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RESEARCH ARTICLE

Empirical analysis of the relationship among urbanization, economic growth and ecological footprint: evidence from Eastern Europe

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Abstract

In recent environmental sustainability literature, ecological footprint is largely seen as the most appropriate indicator of environmental destruction. However, due to lack of clarity in its relationship with economic growth, ecosystem services, biodiversity and human well-being, serious academic and political attention on environmental sustainability has not really reflected on ecological footprint. Using CADF unit root test, Westerlund cointegration test, common correlated effects and Dumitrescu Hurlin causality approaches, we conduct empirical analysis of the relationship among urbanization, economic growth and ecological footprint: evidence from Eastern Europe between 1998Q4 and 2017Q4. We address the following protracted questions in the literature: (1) Can we find a relationship between ecological footprint, urbanization and growth? (2) What explains the relationship, if any? The outcomes of the Westerlund cointegration test reveal cointegration among the variables, (ii) the outcome of the Dumitrescu Hurlin causality test indicates that there is a long-run unidirectional causality running from growth to the ecological footprint and (iii) urbanization does not homogeneously cause ecological footprint. The study has implications for regional policy actions that could support the reduction of ecological deficits through growth and urbanization policies towards improving regional environmental quality.

Keywords Ecological footprint · Urbanization · Sustainability · EKC hypothesis · Growth

JEL classification Q61 · O2 · F18 · O40 · O44 · 052

Introduction

Historically, environmental quality has been threatened by human ecological footprint resulting in global warming and environmental change. This global environmental change is evidenced by the increasingly melting global glaciers, rising atmospheric and ocean temperatures, increasing hurricanes, unpredictable rainfall patterns, falling agricultural output and declining workforce efficiency (Shahbaz et al. 2018). In recent times, environmental economists and governments' attention have been geared towards addressing the worsening environmental quality, especially the global temperature rise, water crisis and changing climatic conditions (Alam et al. 2017; Zhang et al. 2021). The need to address these sustainability problems has resulted in unsettled debates on decoupling socioeconomic development through urbanization and economic growth from environmental externalities (Hickel and Kallis 2020).

Human ecological footprint is defined by the collective effects of the activities of man, evidenced by area of naturally available regenerative capacity (biocapacity) of natural capital such as land for production, water required for production and resultant waste produced (Mansir et al. 2018). Ecological footprint of nations is generally reflective of pressures exerted on the natural environment by human actions, and as clearly been shown by the nature of environmental degradation (Destek et al. 2018; Charfeddine 2017; Ulucak and Bilgili 2018; Khan et al. 2019). In emerging economies, the need for economic growth has historically resulted in

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little interest in environmental degradation as opposed to the developed world. Empirical evidence suggests that in the emerging economies, the disastrous effects of environmental degradation and the increasingly reducing biocapacity are now being felt (Ahmed and Wang 2019; Ahmed et al. 2020). In general, human desires for goods and services result in altering ecosystems by generating ecological pressures including extraction and depletion of resources (i.e. minerals, forest and fisheries), waste pollution and impacts from land use (Tscharntke et al. 2005). The resultant environmental impacts, including changing climatic conditions, land degradation, loss of biodiversity and environmental pollution, normally have dire impacts on susceptible populations in developing economies (Clarke et al. 2019).

Over the years, assessing the nexus between growth and ecological footprint has intensified and continues to rage on in academic literature and political decision-making. One most important hypothesis that explains the linkage between growth and ecological footprint is the claim by environmental Kuznets curve (EKC) initially proposed by Grossman and Krueger (1991). According to EKC hypothesis, environmental degradation initially increases with growth until certain economic development level is reached before it begins to fall due to scale, composition and technology effects (Stern 2004). While a number of empirical studies have confirmed the EKC hypothesis (Zhang et al. 2019; Sinha et al. 2019), others argue that growth and environmental degradation are not related (Beşe and Kalayci 2019; Farhani and Ozturk 2015; Beckerman 1992). Instructively, there are similar studies on the hypothesis that have yielded inconclusive outcomes (Apergis and Ozturk 2015; Gökmenoğlu and Taspinar 2016). Another theoretical argument that has emerged in growth and environment relationship debate is pollution haven hypothesis (Assamoi et al. 2020; Ahmed et al. 2019; Majeed and Mazhar 2019). The theory claims that pollution-related industries generally move from developed economies to emerging economies through trade and cross-border investments mainly due to relaxed pollution control laws. The Heckscher–Ohlin model (Heckscher 1922) further provides the theoretical foundation of pollution haven hypothesis (PHH), explaining that regions export goods using locally abundant inputs. They argue that emerging economies seeking economic growth deliberately relax their pollution laws towards attracting foreign investments, especially in the extractive sector (Assamoi et al. 2020; Ahmed et al. 2019; Majeed and Mazhar 2019). Experts have found that although recent studies of PHH use panel approaches to control for heterogeneity (Brunnermeier and Levinson 2004), initial investigations on the validity of PHH employed cross-sectional data with no control for unobserved To investigate environmental sustainability, economic PHH.

Given that influence of economic activity on environmental sustainability remains unresolved in both economic and political literature, a new variable has emerged—urbanization—as playing a significant role (Kirikkaleli and Kalmaz 2020; Kirikkaleli and Sowah 2020). Empirically, decades of studies on urbanization and environmental sustainability nexus have indicated quite revealing results. For example, studies by Martínez-Zarzoso and Maruotti (2011) indicated that through industrialization, urbanization has profound influences on energy use and ecological footprint, by modernizing traditional energy, which consequently raises energy intensity. In their empirical analyses of the impact of urbanization on energy use and CO_2 emissions, Poumanyvong and Kaneko (2010) considered various stages of growth on a panel of 99 countries between 1975 and 2005. The outcomes of this study indicate varied impacts of energy use and carbon emissions on urbanization at different stages of growth. Furthermore, Wang et al. (2018) investigated the multiple impacts of urbanization on CO_2 emissions. The outcomes of this study indicate that urbanization negatively impacts on CO_2 emissions. Instructively though, investigations by Bekhet and Othman (2017) on the nexus between urbanization, CO_2, energy consumption, GDP, financial development and domestic investment between 1971 and 2015 indicate that urbanization and domestic investment have positive impact on CO_2 emissions.

An investigation into the environmental quality of Eastern European countries indicates that in recent years, an observed increase in ecological footprints from economic growth and urbanization is negatively impacting the biocapacity endowments of the region (Niccolucci et al. 2012). However, a recent investigation conducted by Lazăr et al. (2019) into the nexus between economic growth and pollution indicated that while some Eastern European countries experienced growth with increasing emissions of CO_2, others did not experience such results. Many other investigations concerning growth, urbanization and ecological footprint have equally indicated varied results. According to Lazăr et al. (2019), as Eastern European countries continue to seek economic growth, their urban populations are observed to increase due to industry concentration in such areas, leading to increased energy consumption and destruction of vegetation cover for housing.

Against this background, a special study focused exclusively on Eastern Europe is needed to provide a clearer picture of the environmental sustainability state of the region. This research therefore investigates in greater detail the linkages between ecological footprint, urbanization and economic growth in Eastern Europe from 1998Q4 from 2017Q4 using advanced CADF unit root test, Westerlund cointegration test, common correlated effects (CCE) and Dumitrescu Hurlin causality approaches. Our contribution to the literature is as follows. First, different approaches have been employed over the years for panel data estimation such as GMM, ARDL and panel DOLS (Zoundi 2017; Al-Mulali et al. 2016; Acaravci et al. 2011). However, these approaches consider slope homogeneity and allow only varying intercepts of cross-sectional units. But in reality, slope heterogeneity problems in panel data exist (Westerlund and Urbain 2015). The approaches used in this work—CCE—are able to consider not only slope heterogeneity but also other econometric approaches such as cross-sectional dependency and serial correlation (Chudik and Pesaran 2015; Eberhardt and Bond 2009). Second, although there are studies done on ecological footprints, growth and urbanization in other parts of the world, there is none specially focused on Eastern European region (Weber and Sciubba 2019; Shaker 2015; Clancy 2008; Nathaniel and Khan 2020). This work is the first study to the best of our knowledge, investigating key relationships between ecological footprints, growth and urbanization of Eastern European regions. The work has implications for regional ecological footprint, urbanization and growth project planning and monitoring. It also has implications on regional policy actions that could support the reduction of ecological deficits and increase regional environmental quality. Following this introductory section is the "Literature review" section which reviews relevant literature. The "Methodology and data source(s)" section contains the methods of analysis used in the study while the "Results and discussions" section contains the results and discussions of the study. And the "Conclusion" section contains some brief concluding remarks.

Literature review

In sustainability studies, the standard measure of a sustainable society is defined along safeguarding humanity's future well-being. Initial discussion of environmental degradation in literature was heavily focused on CO_2 emissions as the main indicator (Solarin 2019). However, in recent years, ecological footprint is emerging as the most comprehensive and reliable tool for measuring environmental degradation than CO2 emissions—the direct consequence of fusil energy consumption (Destek and Sarkodie 2019). Ecological footprint illustrates human pressures placed on available natural resources, involving cropland, forest products, fishing grounds, grazing land, built-up spatial resources and carbon (Galli et al. 2012; Isman et al. 2018). According to Kitzes et al. (2009), recent examinations of global ecological footprint indicate grave environmental degradation with little assurance for future human consumption and production, indicating a clear existential threat to humanity. In their study of the economic growth of China and India from 1961 to 2005 through the lens of ecological footprint analysis, Galli et al. (2012) identified negligible differences between them, and confirmed essentially the global industrialization of economies resulting from fossil fuel-driven societies, economic growth and rising population growth.

Over the last few decades, there has been a general increase in academic and policy interest concerning environmental impacts from economic growth. The increasing interest intensified due to the publication on the relationship between economic growth and environmental impacts using the environmental Kuznets curve (Grossman and Krueger 1995). This theory claims there is trade-off between growth and environmental sustainability, challenging the conventional economic theory which claims that economic growth is a prerequisite for environmental sustainability (Grossman and Krueger 1995; Borghesi and Vercelli 2003). This newly developed theory claims that as gross domestic product (GDP) per capita rises, it reflects correspondingly on environmental quality indicators and explains the existence of an inverted *U* relationship between the two—usually referred to as "environmental Kuznets curve" (EKC). The proponents of EKC hypothesis claim that every economy at early phase of economic development exhibits overreliance of industrial production which ultimately leads to rapid environmental pollution. This happens because economic policies tend to emphasize heavily on income generation with little interest in environmental sustainability, until at a later phase of growth when income increases sufficiently before effective environmental regulation and compliance monitoring are done.

In their recent empirical study, Pao and Tsai (2010) investigated the linkage between carbon dioxide emissions, energy consumption and growth in selected BRIC economies from 1971 to 2005, and Russia (1990–2005). The outcomes indicated energy consumption relates to CO_2 emissions, thereby confirming the EKC hypothesis. Mrabet and Alsamara (2017) studied the growth and ecological footprint in Qatar, and the outcomes indicate that economic growth has serious long-term impacts on ecological footprint. In Azerbaijan, a study by Mikayilov et al. (2018) to investigate impacts of growth on the environment between 1992 and 2013 indicates that economic growth causes environmental destruction. One investigation into the linkage between financial sector development and ecological footprints indicates that financial development increases ecological footprint (Baloch et al. 2019). Many other studies testing the EKC hypothesis indicate that changes in income affect ecological footprint (Ulucak and Bilgili 2018; Charfeddine and Mrabet 2017), notwithstanding contrary findings by Destek et al. (2018) and Bello et al. (2018). Using panel analytical approaches to investigate the relationship between foreign direct investment, carbon dioxide emissions, ecological footprint and carbon footprint, Solarin and Al-mulali (2018) find that foreign direct investment does not affect ecological footprint. A similar investigation into the linkages between ecological footprint and other microeconomic variables in newly industrialized economies confirmed EKC hypothesis (Destek and Sarkodie 2019). Furthermore, in their study on the interaction between renewable energy consumption, trade and environmental quality in Nordic counties between 2001 and 2018, using CADF unit root test, cross-sectional dependence (CD) test and dynamic common correlated effect (DCCE) test for model robustness, Khan et al. (2020) found that renewable energy is significantly associated with international trade and improves to environmental quality in Nordic counties. In a similar study to detect the impact of government subsidies on end-of-life vehicle recycling, Khan et al. (2020) establish a game model in the competition between legal and illegal recyclers with the involvement of the government. The result indicates that compared to legal recyclers, subsidizing end-of-life vehicle owners produces effective results. Additionally, the outcomes indicate that differential subsidy policies on end-of-life vehicles are useless if they remain in poor quality, and call for the government's adoption of policies on end-of-life vehicle market development to protect the environment. Furthermore, the study conducted by Ponce et al. (2020) to investigate the effects of internal energy market liberalization on CO_2 emissions in the European Union (within 27 countries between 2004 and 2017) indicates that liberalization of internal energy market relates negatively to CO_2 emissions. The study recommended public policies to reduce carbon dioxide emissions to target barriers imposed on foreign trade.

Urbanization, which has globally transformed housing patterns by grouping populations in large agglomerations, currently seems uncontainable, irreversible and increasingly recognized as a major culprit in environmental degradation (Zhang et al. 2021). Given that urbanization is viewed as one of the major factors contributing to environmental degradation, it has now received tremendous focus in theoretical and empirical literature (Adebayo and Kirikkaleli 2021). In recent years, socioeconomic and institutional quality for urban life has been investigated through the theory of urban environmental transition (Marcotullio 2017). This theory claims cities with environmental problems are largely due to growing urbanization which is noted for the massive destruction of cities' biocapacity and industrial pollution of air and water. Despite the successes of this theory, it has received criticisms from Dogan and Turkekul (2016), who argue that adverse impacts of urbanization are only temporal and normalized with regulation technological advancement and continuous structural improvements. The debate against this theory also finds shelter from the compact city theory introduced by Dantzig and Saaty (1973), claiming that population density due to urbanization promotes economies of scale and facilitates economic growth. Notwithstanding the criticisms, historical studies have identified various stages of urbanization, indicating that the current urbanization phenomenon is critically entering a transition when environmental risk is alarming, because its expression is no longer local but across borders, and very threatening in terms of increasing ecological footprint (Tracy et al. 2017). Recent research by Ahmed et al. (2020) on the impacts of urbanization and human capital on the ecological footprint in G7 economies from 1971 to 2014 indicates human capital and urbanization unidirectionally cause ecological footprint. Quite a number of empirical studies illustrated in Table 1 indicate or confirm a strong nexus between ecological footprint, urbanization and economic growth.

Upon a careful look at the literature above, one could safely find inconclusiveness in the study outcomes, rendering the major issues between ecological footprint, growth and urbanization still open to further academic investigations. Similarly, given recent findings that observed rise in ecological footprints from economic growth and urbanization negatively impact on biocapacity endowments of Eastern European region (Niccolucci et al. 2012), no studies to the best of our knowledge have further explored the veracity or otherwise of the findings. This work covering a period from 1998Q4 to 2017Q4 aims at capturing the relationships among the variables, in addition to bringing clarity into the debate using CADF unit root test, Westerlund cointegration test, common correlated effects and Dumitrescu Hurlin approaches for causality and robustness check**.**

Methodology and data source(s)

This section contains the theoretical framework, methods of analysis and description of the data and their source(s) mused in modelling the nexus between ecological footprint, growth and urban population growth

Data source, type and span

To empirically analyse the relationship among ecological footprint, economic growth and urbanization, this study employed available time series secondary data from 1998Q4 to 2017Q4 on nine (9) Eastern European countries (Ukraine, Romania, Czech Republic, Poland, Moldova, Azerbaijan, Hungary, Russia Republic and Slovakia). Data on the following variables were collected: ecological footprint, economic growth and urbanization. Ecological footprint is measured in global hectares (hga), comprising both land and sea. Datasets for ecological footprint were sourced from Global Footprint Network; economic growth is determined as gross domestic product per capita, in 2010 constant US dollars (Błażejowski et al. 2019). Data on growth was sourced from the World Bank; urbanization is determined by people dwelling in cities as defined by the country's statistical office (as share of total

Table 1 Summary of the nexus between ecological footprint, urbanization and economic growth

Sources	Periods	Countries	Estimator/approach	Causality relationship
Baloch et al. (2019)	1990-2016	59 Belt and Road countries	Driscoll-Kraay panel regression	Growth and Urb → Eco
Nathaniel et al. (2019)	1965-2014	South Africa	ARDL	EG, URB → Eco
Nathaniel (2021)	1971-2014	Indonesia	ARDL	Urb and Growth → EQ
Nathaniel et al. (2020)	1990-2016	Middle East and North Africa	AMG	EG, Urb → Eco
Ulucak and Khan (2020)	1992-2016	BRICS economies	FMOLS, DOLS	Urb, RE → Eco
Sui et al. (2011)	2004-2007	Nanchong	Grey prediction model GM (1, 1)	Urb → Eco
Majeed and Mazhar (2019)	1961 to 2013	27 OECD countries	OLS, Beta and Sigma-convergence	EC → Eco
Luo et al. (2018)	2005 to 2020	China	EF model	Urb → Eco
Isman et al. (2018)	2010 to 2015	Canada	Top-down (MRIO) based	EC → Eco
Clancy (2008).	2000-2008	Africa	Desk review	Urb → Eco
Baloch et al. (2019)	1990-2016	BRI countries	Driscoll-Kraay panel	EC → Eco
Ahmed et al. (2020)	1971-2014	G7 countries	CUP-FM and CUP-BC	EG, URB → Eco
Shaker (2015)	2000 to 2006	33 European countries	Conditional autoregressive (CAR), OLS, Shapiro–Wilk	EG, URB → Eco
Jorgenson (2003)		208 countries	Recursive indirect effect model	EG, URB → Eco
Hassan et al. (2019)	1971 to 2014	Pakistan	ARDL	URB → Eco
Luo et al. (2018)	2005 to 2020	Midwestern China	Improved EF model	URB → Eco
Destek et al. (2018)	1971–2013	MINT countries	ARDL	EG, URB → Eco
Charfeddine (2017)	1970–2015	Qatar	Markov switching equilibrium correction model	EG, URB → Eco
Langnel and Amegavi (2020)	1971–2016	Ghana	ARDL	EG, URB → Eco
Li et al. (2011)	2004-2007	Nanchong city	Grey prediction model GM (1, 1)	URB → Eco
Luo et al. (2018)	2010–2015	China	ECC-based spatial weight matrices	URB → Eco

Note: The direction of the causality is shown by →, ↔ and ‹≠› symbols. Source: authors' compilation

Urb urban population; *Eco* ecological footprint; *EG* economic growth; CO_2 carbon dioxide; *EQ* environmental quality; *ED* environmental degradation; *RE* renewable energy

population). Dataset for the urban population was sourced from the World Bank.

Model and definition of variables

To investigate environmental sustainability, economic growth and urbanization in Eastern Europe, we follow the EKC hypothesis (Beşe and Kalayci 2021 2019) and IPAT framework (Ehrlich and Holdren 1971) which has since been reformulated to analyse stochastic impacts (York et al. 2003). We then write the empirical equation as follows:

$$E = f(Y, U) \quad (1)$$

E is the ecological footprint, *Y* is the GDP per capita used as proxy for economic growth, *U* is the total urban population (Table 2) and *f* is the constant.

Table 2 Data description

Description/variables	*E*	*U*	*Y*
Mean	1.42E+08	21,779,559	9433.621
Median	58,557,190	7,629,063.	9448.238
Maximum	8.51E+08	1.08E+08	23,178.43
Minimum	5,766,865.	1,508,438.	1410.510
Std. Dev.	2.22E+08	31,316,405	5749.102
Skewness	2.232648	2.081463	0.308530
Kurtosis	6.489628	5.927434	2.063942
Jarque-Bera	927.3601	747.8576	36.29491
Probability	0.000000*	0.000000*	0.000000*
Sum	9.83E+10	1.51E+10	6,537,499.
Sum Sq. Dev.	3.41E+19	6.79E+17	2.29E+10
Observations	693	693	693

E is the ecological footprint; *Y* is the GDP per capita used as proxy for economic growth; and *U* is the urbanization population respectively. With *p*-values of 0.000, we reject the null hypothesis of normal distribution for all the variables at *1% level of significance

Model specification and estimation techniques employed

First, we transform the time series data and specify the functional relationship $E = f(Y, U)$ as follows:

$$E_{it} = \beta_0 + \beta_1 E_{1it} + \beta_2 Y_{2it} + \beta_3 U_{3it} + \varepsilon_{it} \tag{2}$$

where the slope of the coefficients is illustrated by β; i illustrates the economies; t is the time (1998Q4–2014Q4); E is the ecological footprint; Y is the GDP per capita used as proxy for economic growth; U is the urban population; and ϵ is the standard error term. The coefficients β_1, β_2 and β_3 indicate long-run elasticity estimates of the dependent variable and ecological footprint, regarding the following independent variables: economic growth and urban population.

Second, given that panel data has limitations of cross-sectional dependence resulting from unobserved factors and shocks in different periods creeping in from cross-border economic factors (Latif et al. 2018), we adopt approaches used by Chudik and Pesaran (2013, 2015) to check whether all cross sections are affected equally by those unobserved factors in the panel data since errors arising out of them can have serious consequences, including unit root test results that have substantial distortions. The results are illustrated in Table 3.

Given that there is cross-sectional dependence in our data, we use several tests to investigate homogeneity using statistical analysis tool, XLSTAT 2016, with four (4) methods of homogeneity test: (i) Pettit's (1979) test; (ii) standard normal homogeneity test (SNHT) (Khaliq and Ouarda 2007a, b); (iii) Buishand's test (BRT) (1982); and (iv) von Neumann's ratio (VNR) test (Von Neumann 1941). The outcomes of the test are illustrated in Table 4.

Having realized that we have the problem of cross-sectional dependence in the panel data, we employ Pesaran (2015)-based LM test to help in the selection of appropriate estimation technique. The outcomes are illustrated in Table 5. Given the outcomes of the LM test indicate cross-sectional dependence which could lead to size distortions and low power, we employ second-generation ADF Fisher type panel unit root tests of Pesaran (2007) to establish the degree of integration in the variables. The usual ADF regression is augmented with lagged cross-sectional means and their first differences in accounting for any cross-sectional dependence occurring through a single-factor model with heterogeneous loading factors for residuals as follows:

$$\Delta y_{it} =_i + {}_i^{*} y_{i;t-1} + d_0 y^{-}_{t-1} + d_1 d^{-}_{t-1} + d_1 d^{-}_{yt} + {}''_{it} \tag{3}$$

The cross-sectional averages y^{-}_{t-1} and $\Delta^{-} y_t$ serve as additional regressors. Regressions can be augmented using two types of differences $\Delta y_{i;t-k}$ and $\Delta^{-} y_{t-k}$. In a second step, averaging across all N t–statistics for ${}^{*}_{i}$ yields a statistic with a tabulated/bootstrapped non-standard null distribution. The approach does not base unit root tests on deviations arising through estimated common factors but augments the standard Dickey-Fuller or augmented Dickey-Fuller regressions with lagged levels of cross-sectional averages as well as first differences of individual series. A truncated adaptation, denoted by CADF, avoids undue extreme outcomes arising in the case of small T samples. This is a successful attempt to build a modified version of the IPS t-bar test on the basis of average individual CADF or CADF statistics. This approach simply extends the serially correlated residuals (Hurlin and Mignon 2007), and an improvement in the earlier work of

Table 3 Cross-sectional dependence test for panel data

Test	Statistic	d.f.	Prob.
Breusch-Pagan Chi-square	1366.534	36	0.000*
Pearson LM normal	155.7443		0.000*
Pearson CD normal	1.991599		0.046*
Friedman Chi-square	475.5767	64	0.000*
Free normal	5.773741		0.000*

Note: *, ** and *** indicate 1%, 5% and 10% levels of significance respectively. With p-values of 0.000, we reject the null hypothesis of cross-sectional independence in the panel at 1% level of significance

Table 4 Slope heterogeneity test

Variable test	Pettitt test	SNHT test	Buishand test	von Neumann test
	(p-values)	(p-values)	(p-values)	(p-values)
E	<0.0001*	<0.0001*	<0.0001*	<0.0001*
Y	<0.0001*	<0.0001*	<0.0001*	<0.0001*
U	<0.0001*	<0.0001*	<0.0001*	<0.0001*

Note: *, ** and *** indicate 1%, 5% and 10% level of significance respectively. With p-values of 0.001, we reject the null hypothesis at 1% level of significance

Table 5 Lagrange multiplier (LM) test for panel data

Null (no rand. effect)	Cross section	Period	Both
Alternative	One-sided	One-sided	
Breusch-Pagan	24,647.61	24.87431	24,672.49
Honda	156.9956	−4.987416	107.486
	0	-1	0
King-Wu	156.9956	−4.987416	147.7934
	0	-1	0*
GHM	--	--	24,647.61
	--	--	0*

Note: In Table 5, *, ** and *** indicate 1%, 5% and 10% level of significance respectively

Table 6 Cross-sectional augmented Dickey-Fuller (CADF) panel unit root test

Variable	Level	1st difference without trend and intercept	Order of integration
E	2.747***	9.76***	*I*(1)
Y	2.602***	9.76***	*I*(1)
U	1.387***	9.77***	*I*(1)

Note: *, ** and *** indicate 1%, 5% and 10% level of significance respectively

Table 7 Westerlund ECM panel cointegration tests

Statistics	Value	*z*-value	*p*-value	Robust *p*-value
Gt	−3.572***	−5.008	0	0
Ga	−14.723***	−2.677	0.004	0
Pt	−10.439***	−5.132	0	0
Pa	−14.014***	−4.372	0	0

Note: *, ** and *** indicate 1%, 5% and 10% level of significance respectively

Bai and Ng (2001) as well as Moon and Perron (2004). The null hypothesis is that the model has a unit root. The outcomes of the panel unit root tests are reported in Table 6.

Traditional cointegration approaches such as those from Pedroni (1999) do not consider cross-sectional dependence and usually lead to biased results. To avoid this, we employ newly developed Durbin-Hausman ECM cointegration-based test of the Fisher effect by Westerlund (2008), which considers cross-sectional dependence, heteroscedasticity and serial correlation by using tests with two dimensions, assuming that the autoregressive parameter is the same for all rejections of the null hypothesis of no cointegration, and indicates the existence of cross-sectional cointegration. The outcomes of this advanced test of cointegration are illustrated in Table 7.

We understand by previous estimation studies that a change affecting one country is transferred to other economies due to trade and globalization. To deal with this estimation problem, this study uses CCE as the most appropriate estimation approach which is able to correct the problem. According to Banerjee and Carrion-i-Silvestre (2017), reliable estimation of the long-run average parameter is possible when cross-sectional dependence is controlled using cross-sectional averages from CCE approaches recommended by Pesaran (2006). The standard equation of CCE model can be written as follows:

$$Y_{it} = \alpha_i + X_{it} + \mu_{it} \quad (4)$$

where Y is the dependent variable, and X is the independent variable, with $t = 1, \dots T$ time periods and $i = 1 \dots, N$ cross-sectional units. The α_i contains the omitted variables, constant over time, for every unit i. The α_i is the fixed effects, and induces unobserved heterogeneity in the model. The X_{it} is the observed part of the heterogeneity. The μ_{it} contains the remaining omitted variables. The outcomes of the CCE estimation are illustrated in Table 8.

Finally, we adopt a very simple test of Granger-based non-causality used by Dumitrescu and Hurlin (2012), for our heterogeneous panel which is based on individual Wald statistics of Granger's non-causality averaged across the cross-sectional units. The test considers both dimensions any context heterogeneity (i.e. heterogeneity of causal relationships as well as heterogeneity in the regression model employed for the test). This test assumes that under the heterogeneous non-causality hypothesis, there is a causal relationship from x to y for a subgroup of individuals. This Granger non-causality test considers cross-sectional dependence using bootstrapped critical values rather than asymptotic critical values. The outcomes of our causality test are illustrated in Table 9.

Results and discussions

This section presents and discusses the empirical findings and discussion of results. It starts by describing the basic features of the data in Table 1. The outcomes reveal that they are not normally distributed as indicated in Table 2.

Table 8 Results of common correlated effects (CCE) estimation

E	Coeff	Std. Err	*Z*	*P*>|z|	95% conf. interval	
Y	0.431622	0.242863	1.78	0.076	−0.04438	0.9076244*
U	1.89057	0.895652	2.11	0.035	0.135124	3.646016**
E	0.814717	0.218801	3.72	0.035	0.385876	1.243558**
Y^l	−0.199	0.285987	−0.7	0.487	−0.75953	0.36152
U^l	−0.35459	2.403797	−0.15	0.883	−5.06595	4.356762
Constant	−10.5952	17.94608	−0.59	0.555	−45.7689	24.57847

Note: *, ** and *** indicate 1%, 5% and 10% level of significance respectively. The top half section represents the short-run and the bottom half represents long-run effects. Y^l and U^l are the long-run parameters

Table 9 Pairwise Dumitrescu Hurlin panel causality tests

Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Test results
Y does not homogeneously cause *E*.	9.609	2.649	0.008*	Rejected
E does not homogeneously cause *Y*.	4.550	−1.298	0.194	Not rejected
U does not homogeneously cause *E*.	13.903	6.000	0.000	Rejected
E does not homogeneously cause *U*.	11.396	4.044	0.000	Rejected

Note: *, ** and *** indicate 1%, 5% and 10% level of significance respectively

The table shows measures of central tendency, dispersion and normality of the data. The means for *E*, *U* and *Y* are 1.42E+08, 21,779,559 and 9433.621, respectively. A normal distribution is characterized by zero skewness and kurtosis of 3. Comparing the values reported for the various series to the default normal distribution values, we realize the variables do not mirror a normal distribution, except "*Y*" which is 0.308530. However, this does not affect the viability of results that will be obtained when used in statistical analysis because, for a large sample, a violation of the normality assumption is virtually unimportant since with reference to the central limit theorem (Huang et al. 2020), the test statistic will asymptotically follow the appropriate distribution even in the absence of normality. Standard deviation gives an idea of how spread out, scattered or dispersed each series's data points are from the mean.

Table 3 shows that there is a presence of cross-sectional dependence in the panel data. Commodity price shocks worsened in the first half of 2008, causing headline inflation spikes and weakening real disposable income and consumer demand. The report claims that Europe was generally affected directly via bank losses and tightening financial borrowing conditions. The already increased economic and financial integration across Europe resulted in strong interdependencies between cross-sectional units, possibly explaining individual countries' propensity to respond similarly to common "shocks" or common unobserved factors.

As the computed *p*-value is lower than the significance level alpha = 0.05, we reject the null hypothesis H0 of slope homogeneity and accept the alternative hypothesis Ha (indicating heterogeneity in the panel). The result corroborates with Campello et al. (2019) who claims that standard econometric approaches normally overlook individual heterogeneity leading to generating inconsistent parameter estimations in panel data models (see Table 4)

From the table, we find that the null hypothesis of cross-sectional independence is rejected at 1% significance level. This is vital in the determination that second-generation panel unit root tests are most appropriate for the estimation process (Pesaran 2012).

The results indicate all variables are integrated at order one without a trend. From these results, the null hypothesis of all panels contains unit roots rejected at 10% levels of significance. As variables are integrated at the same order, it confirms the existence of a long-run relationship. It allows us to conduct the Westerlund ECM cointegration test since the approach is able to deal with heterogeneous panels. This outcome supports the findings and empirical works of Bai and Ng (2004).

From Table 7, the outcomes indicate that the probability values of Ga, Gt, Pa and Pt are highly significant. The results indicated the null hypothesis of no cointegration is rejected at 1% level of significance, confirming long-run linkages among the variables. The result corroborates the study by Nathaniel et al. (2019) and Ahmed et al. (2020).

From Table 8, we observe that in the long run, a 1% change in GDP and urbanization negatively affects ecological footprint by 0.19% and 0.35%, respectively. Moreover, we find that in the short term, a percentage change in growth affects ecological footprint by 43.16%, while in the long run, a similar change in urbanization increases ecological footprint by 19.9%. The results corroborate the work of Ahmed et al. (2020) and Luo et al. (2018).

Table 9 reports the outcomes from Dumitrescu Hurlin panel causality tests. The null hypothesis that "*Y*" and "*U*" do not Granger cause "*E*" is rejected at 1% statistical level of significance, indicating that both growth and urbanization cause ecological footprint.

Discussion of findings

In the study, we have sought to investigate the role of urbanization and economic growth on global ecological footprint discussions emerging as the most important tool for environmental sustainability determination. In a heterogeneous panel of 9 countries in Eastern Europe, the outcomes of the test indicate the existence of cross-sectional dependence in the panel, which validates the World Bank (2008) reports that price shock of commodities worsened in the first half of 2008, leading to inflation spikes, weakened real disposable income and consumer demand. The cross-border price shocks impacted economic and financial integration across Europe, resulting in individual countries' propensity to respond similarly to common "shocks" or to the common unobserved factors (Gomez-Gonzalez et al., 2018). Besides, the Westerlund cointegration test confirms long-run linkages among the variables, similar corroborating findings by Nathaniel et al. (2019) and Ahmed et al. (2020). In addition, the CCE estimations indicate that urbanization and growth have direct negative consequences on ecological footprint, confirming earlier findings of Ahmed et al. (2020) and Luo et al. (2018).

Conclusion

The context and established standard of economic growth in Europe generally indicate the pressure placed on the newly admitted European Union economies to ensure the realization of robust and sustained economic growth. Pursuing these growth targets in the Eastern European economies has culminated in increased extractions of minerals, oil and other natural capital for both production and consumption. This is happening at an alarming rate as these economies enter into a new era of biocapacity constraints, evidenced by constricting supplies of natural resources (Niccolucci et al. 2012). Given the current debates in regional sustainability studies, this study conducts an empirical analysis of the relationship among urbanization, economic growth and ecological footprint: evidence from Eastern European countries from 1998Q4 to 2017Q4, in relation to the current state of available biocapacity of those economies. To the best of our knowledge, no study has investigated this relationship, especially using Westerlund cointegration and common correlated effect (CCE) approaches for the region. The uniqueness of these approaches is that they are able to account for problems of slope heterogeneity, cross-sectional dependence and unobserved factors arising out of demand shocks, economic proximity, changes in economic structures and other macroeconomic factors. The outcomes of the Westerlund cointegration test reveal evidence of cointegration among the variables. (ii) The outcome of the Dumitrescu Hurlin causality test indicates that there is a long-run unidirectional causality running from growth to ecological footprint and (iii) urbanization does not homogeneously cause ecological footprint. The results support similar empirical findings by Uddin et al. (2017), Hassan et al. (2019) and Jorgenson (2003). The outcomes further indicate growth negatively impacts on ecological footprints since biophysical resources are needed to propel further growth. The study contributes to the pollution haven hypothesis and ecological modernization theories (Mol 1997), and further supports the study conducted by Ibrahim (2020), claiming that environmental quality generally worsens at preliminary stages of economic growth until it is corrected through either regulatory policies or market mechanisms.

Based on the outcomes of this empirical study, and recognizing that extraction of natural resources and uncontrolled consumption not only is unsustainable in individual countries but also affects regional economies, we suggest (i) policy actions and strengthening of existing institutions regarding extraction of minerals, water pollution, land degradation and enforcement along the path of growth. (ii) In particular, the study has implications on regional policy actions that could support growth but reduce ecological deficits and urbanization and increase regional environmental quality. (iii) Given that in emerging economies, speedy rise in urban population most likely results in squatter settlements, urbanized slums and overburdening in water supply and waste-disposal systems, policies for establishing projects in villages to reduce urbanization should be encouraged in addition to changing production methods to improve on ecological footprint. (iv) Having realized the serious ramification of urbanization on our biophysical ecosystems, there is an urgent need for urban development planning policy to ensure energy efficiency improvements through modern innovative technologies as well as green lifestyle behaviours such as the use of solar lighting, sustainable consumption, ethanol for vehicles or more application of renewable technologies. (v) Similarly, given that a unit change in growth negatively impacts ecological footprint, relevant growth policies should consider the protection of the economy's biophysical capacities. It is recommended that governments encourage investments in developing technologies to ensure minimal impact of the ecosystem along the growth pathway. Although the present study provides a valuable contribution to the literature of ecological footprint and environmental sustainability research, we suggest further studies to determine the exact disaggregated levels of impact from urbanization and growth on ecological footprint and an examination of feasible decoupling measures for individual countries.

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2. BS reviewed the introduction and the literature reviews of the article.

3. DK reviewed the methodology of the article.

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