EF = \left(\frac{P}{YN}\right) * YF * EQF \tag{2}$$

where P is the amount of a CO_2 emitted product produced (corresponds to D above); YN is country's average yield for P (corresponds to the CO_2 emissions uptake capacity); and YF is the yield factor corresponding to the difference between country-level and world's average productivity. The EQF (equivalence factor), as a ratio, represents the difference between the productivity of a country's land type and the world average biologically productive land types (Giampietro and Saltelli 2014; Galli 2015; Lin et al. 2018).

The world average EF in 2017 was 2.77 global hectares (gha) per person, whereas the world average available biocapacity (BIO) was only 1.6 gha per person (Global Footprint Network 2020). This global ecological deficit (EF > BIO) of 1.17 gha clearly reveals that people demand more than the nature, and this makes global environmental policy unsustainable. This deficit (also called overshoot) shows the dose of human stress on the global environment and ecosystem as well. The average ecological deficits or surpluses (denote BIO > EF) of the USMCA countries, as this study's sample countries, are shown in Fig. 1 for Mexico, Canada, and the USA, respectively. The charts were drawn from the data obtained by the Global Footprint Network (2020).

The patterns of these three countries in Fig. 1 indicate that while the USA and Mexico experience huge ecological deficits, Canada does surpluses between 1961 and 2016. However, biocapacities (BIO) of all countries are decreasing. This result may require common environmental policies-actions among the USMCA countries to keep a sustainable balance between BIO and EF. In EF, six main land use categories are tracked: cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land. The individual category graphs of the USMCA countries are shown in the appendix.

In this study, we investigate the convergence of per capita EF for the USMCA countries. The reason for selecting the USA, Mexico, and Canada is that these countries establish the world's largest trilateral merchandize trade bloc of 1.2 trillion $ with no tariffs (US Census Bureau 2020). Hence, this size of trade may have different positive or negative impacts on these countries' environment in terms of the EF. Moreover, while the USA and Mexico have ecological deficits with −4.6 and −1.48, respectively, Canada has a surplus with 6.9. These different level deficits and surpluses make the USMCA countries unique sample countries in analyzing the ecological convergence of the EF. This type of convergence is based on a postulation that the environmental qualities of the countries will converge if they have similar dynamics and conditions, which can affect the *environmental quality* (Brock et al. 2003).

Therefore, the empirical results of this study may show us whether per capita EFs have converged across the USMCA countries. If so, is this converge in regime I or II, and which one is the transition country between the regimes? In the existence of the convergence, countries in USMCA together follow a common policy to mitigate the EF. We seek the answers to these questions in this study.

The rest of the study is divided into three sections. Section 3 provides a literature review in the EF. Section 4 explains the empirical methodology, and Section 5 provides empirical results. Finally, Section 6 presents concluding remarks with possible recommendations for further research.

Literature review

In response to the awareness of climate change, which is increasing in the world, researchers who investigate EKC relationships started to include energy consumption in their models while testing the EKC hypothesis. The extent to which energy consumption affected the relationships between economic development and environmental degradation was not taken into consideration in earlier studies, even though a theoretical basis had been formed in the literature. Studies on the environmental economy are mostly concerned with the EKC hypothesis. The hypothesis argues that there is an inverse, U-shaped relationship between income per person in the long term and environmental development. According to the hypothesis, the level of pollution increases as income per person increases at the earlier stages of economic development. However, growth in income per person reduces economic pollution when a certain threshold level is exceeded. On the other hand, it might be misleading to isolate the potential effects of energy consumption on environmental pollution while testing the EKC hypothesis because energy consumption plays significant role in determining the degree of environmental pollution. Therefore, the roles of energy consumption should also be analyzed in testing the EKC assumptions. Global warming and climate change have been at the center of discussions on the environment for a long time.

The environmental convergence hypothesis has been the subject matter of a considerable number of empirical studies in the literature. The studies differ in terms of groups of countries chosen and results obtained as well

Fig. 1 Per capita ecological footprints and per capita biocapacities (gha) of Mexico, Canada, and the USA

as in the methods used to test the variables representing environmental pollution and/or the hypotheses. While some of them obtained findings supportive of convergence, some others obtained findings unsupportive of convergence. A summary of the abovementioned studies are as in the following: List (1999), in a study conducted with SO_2 and NO_2 variables in time series technique, analyzed the period between 1929 and 1994 in the USA and obtained results supportive of convergence. Strazicich and List (2003) examined the environmental convergence hypothesis for 21 OECD countries by using CO_2 emission in the period between 1960 and 1997 with horizontal section and panel unit root analyses and obtained results supporting convergence. Lanne and Liski (2004) tested the period between 1870 and 2028 for 16 countries by using the same variable with structural break panel unit root test and could not obtain empirical findings supportive of the hypothesis. Nguyen Van (2005) analyzed 100 countries with non-parametric distribution analysis by using the CO_2 emission between 1966 and 1996. No results were obtained for convergence on doing the analysis for 100 countries, but results supportive of convergence were obtained only on analyzing the sample of industrialized countries. In the same vein, Aldy (2006) also analyzed a sample of 88 countries by using CO_2 values with unit root and Markow transformation matrix analysis in the period between 1960 and 2000 and obtained results supporting convergence for 13 countries. On using long-term emission predictions in the analyses, however, results supporting divergence were obtained. Camarero et al. (2008), as different from previous studies, used environmental performance index (EPI) values and analyzed OECD countries for the period between 1971 and 2002 in data envelopment and SURADF unit root methods. The results were considered to support convergence. Panopoulou and Pantelidis (2009) considered convergence in the context of club convergence and applied the panel club convergence test developed by Phillips and Sul (2007) to the CO_2 values of 128 countries in the period between 1960 and 2003. The results obtained in the study confirmed that there was no convergence for all countries but that the countries converged each other in terms of various groups. Herrerias (2013) also put the CO_2 values of 162 countries between 1980 and 2009 stemming from fossil fuels to the same analysis and obtained results that supported convergence for a large group. Yet, the study also used pairwise unit root analysis and yielded results supportive of divergence. Li and Lin (2013), by using the CO_2 data for 110 countries between the years 1971 and 2008, did analyses in panel GMM method and obtained findings supportive of convergence. Wang et al. (2014) tested the cities which were dependent on China in panel club convergence analysis by using CO_2 data between 1995 and 2001 and obtained results supporting convergence for groups but did not have any findings supporting convergence for the whole sample. Burnett (2016) used the same analysis with data of the states in the USA for the period between 1960 and 2010 and obtained club convergence results for 26 states but divergence results of the remaining states. Using nonlinear time series and panel unit root tests, Tiwari et al. (2016) analyzed the CO_2 data of 35 sub-Saharan African countries in the period between 1960 and 2019 and obtained results supportive of convergence for 27 countries in time series analysis and results supportive of convergence for15 countries in panel analysis. Ahmed et al. (2016) analyzed the CO_2 data for 162 countries between 1960 and 2010 in the wavelet unit root method and obtained results supportive of convergence for 38 countries and results supportive of divergence for 124 countries. Apergis and Payne (2017), following the concept of club convergence, analyzed the CO2 data for the states in the USA in the period between 1980 and 2013 and found that some states converged while some others diverged. Review of the literature demonstrates that panel unit root tests are heavily used in testing the convergence hypothesis. Apart from that, the panel club convergence test developed by Phillips and Sul (2007) is also one of the most frequently used methods. As will be explained in the next section, the test is more advantageous in analyzing convergence than unit root tests, and it was developed so as to analyze convergence directly. Therefore, this paper uses the club convergence test—which was developed by Phillips and Sul (2007). As different from the current literature, this study uses the variable of EF, which is regarded as a more comprehensive indicator of environmental pollution.

EKC emphasizes that economic growth deteriorates environmental quality at the first stages and that it increases the environmental quality only after income per person reaches the threshold level at the next stage of economic growth (Brock et al. 2003). According to EKC, countries which reach a certain level of income reduce their emission. As long as the claim is true, an increase in levels of income per person will bring levels of emission close to each other. This is what convergence in relation to EKC means exactly (Strazicich and List 2003). Secondly, such a convergence is based on efforts made to stop global warming and climate change with the guidance of international agreements such as an intergovernmental panel on climate luck, IPCC, and Kyoto protocol (Aldy 2006). And finally, the initial levels of pollution emissions, emission intensity, or concentration are associated with slower growth in parallel to growth convergence (Csereklyei and Stern 2015). Such potential expectations provided in relevant literature have caused to research environmental convergence.

It contributes to the literature in two ways: first, the current literature is mostly based on carbon dioxide emission per person, and it does not take any variables of environmental degradation into consideration. For this reason, relevant observations should be based on resource stocks such as soil stocks, forestry stocks, mining stocks, and petrol stocks (Arrow et al. 1996; Csereklyei and Stern 2015). Hence, this study uses the concept of EF—which was developed by Wachernagel & Rees et al. (1996)—as a comprehensive variable of environmental degradation, and (ii) most of the relevant literature considers unit root approach or growth regressions so as to reach conclusions about whether or not convergence is true or not for their examples. In addition to that, pollution and environmental degradation have diffusion effects between regions and countries. Besides, some countries have similar dynamics and conditions in terms of the driving forces of environmental quality. Thus, convergence can be confirmed by similar conditions such as dependence on environmental resources, changes in the composition of renewable and non-renewable in energy production, and changes in the composition of energy consumption. For this purpose, the study uses a club convergence approach developed by Phillips and Sul (2007)—who think that certain countries, states, sectors, or regions belonging to a club change from their position of imbalance into a position of the special constant state.

In most of the empirical studies, CO_2 emissions are used as an environmental degradation indicator. However, this is argued that the other indicators such as water, soil, and forestry pollutions should be considered as well (Arrow et al. 1995). Furthermore, new additional indicators, which can also represent and measure *e*nvironmental degradations, are strongly suggested. In this context, EF, as a proxy indicator, has been finding a wide place in recent studies.

In this section of the study, we provide the empirical studies which have analyzed environmental convergence with different methodologies-environmental degradation indicators for different countries in Table 1.

The empirical findings of the studies in Table 1 are ambiguous about the environmental convergence for some and the same countries.

Model, data, and methodology

The empirical methodology of this study is the *TAR* (threshold autoregressive) *panel unit* root test. This methodology is based on the probability that the convergence process may not be uniform. This means that the countries may converge under certain economic, political, and managerial conditions; otherwise, they may diverge. Changes in these conditions may change the rates of countries' convergence as well. Additionally, the convergence process may not be in a linear

Table 1 Environmental convergence

Author/s period	Country	Methodology	Environmental degradation indicator	Empirical findings
List (1999) (1929–1994)	USA	Time series unit root	SO_2, NO_2	+
Strazicich and List (2003) (1960–1997)	21 countries	Panel unit root	CO_2	+
Lanne and Liski (2004) (1870–2028)	16 countries	Panel unit root	CO_2	
Nguyen Van (2005) (1966–1996)	100 countries	Non-parametric approach	CO_2	+
Aldy (2006) (1960–2000)	88 countries	DF-GLS Unit root	CO_2	+
Aldy (2007) (1960–1999)	US states	Panel unit root	CO_2	+
Ezcurra (2007) (1960–1999)	87 countries	Non-parametric approach	CO_2	+
Romero-Ávila (2008) (1960–2002)	23 industrialized countries	Panel unit root	CO_2	+
Lee and Chang (2008) (1960–2000)	21 OECD countries	SURADF panel unit root	CO_2	+
Camarero et al. (2008) (1971–2002)	OECD countries	SURADF unit root	EP	+
Westerlund and Basher (2008) (1870–2002)	16 developed, 12 developing countries	Panel unit root	CO_2	+
Panopoulou and Pantelidis (2009) (1960–2003)	128 countries	Panel club convergence test	CO_2	+
Brock et al. (2010) (1960–1998)	173 countries	Cross-sectional approach	CO_2	+
Yavuz and Yilanci (2013) (1960–2005)	G7 countries	TAR panel unit root	CO_2	+
Herrerias (2013) (1980–2009)	162 countries	Pair-wise unit root test	CO_2	+
Christidou et al. (2013) (1870–2006)	36 countries	Linear and nonlinear panel unit root tests	CO_2	+
Li and Lin (2013) (1971–2008)	110 countries	Panel GMM	CO_2	+
Huang and Meng (2013) (1985–2008)	Provinces of China	Spatial econometrics models	CO_2	+
Li et al. (2014) (1990–2010)	50 US	Sequential panel selection method	CO_2	+
Wang et al. (2014) (1995–2011)	Provinces of China	Panel club convergence test	CO_2	+
Presno et al. (2015) (1901–2009)	28 OECD countries	Nonlinear stationarity test	CO_2	+
Burnett (2016) (1960–2010)	USA	Panel club convergence test	CO_2	+
Tiwari et al. (2016) (1960–2009)	35 sub-Saharan countries	Nonlinear time series and panel unit root	CO_2	+
Ahmed et al. (2016) (1960–2010)	162 countries	Wavelet unit root	CO_2	+
Acaravcı and Erdogan (2016) (1960–2011)	7 regions of the world	Panel unit root test	CO_2	+
Acar and Lindmark (2016) (1950–2010)	86 countries	Growth regression	CO_2	+
Apergis and Payne (2017) (1980–2013)	USA	Panel club convergence test	CO_2	+
Acar and Lindmark (2017) (1970–2010)	OECD	Growth regression	CO_2	+
Solarin (2019) (1961–2013)	27 OECD	RALS-LM	CO_2, EF	+
Ozcan et al. (2019) (1961–2013)	All high-income countries	Panel unit root tests	EF	+
Bilgili et al. (2019) (1961-2014)	15 countries	Panel KPPS	EF	
Yilanci and Pata (2020) (1961-2016)	ASEAN-5	TAR panel unit root	EF	+

"+" denotes evidence for convergence; " " denotes no evidence for convergence; *EF* ecological footprint, *NO_2* nitrogen dioxide, *SO_2* sulfur dioxide, *CO_2* carbon dioxide, *EPIs* environmental performance indicators

character, and relying on the linear panel data may provide misleading results (Beyaert and Camacho 2008; Beyaert and Solanes 2014). Hence, the TAR panel unit root approach, as a nonlinear extension of the Evans–Karras approach (Evans and Karras 1996), considers all these and enables us to split the data into two regimes under nonlinear approach. With this approach, we can decide the existence of convergence or divergence in two regimes separately. In the application of the TAR panel unit root approach, we first test the linearity of the series if linearity (null hypothesis) is rejected, and then we apply this nonlinear approach (alternative hypothesis) (Beyaert and Solanes 2014; Yavuz and Yilanci 2013).

In order to examine the convergence of the EF in the USMCA countries, we use the following econometric methodology of Beyaert and Camacho (2008):

$$\Delta EF_{n,t} = \left[\delta_n^I + \rho_n^I EF_{n,t-1} + \sum_{i=1}^{p} \varphi_{n,i}^I \Delta EF_{n,t-i}\right] I_{\{Z_{t-1}<\lambda\}} + \left[\delta_n^{II} + \rho_n^{II} EF_{n,t-1} + + \sum_{i=1}^{p} \varphi_{n,i}^{II} \Delta EF_{n,t-i}\right] I_{\{Z_{t-1}\geq\lambda\}} + \varepsilon_{n,t} \quad (3)$$

where n=1,…N, and t=1,…T. In this model, I(x) represents an indicator that turns to 1 when x is true and zero otherwise with dummy variables. Hence, the model includes two different regimes. In the condition of 1, regime I can be shown in Eq. (4):

$$\Delta EF_{n,t} = \delta_n^I + \rho_n^I EF_{n,t-1} + \sum_{i=1}^{p} \varphi_{n,i}^I \Delta EF_{n,t-i} + \varepsilon_{n,t} \quad (4)$$

Similarly, in the condition of zero, regime II can be shown in Eq. (5):

$$\Delta EF_{n,t} = \delta_n^{II} + \rho_n^{II} EF_{n,t-1} + \sum_{i=1}^{p} \varphi_{n,i}^{II} \Delta EF_{n,t-i} + \varepsilon_{n,t} \quad (5)$$

where λ is threshold parameter and Z_t is threshold variable, which requires to be stationary. Z_t is calculated in the form of $Z_t = EF_{m,\ t} - EF_{m,\ t-d}$. In the first step, we test whether the coefficients of both models are equal to each other. If not equal, we follow nonlinear approach. In this examination, the critical values are obtained by the bootstrap simulation. In this step, the null hypothesis ($H_{0,1} = \delta_n^I = \delta_n^{II},\ \rho_n^I = \rho_n^{II},\ \varphi_{n,i}^I = \varphi_{n,i}^{II}$) is tested (Beyaert and Camacho 2008). If the null hypothesis is rejected, the convergence is tested in the nonlinear approach. In the second step, if the null hypothesis ($H_{0,2} = \rho_n^I = \rho_n^{II} = 0\forall_n$) is not rejected, the convergence of the countries is tested in regimes I and II in three alternatives. These are as follows: (1) $H_{A,2a}: \rho_n^I < 0, \rho_n^{II} < 0\forall_n$, (2) $H_{A,2b}: \rho_n^I < 0, \rho_n^{II} < 0\forall_n$ and (3) $H_{A,2c}: \rho_n^I = 0,\ \rho_n^{II} < 0\ \forall_n$. The first alternative represents the convergence of the countries in regime I and regime II, which is called "full convergence." The second and third alternatives represent the convergence in regime I or regime II, which is called "partial convergence." Finally, we test the convergence, whether it is absolute or conditional. The yearly dataset was obtained from the Global Footprint Network. The sample period of the study is between 1961 and 2016.

Results

In this section of the study, we first report descriptive statistics in Table 2.

The test results in Table 2 indicate that while the USA has the highest EF score with 9.6, Mexico has the lowest at 2.4, and Canada has 8.9. The normality test reveals that none of the countries are normally distributed. The EFs of the USA and Canada are negative, and Mexico is positively skewed and leptokurtic in shape. In order to show the convergence, the EF scores of these three countries are given in Fig. 2.

The patterns of the EF scores of the countries in Fig. 2 clearly show that the USA and Canada are very close in convergence, but Mexico is far from them. The test results of the TAR panel unit root test are reported in Table 3. For the linearity test, the Wald test is used.

Test results in Table 3 indicate that convergence is in regime II only since its bootstrap *p*-value (0.0004) is significant at 5%. The grid search reveals that Canada is the transition country between the regimes. The progress of Canada's EF determines the shift from one regime to the other. The delay parameter is found 2, and the transition variable is $Z_t = EF_{Canada,\ t} - EF_{Canada,\ t-2}$. The threshold parameter is estimated as 0.0174. The threshold parameter and variable are shown in Fig. 3.

Regime I (lower part) and regime II (upper part) correspond to %51.92 and %48.08 observations of the sample. Regime I refers to the years in which Canada's rate of EF is 0.0174 lower than the remaining countries of the USMCA. Similarly, regime II corresponds to the years in which the rate is 0.0174 higher the USA and Mexico. The existence of unit root signifies diversity. Hence, the test results of convergence analysis reveal that while convergence is in regime II (*p*-value of 0.0004) and *both* (*p*-value of 0.0916), divergence is in regime I (*p*-value of 0.4261). The convergence in regime II reveals a "partial convergence" in the USMCA countries.

Table 2 Descriptive statistics

	USA	Mexico	Canada
Mean	9.670506	2.498598	8.935905
Median	9.832159	2.496453	8.922328
Maximum	11.09675	3.879219	10.27679
Minimum	8.049403	1.783917	7.386358
Std. Dev.	0.833192	0.430630	0.700291
Skewness	−0.467678	0.498367	−0.017325
Kurtosis	2.269691	3.385971	2.230086
Jarque-Bera	3.285895	2.665718	1.385926
Probability	0.193409	0.263722	0.500092
Observations	56	56	56

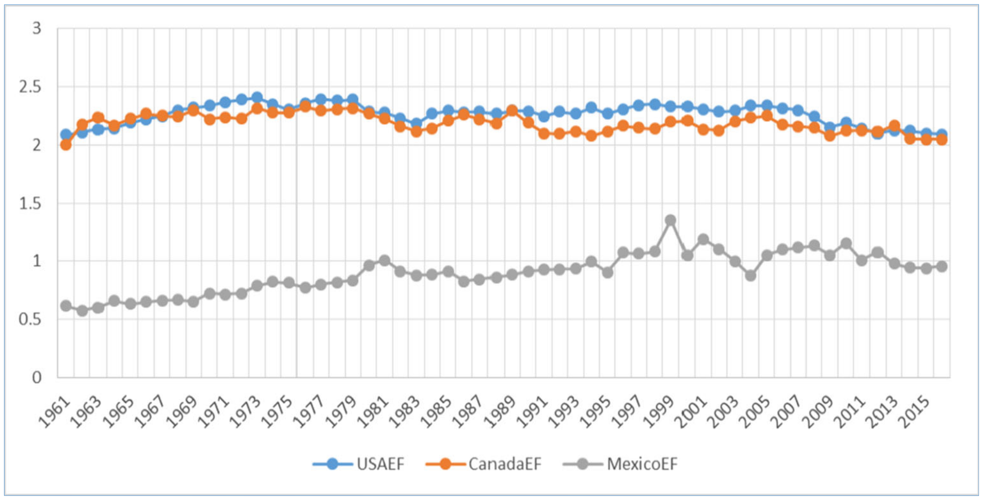


Fig. 2 Logs of ecological footprint per capita for the USMCA countries

Furthermore, the *p*-values of regime II (0.1214) and *both* (0.1880) reveal an absolute convergence in the USMCA countries. This means that the initial conditions of the countries are not important for convergence. The differences in environmental quality will diminish, and e*nvironmental degradation* indicators will converge over time.

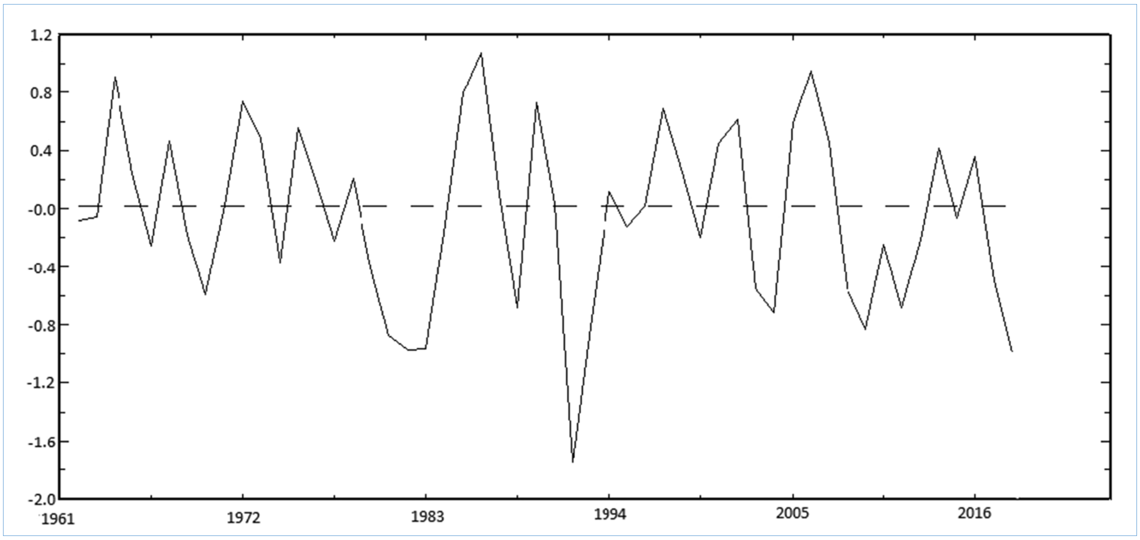
Concluding remarks and policy recommendation

The population's EF has been exceeding the world's biocapacity (BIO) over time. This deficit threatens the humanity and may be compensated through common sustainable environmental policies-actions among the countries (Alvarado et al. 2021). Before taking expensive and time-consuming actions, we first should understand how these two indicators interact, whether they converge or diverge from one another. The answer of this question may be more apparent, clearer, and important for a group of countries since their specific potential actions can be fulfilled more easily-quickly than the global scale. This is the same for the USMCA countries, which have large EFs and decreasing BIOs. In this context, this study aims to investigate the convergence of the EF in the USMCA countries. To this aim, the *TAR* (threshold autoregressive) *panel unit* root *test* is applied. The empirical findings indicate that the convergence of the EF exists in the second regime. This means that the differences of the EFs diminish, and the countries converge in this indicator over time. This detection may signify and suggest common environmental policies-actions among the USMCA countries to mitigate-stop their environmental degradation. This detection also may help the policymakers of these countries to find-understand which specific strategies-policies-actions converge or diverge them in the case of EF. Hence, the policymakers can focus on those more sustainable-effective policies which converge them for a habitable environment for themselves. Canada, among the USMCA countries, seems to be the transition country between the two regimes. The

Table 3 Results for panel threshold unit root test

Linearity test		Transition country	d	Threshold	% observations in regime I
Test statistic	23.0909	Canada	2	0.0174	51.9231
Unrestricted bootstrap *p*-value	0.0750				
Restricted bootstrap *p*-value	0.0692				
Convergence tests					
Divergence vs convergence					
Regime I test statistic	Bootstrap *p*-value	Regime II test statistic	Bootstrap *p*-value	*Both*	Bootstrap *p*-value
−1.7752	0.4261	−3.3294	0.0004**	14.2357	0.0916***
Absolute vs relative convergence					
Regime I test statistic	Bootstrap *p*-value	Regime II test statistic	Bootstrap *p*-value	*Both*	Bootstrap *p*-value
---	---	6.9615	0.1214	4.1860	0.1880

** and *** denote 5% and 10% significance



Notes: Horizontal dotted line refers to the threshold (0.0174). Sample: 1961–2016. Canada data ($d = 2$).

Fig. 3 Threshold variable. Horizontal dotted line refers to the threshold (0.0174). Sample: 1961–2016. Canada data ($d = 2$)

empirical results of this study put the need for future empirical studies using different methodologies for different countries. These studies may help the policymakers to create globally applicable environmental-managerial and economic (growth) policies. It can be argued that using only three sample countries can limit the study's main aim. However, we believe that countries, which have different socioeconomic structures and in a specific trading group such as the USMCA, may be unique sample countries. Because they provide us clearer results whether they converge or diverge in a group. Let us say if they diverge, they can more easily fulfill the common applicable effective policies rather than the global scale. They can benefit from being a group member country in this convergence. Therefore, in order to make a contribution to the related literature in the context of this study, it recommended more future empirical studies which will focus on other group of countries such the EU and APEC. We believe that the results of these studies will clearly show us the importance of common sustainable policies-actions within these group of countries for the environment.

In light of the abovementioned results, some strenuous policies could be implemented to trigger the ecological footprints mitigation. The group of developed countries like as USMCA contains the required capacity to implement policy tools for mitigating the ecological footprints to achieve a common convergence. This is possible through collaborative efforts. In this regard, the following strategies can be options for a sustainable environmental path. (i) The production processes should be subjected to transition from fossil fuel-based to the cleaner production processes. The switching from unsustainable to sustainable methods would not only conserve natural resources, such as coal, oil, and natural gas, but also would mitigate the environmental pollution. Thus, the existing forestation would have less burden of carbon sequestration, providing a clean air atmosphere. (ii) The incentive system should divert the agriculture sector's taxation burden on the industrial sector to promote the agriculture sector. It would help increase the pastures, agricultural lands, and forestation, being the major constituents of ecological footprints. It would help replenish the biocapacity of the group of countries under-analysis. (iii) Transportation exerts enormous pressure on ecological footprints by emitting more than the ecosystem's absorptive capacity; therefore, vehicles relying on renewable energy resources should be promoted. It would help reduce the emissions concentrations in the ecosystem of the stated countries. (iv) Public transportation might help conserve the energy use and put a check on the rising environmental pollution. Therefore, policy intervention should limit the use of personal vehicles (only fossil fuel-based), or alternatively, efficient energy or clean energy vehicles, such as electric vehicles, should be promoted.

Author contribution Conceptualization: C.I., S.O., and D.O. Methodology: C.I., S.O., and D.O. Investigation: M.A., M.I. and R. A.Writing—original draft preparation: C.I., S.O., D.O., M.A., M.I., and R.A.Writing—review and editing: C.I., S.O., D.O., M.A., R.A., and M.I.Supervision: C.I. and S.O. 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, Materialflows.net, World Intellectual Property Organization repository, http://data.worldbank.org.

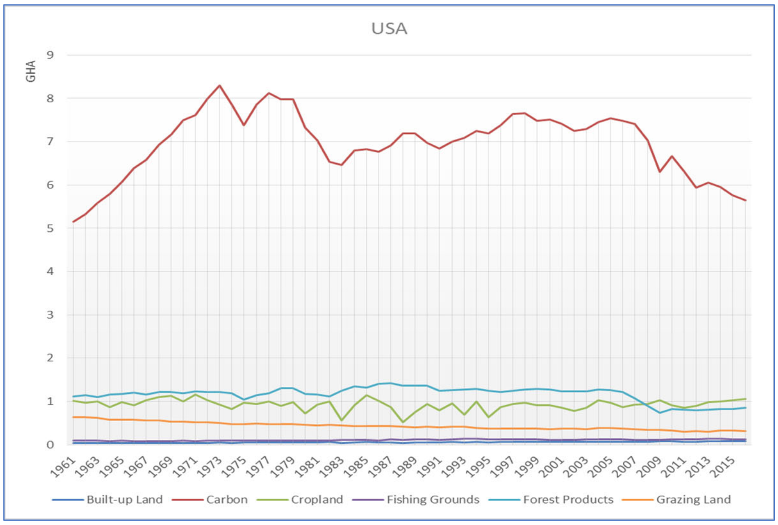
Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

Appendix


USA
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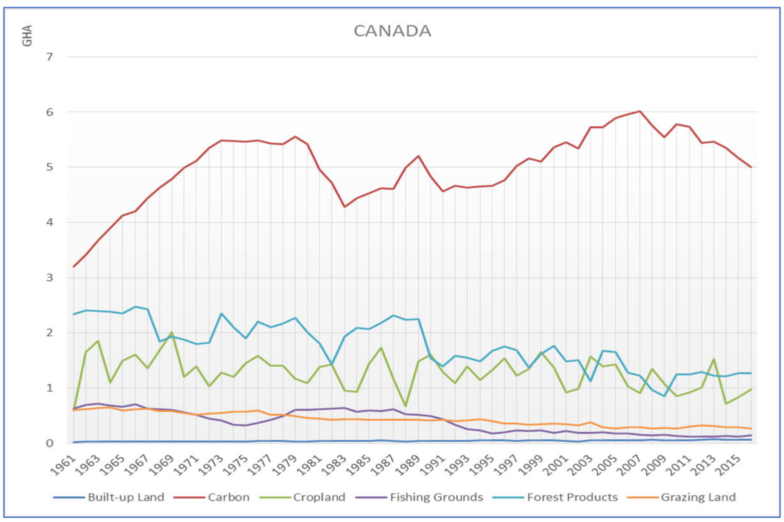
1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Built-up Land
Carbon
Cropland
Fishing Grounds
Forest Products
Grazing Land


CANADA
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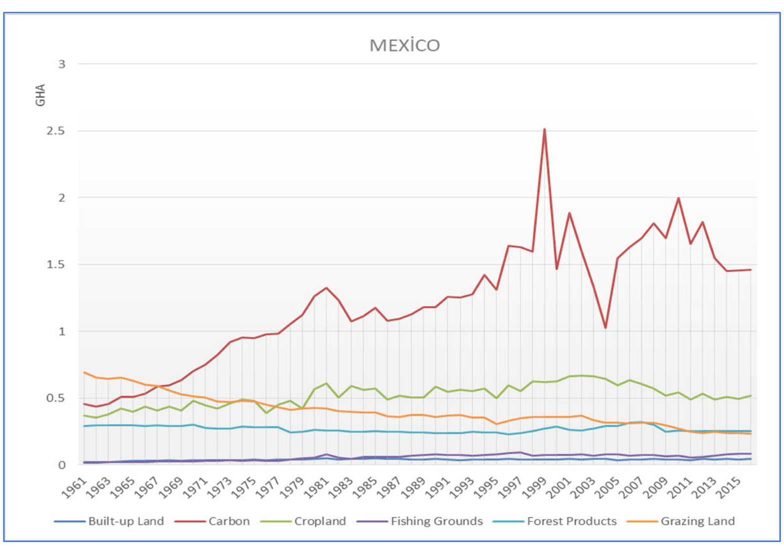
Grazing Land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1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Built-up Land
Carbon
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Fishing Grounds
Forest Products
Grazing Land

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