



Dynamics among economic growth, urbanization, and environmental sustainability in IEA countries: the role of industry value-added

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Received: 11 June 2021 / Accepted: 12 August 2021 / Published online: 17 August 2021
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Abstract

As an indicator of environmental degradation, the ecological footprint has seen a terrific focus in the literature. We explore the dynamics among economic growth, urbanization, and environmental sustainability in the presence of population growth and industry value-added in the thirty International Energy Agency (IEA) member countries. We apply advanced econometric modeling for empirical analysis over the period 1992 to 2016. This study's short-run results suggest that capital formation and biocapacity increase ecological footprint in the short run. The findings of long-run estimates demonstrate that industrial value-added and capital formation improve environmental sustainability. However, economic growth, urbanization, biocapacity, and population growth deteriorate environmental sustainability in the long run. Policymakers in the IEA countries are encouraged to establish policies that promote a sustained lifestyle, ecological awareness, clean technological innovations, efficient production and consumption measures, and enlarge cities to limit the adverse effects of urbanization on environmental sustainability. Finally, study limitations and future research directions are discussed.

Keywords Environmental sustainability · Economic growth · Urbanization · Industry value-added · IEA countries

Introduction

Environmental sustainability is the biggest challenge facing humanity today (Khan and Hou 2021a; Tawiah et al. 2021). Human activities threaten the ecosystem and the availabilities of basic human necessities like food, water, shelter, clean energy, and pollution-free air. The increasing demand for clean energy, infrastructure, water, nutrition, etc. persuades ecological stress, promoting emissions, depletion of resources, and distortion in the economic and environmental system (Ahmed 2019). The economic system is ultimately contingent on

ecological resources and their capacity in provisioning the necessities and ecological services for the life-support system. The latter is the crucial factor to decision-makers worldwide. Since the necessary condition to reach the objectives of Sustainable Development Goals (SDGs) of global sustainability is to survive within the boundaries of the biosphere's ecological resources (Costanza et al. 2014; Galli et al. 2015).

Rees and Wackernagel (1996) presented the concept of ecological footprint, which quantifies the bio-productive area obligatory to endure a population share. The ecological sources that a specific community requires to crop natural resources consume deal with the ecological footprint's demand side. The supply-side biocapacity represents the output of its ecological resources (Khan and Hou 2020). The ecological footprint accounts for the environmental magnitudes of producing goods and services to sustain a needed lifestyle (Hassan et al. 2019; Nathaniel 2020). The demand for ecological resources is already overlapping (Alola et al. 2019; Baz et al. 2020; Marti and Puertas 2020). It stipulates the higher consumption of the planet's resources than the speed of its regeneration process, resulting in climate change (Murshed and Dao 2020), nutrition scarcity, and biodiversity damages (Ahmed et al. 2019, 2020b; Rashid et al. 2018).

Responsible editor: Ilhan Ozturk

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Apart from the historical links between industrial and urbanization, people travel to the cities because of better health, education, and employment accessibilities. Urbanization drivers matter for economic and social transformations in society (Poumanyong and Kaneko 2010). However, the increasing urbanization trend required higher energy demand, intensifying CO₂ emissions, which accounts for 74.1% directly related to household utensils usage (Wang et al. 2020). As nations develop and living standards improve, the energy demand grows more rapidly (Saud et al. 2018; Troster et al. 2018). Industrial development entices economic growth through cross-sectorial events, which ultimately accelerates demand for energy and CO₂ emissions. Urbanization increases energy consumptions and eventually promotes environmental degradation on the one side (Al-Mulali and Ozturk 2015; Poumanyong and Kaneko 2010; Sheng et al. 2017; Zhang et al. 2015). On the other side, urbanization also witnessed a lower environmental degradation rate by provisioning innovations, research, and development opportunities towards green technology and resource efficiencies (Charfeddine and Ben Khediri 2016; Charfeddine and Mrabet 2017).

The contribution of this study is manifold. For instance, as per our understanding, prior studies have not examined the role of industry value-added, population growth, and gross fixed capital formation on the ecological footprint in the context of environmental sustainability for the International Energy Agency (IEA) countries. Literature from urbanization has no sufficient consensus on the relations with environmental sustainability. Some studies such as Al-Mulali and Ozturk (2015), Poumanyong and Kaneko (2010), Sheng et al. (2017), and Zhang et al. (2015) reveal that urbanization endorses environmental degradation, while studies such as Charfeddine and Ben Khediri (2016) and Charfeddine and Mrabet (2017) argue that urbanization is lowering the ecological degradation. Nevertheless, urbanization has both positive and adverse associations with environmental sustainability, and the empirical investigation is a prerequisite to check the net effects.

Moreover, questionings persist about the role of industry value-added and population growth in mitigating environmental unsustainability. Nonetheless, complexities of diverse economic structures and environmental legislation challenge constructing a consensus on industrialization for environmental degradation matters. The empirical investigation of this research is also worthwhile for climate concerned policy implications. We adopt advanced econometric methodologies for empirical analysis. We check the cross-section dependence and apply a second-generation unit root test for stationary diagnostics. We use Westerlund's (2007) second-generation panel co-integration test to check the long-run relationship. For short-run estimates, this study employs Eberhardt and Teal's (2010) Augmented Mean Group (AMG), Pesaran's

(2006) Common Correlated Effects Mean Group (CCE-MG), and Pesaran and Smith's (1995) Pooled Mean Group (PMG) estimates. This study applies the long-run estimates of the panel-corrected, heteroscedastic-corrected, and independent-corrected across panel regressions (PCSEs) in environmental research.

This research's preliminary plan is to explore the impact of economic growth, urbanization, biocapacity, industry value-added, capital formation, and population growth on the ecological footprint of 30 IEA member countries. The scientific explanation and justification for selecting IEA countries are specified by higher economic growth on higher energy consumption. Further, increasing interest in research and development of IEA countries in oil and gas extraction, innovations in hydraulic fracturing, policy advocating, enhancing the reliability, affordability, and sustainability of the energy efficiency vastly increased the importance of IEA countries (IEA 2019). Overall, this study seeks to address the SDG agenda of 2030 by considering sustainable development's environmental dimensions. Due to all these reasons, we expect that this research will prove a significant contribution to the literature.

The remaining parts of this study are structured as follows: the "Literature review" section discusses the literature review. Theoretical background and data are discussed in the "Theoretical background and data" section. The "Econometric modeling" section contains econometric modeling. The result and discussion are presented in the "Results and discussion" section, while the last section has conclusions and policy implications.

Literature review

The existing literature on the relationships of urbanization and ecological footprint has varied opinions. Some studies, such as Cole and Neumayer (2004) and Parikh (1995), claim that increasing urbanization is causing higher energy consumption, producing dangerous emissions, and resulting in environmental sustainability deterioration. However, Chen et al. (2008) explain that growing urbanization increases energy efficiency, which reduces energy demand; consequently, ecological settings improve. Nathaniel and Abdul (2020) examine the nexus between urbanization and ecological footprint for ASEAN countries from 1990 to 2016. Their finding indicates that urbanization stimulates ecological footprint during the study period. Also, Ahmed et al. (2020a) confirm that urbanization promotes China's ecological footprint, hence deteriorating environmental sustainability.

In contrast, Danish et al. (2020) examined urbanization's role in determining the ecological footprint of BRICS economies. Using FMOLS and DOLS, these researchers reported that urbanization decreases the ecological footprint and,

hence, improve environmental sustainability (Ahmad et al. 2021a). The studied literature has a mixed opinion, but this study assumes that urbanization expects to increase ecological footprint. Therefore, we propose that urbanization deteriorates environmental sustainability in IEA countries.

Grossman and Krueger (1991) developed the primary concept of environmental sustainability by assessing GHGs and economic development dynamics (Al-Mulali et al. 2016; Rauf et al. 2018). After that, Grossman and Krueger (1995) empirically investigated the environmental Kuznets curve (EKC) hypothesis and pinpoint that economic development is crucial for the environment. In the extreme is the consensus that environmental deterioration is obligatory aftermath of economic growth (Uddin and Gow 2016). Using the ARDL model, Udemba (2020) identifies that Nigeria's ecological footprint and economic development are increasing in the same direction from 1981 to 2018. Hassan et al. (2019) examined the dynamics of economic growth with ecological footprint for the Pakistan economy from 1970 to 2014. This finding asserts that the existence of the EKC framework in the Pakistan economy during the study period. Similar results were also concluded by Murshed et al. (2020b). Based on the above discussion, this study assumes that ecological footprint is positively trending with economic growth. Hence, we propose that economic growth deteriorates environmental sustainability (Murshed et al. 2020a).

The accessibility and consumption of ecological resources are essential to operate each industry, which underwrites everyday human life. Industry value-added and ecological footprint's significance cannot be separated from the daily social life, including the construction of houses where we live, growing the foodstuff we eat, the transportation sector we use, and the activities humans enjoy (GFN 2019). Wackernagel and Galli (2012) argued that we should consider ecological stability and industrial output to stay competitive in the present scarce resource world. Industrial and environmental policies are characteristically tangled, as industry value-added offers an excellent means to encourage green growth. However, we find no study examining this crucial relationship between ecological footprint and industry value-added. Thus, we expect that industry value-added decreases ecological footprint and thus improves environment sustainability during the study period.

The present literature has a significant gap in empirically analyzing the role of gross fixed capital formation in influencing ecological footprint. The gross fixed capital formation causes around 30% of the world's GHGs; such an overlook is a considerable omission. We observe that no previous study assesses the effects of gross fixed capital formation on the ecological footprint. Wood and Hertwich (2017) reveal that gross fixed capital formation has significant environmental impacts. They show that China has the highest gross fixed capital formation over the last decade, constituting 57% of

the CO₂ emissions. Construction accounts for 60% globally, and investing in buildings and roads represents 83% of its footprint. However, the carbon intensity of gross fixed capital formation alters based on the kind of capital good a specific country invested. For instance, construction and machinery are more carbon-intensive. In contrast, software and services businesses are not. Therefore, based on the above discussion, in this study, we presume that gross fixed capital formation expects to decrease ecological footprint and, hence, improves environmental sustainability in IEA countries.

Theoretical background and data

Beforehand with econometric modeling, we institute the theoretical background of this study. The idea of ecological footprint, firstly given by Rees and Wackernagel in the 1990s, is the degree of environmental degradation resulting from natural resource consumption (Hoekstra 2009; Rees and Wackernagel 1996). Since its inception, several researchers employ this measure for various objectives. This research uses ecological footprint to determine environmental sustainability and factors such as energy biocapacity, economic growth, industry value-added, urbanization, gross fixed capital formation, and population growth. The environmental sustainability, assessment, and resource deployment management can be evaluated through ecological footprint (Solarin et al. 2019). The ecological footprint, in the broader perspectives considering global-warming increasing carbon emissions, land use, higher consumption of the forest areas in tropical zones, and climate change, hurts the ecosystem (Ahmed et al. 2020b; Bilgili and Ulucak 2019).

Urbanization's environmental features are studied using three well-known theories, i.e., ecological modernizations, compact cities, and urbanization-transition theories. Ecological modernizations emphasize that urbanization development transfigures societies and creates environmental problems. However, transformed communities with higher income levels encourage and motivate people towards a clean environment. Nevertheless, innovations, research and development, green technology usage, and environmental-friendly legislatures contribute to monitoring the environmental degradations (Mol and Spaargaren 2014). Likewise, compact city theory focuses on developing dense cities and large population sizes, effective transport systems, and household facilities. The expansion of compact metropolises decreases energy consumption, which moderates emissions (Rehman et al. 2021). While transition theory explains the relationship between environmental degradations and income levels and reveals that ecological burden is because of climbing income levels, government intervention is the only key to reduce this pressure (Bekhet and Othman 2017; McGranahan et al. 2001).

The dynamics between environmental qualities with economic growth have immense importance in the literature (Al Mamun et al. 2014; Koondhar et al. 2021; Le and Ozturk 2020). Continuously controlling CO₂ emissions with sustained economic growth is vital for sustainable economic growth (Ahmad et al. 2021b). Higher economic growth may feed adversative ecological and sustainability questions (Lu 2017). Socio-economic sustainability is a prerequisite to accelerate living standards, promote social welfare, and flourish in a friendly environment (Zhou et al. 2018). The other intertwined crucial aspects include but are not limited to compound population growth, which is also positively associated with the ecological footprint, hence environmental sustainability. Because population growth is outpacing the ecological footprint, the growing population witnessed rapid resource depletion (Alam et al. 2016), resulting in severe ecological concerns like global warming, deforestation, and declining biodiversity. Similarly, the gross fixed capital formation generates overhead capital and improves conditions and methods for production and the virtual environment for economic development.

These are the prospective trepidations that many countries have, but environmental sustainability stands first to ensure humankind’s sustainable future (Ahmad et al. 2021c). Thus, energy biocapacity, urbanization, economic growth, and population growth are significantly positively associated with the ecological footprint in this academic setting. At the same time, industry value-added and gross fixed capital formation are adversely related to the ecological footprint for 30 IEA member countries.

We explore the dynamics between economic growth, urbanization, and environmental sustainability (ecological footprint) by taking the industry value-added, population growth, gross fixed capital formation, and energy biocapacity as the additional indicators, using a multivariate production function.

$$EFP_{it} = \beta_0 + \beta_1 EBC_{it} + \beta_2 GDP_{it} + \beta_3 INDVA_{it} + \beta_4 URB_{it} + \beta_5 GFCF_{it} + \beta_6 PG_{it} + \mu_{it} \tag{1}$$

where β_0 is coefficient’s slope; β_1 to β_6 are the coefficients of energy biocapacity (ECB), economic growth (GDP), industry value-added (INDVA), urbanization (URB), gross fixed capital formation (GFCF), and population growth (PG), respectively; t is the time (1992–2016); i denotes the cross-sections; and μ shows residuals.

This study’s central purpose is to check the dynamics between economic growth, urbanization, environmental sustainability, and the role of industry value-added, population growth, gross fixed capital formation, and energy biocapacity in the 30 IEA member countries. The IEA includes 30 member countries (country details in Table 9 in the Appendix). The data for the panel of these countries are arranged from three different sources. We collect the data from the Global Footprint Network (GFN) for ecological footprint and energy biocapacity. We collected GDP, industry value-added, urbanization, gross fixed capital formation, and population growth data from the World Development Indicators (WDI). This study involves the period from 1992 to 2016—the complete details of all these variables are presented in Table 1.

Econometric modeling

In this paper, we apply the cross-section dependence (CD) analysis proposed by Pesaran (2004) to test the cross-sectional dependence in Equation (2).

$$CD = \sqrt{\frac{2}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \sqrt{T_{ij} \hat{\rho}_{ij}} \right) CD \sim N(0, 1) \tag{2}$$

Table 1 Detail of variables

Variable name	Symbols	Unit of measurement	Definition	Data sources
Ecological footprint	EFP	GHA per-capita	gha per-capita consumption of ecological footprint	GFN
Energy biocapacity	EBC	GHA per-capita	Energy biocapacity gha per-capita	GFN
Economic growth	GDP per capita	Constant 2010 US\$	Constant 2010 US\$, gross domestic product divided by midyear population	WDI
Industrial value added	INDVA	% of GDP	Industry (including construction), value-addition in mining, manufacturing, construction, electricity, water, gas, etc.	WDI
Urbanization	URB	% of total population	People living in urban areas	WDI
Gross fixed capital formation	GFCF	Constant 2010 US\$	Land improvements, plant, equipment, and paraphernalia procurements; and the building of infrastructures, railways, and the like, including schools, offices, hospitals, private residentially, and commercial and industrial structures	WDI
Population growth	PG	Annual %	Population-based on the de-facto definition, which includes all residents irrespective of their citizenship	WDI

where N represents a sample, T is the study time, and $\widehat{\rho}_{ij}$ shows the coefficient correlations of variables or residuals.

We applied Pesaran's (2007) second-generation panel unit-root analysis, cross-sectional ISP (CIPS), and cross-sectional ADF (CADF), for the stationary review.

$$\Delta Y_{i,t} = \alpha_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + d_i \Delta \bar{Y}_t + \varepsilon_{i,t} \quad (3)$$

where $\bar{Y}_t = \frac{1}{N} \sum_{i=1}^N Y_{i,t}$, $\Delta \bar{Y}_t = \frac{1}{N} \sum_{i=1}^N \Delta Y_{i,t}$; a , c , and d are parameters; and $\varepsilon_{i,t}$ denotes error. Equation (4) represents the equation for CIPS.

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i. \quad (4)$$

Both CIPS and CADF measures claim that cross-sections are non-stationary, and a minimum of one cross-sectional unit is stationary between the study panels (Khan et al. 2021a, 2021c).

We apply the Westerlund's (2007) second-generation panel co-integration analysis to observe the long-run relationships.

$$\Delta y_{it} = c_i + a_{0i} (y_{i,t-1} - b_{ixi,t-1}) + \sum_{j=1}^{K_{1i}} a_{1ij} \Delta y_{i,t-j} + \sum_{j=-K_{2i}}^{K_{3i}} a_{2ij} \Delta x_{i,t-j} + \mu_{it}. \quad (5)$$

where again i is the cross-section, t is the study period, and a_{0i} shows the speed of adjustment of the correlation error term.

Given the confirmation of panel unit-root and panel co-integration analysis, we further evaluate how ecological footprint, energy biocapacity, and environmental sustainability react in the short run. We use Eberhardt and Teal's (2010) AMG, Pesaran's (2006) CCE-MG, and Pesaran and Smith's (1995) PMG estimates. This study applied panel-corrected, heteroscedastic-corrected, and independent-corrected across panel regressions (PCSEs) for the long-run approximations. Nevertheless, we also analyze the empirical distribution test and pairwise Dumitrescu and Hurlin's causality analysis to strengthen the econometric methodologies.

Results and discussion

The result of descriptive empirical distribution analysis and pairwise correlation matrix is discussed in Table 2 for ecological footprint, energy biocapacity, economic growth, industry value-added, urbanization, gross fixed capital formation, and population growth of IEA member countries. The empirical distribution result shows that all the variables have a statistically normal distribution and are highly significant. Pairwise correlation analysis depicts that ecological footprint is

positively associated with energy biocapacity, economic growth, urbanization, and population growth, while negatively trending with industry value-added and gross fixed capital formation. These descriptive statistics are significant at different levels. However, their other associations were conferred in detailed empirical investigations.

Table 3 consulted Pesaran's (2004) CD analysis for the panel of 30 IEA member countries. Result reveals that ecological footprint, energy biocapacity, economic growth, industry value-added, urbanization, and gross fixed capital formation are 1% significant, and population growth is 5% significant. This finding rejects the null hypothesis of cross-section independence. Thus, this study's variables enjoy the cross-sectional dependency during the study period of 1992 to 2016.

The result in Table 3 confirms the CD across the cross-section. Table 4 discussed the outcome of Pesaran's (2007) unit root analysis using Pesaran-CIPS and Pesaran-CADF. Findings of both Pesaran-CIPS and Pesaran-CADF approaches confirm the significance of variables at a 1% level. This confirmation implies the stationary properties at first-ordered differences.

After accepting the integration order, Westerlund's (2007) second-generation panel co-integration analysis is observed in Table 5. As per Westerlund's (2007) suggestion, we incorporate trend and constant in our estimations of panel co-integration. Findings without constant and trend, with constant, and with constant and trend reveal that study variables are co-integrated at a 1% and 5% significant level. This finding implies that the long-run relationship is present among the variables ecological footprint, energy biocapacity, economic growth, industry value-added, gross fixed capital formation, and population growth of 30 IEA member countries over the study period, 1992–2016.

Table 6 discusses the outcome of Eberhardt and Teal's (2010) AMG, Pesaran's (2006) CCE-MG, and Pesaran and Smith's (1995) PMG estimates for short-run analysis as estimated by Li et al. (2020). Findings from the three methodologies reveal the consensus that energy biocapacity and gross fixed capital formation influence the ecological footprint even in the short run. Further, both energy biocapacity and gross fixed capital formation have a short-run positive relationship with the ecological footprint. This finding implies that both energy biocapacity and gross fixed capital formation negatively influence environmental sustainability in the short run.

In Table 7, we represent the PCSEs long-run estimates of the study variables. Result explains that all the variables are significant at 1% and 5% levels of significance. Result reveals that energy biocapacity, economic growth, urbanization, and population growth are positively trending, while industry value-added and gross fixed capital formation are negatively trending with ecological footprint of 30 IEA member countries. Findings elucidate that 1% of acceleration in the energy

Table 2 The empirical distribution analysis and pairwise correlation matrix

Variables/methods	EFP	EBC	GDP	INDVA	URB	GFCF	PG
Lilliefors (D)	0.146772 *** (0.000)	0.255782 *** (0.000)	0.338542 *** (0.000)	0.033361 ** (0.0466)	0.091654 *** (0.000)	0.034744 ** (0.0320)	0.071479 *** (0.000)
Cramer-von Mises (W2)	4.332193 *** (0.000)	15.98356 *** (0.000)	29.85050 *** (0.000)	0.168108 ** (0.0138)	1.159070 *** (0.000)	0.208082 ** (0.0042)	0.800152 *** (0.000)
Watson (U2)	3.645267 *** (0.000)	14.21228 *** (0.000)	27.86836 *** (0.000)	0.167885 ** (0.0087)	1.054327 *** (0.000)	0.207468 ** (0.0024)	0.766524 *** (0.000)
Anderson-Darling (A2)	25.07465 *** (0.000)	82.91441 *** (0.000)	156.0524 *** (0.000)	1.335291 ** (0.0018)	7.060223 *** (0.000)	1.471174 *** (0.0008)	4.553197 *** (0.000)
MU	6.035172 *** (0.000)	4.336523 *** (0.000)	398.1520 *** (0.000)	25.82976 *** (0.000)	75.38696 *** (0.000)	25.39377 *** (0.000)	0.575202 *** (0.000)
SIGMA	2.242618 *** (0.000)	4.680026 *** (0.000)	951.2692 *** (0.000)	5.227576 *** (0.000)	10.16997 *** (0.000)	1.446242 *** (0.000)	0.636727 *** (0.000)
EFP	1.000						
EBC	0.277*** (0.000)	1.000					
GDP	0.240*** (0.000)	-0.060* 0.098	1.000				
INDVA	-0.392*** (0.000)	0.054 (0.138)	-0.103** (0.005)	1.000			
URB	0.443*** (0.000)	0.249*** (0.000)	0.126** (0.001)	-0.291*** (0.000)	1.000		
GFCF	-0.106** (0.004)	-0.157*** (0.000)	0.592*** (0.000)	0.071* (0.053)	0.257*** (0.000)	1.000	
PG	0.287*** (0.000)	0.145*** (0.000)	0.100** (0.006)	-0.060 (0.103)	0.235*** (0.000)	0.192*** (0.000)	1.000

***, **, and * direct the significance levels at 1%, 5%, and 10% accordingly.

biocapacity powers the ecological footprint of IEA countries by 0.56%. The positive value of the coefficient of energy biocapacity implies that energy biocapacity harms environmental sustainability (ecological footprint) in the long run, which stimulates the pressure on ecological degradation. These results are analogous with the studies (Danish et al. 2019; Saleem et al. 2019).

Similarly, a 1% increase in economic growth powers the ecological footprint in IEA countries by 0.001%. It implies that an increasing level of economic growth may feed

adversative ecological and sustainability questions (Lu 2017) and higher energy consumption stressing and hurt hard the environment. These results are analogous with Charfeddine’s (2017) findings and contrary to Altıntaş and Kassouri (2020).

A negative coefficient value of industry value-added depicts the negative associations with the ecological footprint. A 1% increase in industry value-added decreases the level of ecological footprint by 0.086%. It implies that research and development activities and innovations towards green

Table 3 Cross-section dependence analysis

Variable	CD-test	p-value	corr	abs(corr)
EFP	33.550 ***	0.000	0.322	0.421
EBC	44.440 ***	0.000	0.426	0.614
GDP	33.840 ***	0.000	0.324	0.422
INDVA	42.910 ***	0.000	0.411	0.530
URB	37.370 ***	0.000	0.358	0.854
GFCF	68.770 ***	0.000	0.659	0.743
PG	02.020 **	0.043	0.019	0.343

Under the null hypothesis of cross-section independence, CD ~ N(0,1) *** and ** direct the levels of significance at 1% and 5% accordingly.

Table 4 Second-generation unit-root tests

Variables	Pesaran-CIPS		Pesaran-CADF	
	Level	Difference	Level	Difference
EFP	-2.583	-5.528 ***	0.410	-3.480 ***
EBC	-3.342	-5.794 ***	-0.383	-2.962 ***
GDP	-1.728	-4.677 ***	0.255	-9.220 ***
INDVA	-2.172	-4.700 ***	0.504	-9.642 ***
URB	-0.428	-1.328 ***	6.193 ***	-0.271 ***
GFCF	-1.677	-4.036 ***	-0.400	-1.723 ***
PG	-1.512	-3.400 ***	2.538 ***	-1.164 ***

Footnote:*** directs the significance at 1%.

Table 5 Westerlund's second-generation panel co-integration analysis

Statistic	Without constant and trend			With constant			With constant and trend		
	Value	z-value	p-value	Value	z-value	p-value	Value	z-value	p-value
Gt	-3.497 ***	-5.749	0.000	-3.595 ***	-4.326	0.000	-3.586 **	-2.453	0.007
Ga	-7.589	4.116	1.000	-6.945	6.234	1.000	-6.714	8.211	1.000
Pt	-23.901 ***	-10.271	0.000	-21.138 ***	-6.527	0.000	-20.937 ***	-4.784	0.000
Pa	-12.727 **	-1.701	0.045	-10.693	1.597	0.945	-10.046	4.361	1.000

*** and ** direct the significance at 1% and 5% accordingly.

technology reduce emissions, improve environmental sustainability, and decrease ecological footprint. Further, these findings are associated with the composition effect concept, which reflects that the advanced industrialization process reduces the pollutants and encourages cleaner technology as income level increases (Khan et al. 2021b, 2021d; Khan and Hou 2021b).

The relationship between urbanization and ecological footprint is positive. The positive coefficient value of 0.082% reflects the truth that a 1 % growth in urbanization may influence the ecological footprint of IEA countries by 0.082% during the study period. This positive association between urbanization and ecological footprint demonstrates that many IEA countries' population lives in urbanization areas. The vast populace of metropolitan regions is directly linked with higher consumption and environmental threats (Ahmed et al. 2020b;

Jorgenson 2005). IEA states that higher-income urbanization communities necessitate transport, health, nitration, clean energy, water, and loading facilities." The increasing demand for natural assets is misbalancing and exploiting natural resources. Thus, excessive energy consumption, transportation, infrastructure, refrigeration, and deforestation are most associated with urbanization development. Consequently, urbanization in the IEA economies increases ecological footprint. These judgments are consistent with the findings of Al-Mulali and Ozturk (2015) and Charfeddine (2017).

Population growth is a significant measure of world demand for natural resources. According to GFN, 86% of the world's population survives in the ecological deficit; hence, the growing population exerts environmental pressure, increasing its ecological footprint. The findings of this study

Table 6 Short-run elasticity

CCE-MG estimations			AMG estimations			PMG estimations		
Variables	Coefficients	p-value	Variables	Coefficients	p-value	Variables	Coefficients	p-value
EBC	1.316077 **	0.001	EBC	.8760642 ***	0.000	EBC	.9146192 **	0.004
GDP	.0114713	0.382	GDP	-.0025616	0.700	GDP	.0292072 **	0.007
INDVA	-.0234304	0.367	INDVA	-.0013405	0.964	INDVA	.0124895	0.647
URB	.2544023	0.411	URB	.0439765	0.875	URB	.1400729	0.688
GFCF	1.600688 ***	0.000	GFCF	.8606595 **	0.004	GFCF	1.321522 ***	0.000
PG	.0702459	0.773	PG	-.0085016	0.941	PG	.013225	0.916
TREND	.2075322	0.226	c_d_p	1.050775 ***	0.000	TREND	.0607872	0.395
EFP_avg	1.188535 **	0.009	TREND	.112425	0.134	_cons	-51.74839	0.116
EBC_avg	-.9142122	0.177	_cons	-32.29573	0.184			
GDP_avg	-.0027609	0.629						
INDVA_avg	.0452499	0.569						
URB_avg	-.6226138	0.353						
GFCF_avg	-2.661484 **	0.005						
PG_avg	-.1729606	0.725						
_cons	45.12242	0.519						

*** and ** direct the significance level at 1% and 5% accordingly.

Table 7 Long-run estimations

Variables	Panel-corrected PCSE			Heteroscedastic-corrected PCSE			Indep-corrected PCSE		
	Coefficients	Std. Err.	p-value	Coefficients	Std. Err.	p-value	Coefficients	Std. Err.	p-value
EBC	.0558285 ***	.0063695	0.000	.0558285 **	.0166791	0.001	.0558285 ***	.0136761	0.000
GDP	.0010246 ***	.000027	0.000	.0010246 ***	.0000522	0.000	.0010246 ***	.0136761	0.000
INDVA	-.0858162 ***	.0112814	0.000	-.0858162 ***	.012518	0.000	-.0858162 ***	.0123254	0.000
URB	.0817415 ***	.0033156	0.000	.0817415 ***	.0064844	0.000	.0817415 ***	.0067862	0.000
GFCF	-.7243825 ***	.0396125	0.000	-.7243825 ***	.0832712	0.000	-.7243825 ***	.0556968	0.000
PG	.7640565 ***	.0736532	0.000	.7640565 ***	.1414276	0.000	.7640565 ***	.0962683	0.000
_cons	19.39482 ***	.9607689	0.000	19.39482 ***	1.953763	0.000	19.39482 ***	1.305412	0.000

*** and ** direct the significance level at 1% and 5% accordingly.

are on the same footprint. The positive coefficient value of 0.76% of population growth implies that a 1% increase in the population growth may accelerate the ecological footprint of IEA countries by 0.76% in the study period. The environmental impact of gross fixed capital formation on ecological footprint is negative, as depicted by the gross fixed capital formation coefficient value. A 1% increase in a gross fixed capital formation decreases the ecological footprint of IEA countries by 0.72%. The investment in capital goods, green technology, and innovations is a well-known environmental driver. Hence, the gross fixed capital formation condenses the ecological footprint of IEA countries. These findings are in line with Södersten et al. (2020) study and opposing the fall-outs (Södersten et al. 2020).

After analyzing the short- and long-run estimates, the findings of Dumitrescu and Hurlin’s (2012) Granger causality analysis are conferred in Table 8 to evaluate the causal relationship among the variables. Result reveals that the unidirectional Granger causality prevails between ecological footprint, energy biocapacity, urbanization, and gross fixed capital formation. Simultaneously, bidirectional Granger causality exists from ecological footprint to economic growth, industry value-added, and population growth. The finding that urbanization makes unidirectional Granger cause ecological footprint implies that urbanization stimulates ecological footprint and is consistent with the literature (Ahmed et al. 2020b; Al-Mulali and Ozturk 2015). The unidirectional Granger causality exists between gross fixed capital formation and ecological footprint while they receive adverse associations. It implies that investment and capital formation in green technology reduce environmental degradation in IEA countries. The two-way causality relationship between industry value-added, population growth, and ecological footprint depicts that industrialization has exerted ecological pressure. However, population growth is hampering the ecological footprint.

Conclusion and policy implications

Since the inception of this decade, environmental degradation has steadily amplified worldwide (Dong et al. 2020). We examine the dynamics among economic growth, urbanization, and environmental sustainability of 30 IEA member countries. We take the industry value-added, energy biocapacity, gross fixed capital formation, and population growth as the additional indicators, using a multivariate production function—the data for the panel of these countries were arranged from two different sources. For ecological footprint and energy biocapacity, we collect the data from GFN. We collect the economic growth, industry value-added, urbanization, gross fixed capital formation, and population growth data from WDI. This study involves the study period from 1992 to 2016 .

The empirical distribution analysis result confirms that all the variables are statistically normally distributed and highly significant. Pairwise correlation analysis depicts that ecological footprint is positively associated with energy biocapacity, economic growth, urbanization, and population growth while negatively trending with industry value-added and gross fixed capital formation. Pesaran’s (2004) CD analysis reveals that study variables are enjoying cross-sectional dependency. Findings of both Pesaran-CIPS and Pesaran-CADF approaches confirm the significance of variables at 1%. The findings of Westerlund’s (2007) second-generation panel co-integration confirm that the long-run relationship is present in the variables. Short-run analysis of AMG, CCE-MG, and PMG reflects that energy biocapacity and gross fixed capital formation influence environmental sustainability even in the short run. The long-run estimates of PCSEs reveal that energy biocapacity, economic growth, urbanization, and population growth are positively trending, while industry value-added and gross fixed capital formation are negatively trending with

Table 8 Pairwise Dumitrescu-Hurlin panel causality tests

Dependent	Independent						
	EFP	EBC	GDP	INDVA	URB	GFCF	PG
EFP	_____	6.0520 *** (0.000)	-2.2515 ** (0.0244)	3.0759 ** (0.0021)	6.7831 *** 0.000	4.2795 *** (0.000)	2.3347 (0.0196) **
EBC	0.1689 (0.8659)	_____	0.0622 (0.9504)	3.3424 *** (0.0008)	10.7578 *** (0.000)	2.7216 ** (0.0065)	-0.3129 (0.7544)
GDP	-2.0580 ** (0.0396)	5.9058 *** (0.000)	_____	3.3219 *** (0.0009)	7.0461 *** (0.000)	4.8913 *** (0.000)	2.9188 ** (0.0035)
INDVA	2.3903 ** (0.0168)	4.3951 *** (0.000)	2.2231 ** (0.0262)	_____	6.8267 *** (0.000)	9.9255 *** (0.000)	1.2218 (0.2218)
URB	0.2637 (0.7920)	2.3012 ** (0.0214)	-0.0436 (0.9652)	4.1604 *** (0.000)	_____	8.2570 *** (0.000)	6.4127 *** (0.000)
GFCF	1.5255 (0.1271)	3.1569 ** (0.0016)	1.5283 (0.1264)	2.7243 ** (0.0064)	7.3185 *** (0.000)	_____	0.7160 (0.4740)
PG	2.0077 ** (0.0447)	6.0025 *** (0.000)	1.9817 ** (0.0475)	7.4058 *** (0.000)	14.3653 *** (0.000)	8.3533 *** (0.000)	_____

*** and ** direct the significance at 1% and 5% accordingly.

the ecological footprint of 30 IEA member countries over the study period.

The finding elucidates that urbanization and economic growth increase environmental degradation pressure because IEA countries' higher-income urbanization communities require transport, health, nitration, clean energy, clean water, and loading facilities. Excessive energy consumption, transportation, infrastructure, refrigeration, and deforestation are mainly associated with urbanization development. Hence, this study suggests that IEA countries should offer several environmental awareness packages to urbanization communities. The supply of energy-efficient home utensils and subsidized solar energy panels should be ensured in the residential neighborhoods.

Long-run estimates of this study confirm that gross fixed capital formation and industry value-added are negatively associated with the ecological footprint, implying that gross fixed capital formation and industry value-added encourage environmental sustainability. The urbanization industrial sector should support and devise green renewable equipment to control the environmental pollution caused during the production process. Hence, the urbanization transportation sector's innovations should be realized, and the fossil fuel consuming urbanization transport sector should be renewed to green renewable technology (Irfan et al. 2021a, 2021b). IEA countries' transport industry should adopt innovative technology and introduce hybrid energy-efficient automobiles to ensure a sustainable environment. Both the public and business enterprises should equally contribute to energy technological innovations. The research and development in renewable energy technologies may prove helpful in tackling the adversely

impacting factors of energy consumption on ecological footprint.

The long-run estimates conclude that population growth encourages environmental degradation. In this scenario, this research suggests that IEA countries' government promotes the growing population to accept and follow a sustained lifestyle. The sustainable lifestyle may help pro-environmental accomplishments, including energy-saving, water-saving, usages of renewable sources utensils, and resource recycling.

The government of IEA countries should design legislation for a clean environment. IEA countries' economies should subsidize the renewable energy sector, make it tax-free, and impose restrictions on non-renewable source dependence and dirty imports. Through social, print, and electronic media, environmental publicity should be realized by the IEA economies to promote environmental awareness among the increasing population. The insertion of environmental sustainability chapters in the educational syllabus may prove sufficient to deliver the message of ecological sustainability. The environmental institutions of respective countries should be subsidized and encouraged to approach the national and international business firms and industries to adopt sustainable and efficient energy measures for their production process.

This study has the limitations of not categorizing the IEA countries into groups of developing or developed countries. Future research should incorporate this and analyze the differences between the states and between the panels. Also, this study contains only the environmental sustainability resulting from the ecological footprint and energy biocapacity. Future studies should also include the economic and socio-economic aspects of the ecological footprint. Nevertheless, the life

sustainability index’s enclosure could make future research more interesting while exploring the relationship between ecological footprint and sustainability.

Author contribution Xiaotian Yang: Structure and reviewing.
 Irfan Khan: Writing (original draft preparation), conceptualization, methodology, modeling, software, etc.
 Availability of data and materials
 Not applicable.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

Appendix

Table 9 List of IEA countries

Member countries		
Australia	Germany	Norway
Austria	Hungry	Poland
Belgium	Ireland	Portugal
China	Italy	Slovak Republic
Canada	Japan	Spain
Czech Republic	Korea	Sweden
Denmark	Luxembourg	Switzerland
Estonia	Mexico	Turkey
Finland	New Zealand	United Kingdom
France	Netherlands	United States

References

Ahmad M, Jabeen G, Irfan M, Işık C, Rehman A (2021a) Do inward foreign direct investment and economic development improve local environmental quality: aggregation bias puzzle. *Environ Sci Pollut Res*:34676–34696. <https://doi.org/10.1007/s11356-021-12734-y>

Ahmad M, Jan I, Jabeen G, Alvarado R (2021b) Does energy-industry investment drive economic performance in regional China: implications for sustainable development. *Sustain Prod Consum* 27:176–192. <https://doi.org/10.1016/j.spc.2020.10.033>

Ahmad M, Muslija A, Satrovic E (2021c) Does economic prosperity lead to environmental sustainability in developing economies?

Environmental Kuznets curve theory. *Environ Sci Pollut Res* 28: 22588–22601. <https://doi.org/10.1007/s11356-020-12276-9>

Ahmed Z (2019) Investigating the impact of human capital on the ecological footprint in India: an empirical analysis. *Environ Sci Pollut Res* 26:26782–26796

Ahmed Z, Wang Z, Mahmood F, Hafeez M, Ali N (2019) Does globalization increase the ecological footprint? Empirical evidence from Malaysia. *Environ Sci Pollut Res* 26:18565–18582. <https://doi.org/10.1007/s11356-019-05224-9>

Ahmed Z, Asghar MM, Malik MN, Nawaz K (2020a) Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. *Res Policy* 67:101677. <https://doi.org/10.1016/j.resourpol.2020.101677>

Ahmed Z, Zafar MW, Ali S, Danish (2020b) Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. *Sustain Cities Soc* 55:102064. <https://doi.org/10.1016/j.scs.2020.102064>

Al Mamun M, Sohag K, Hannan Mia MA, Salah Uddin G, Ozturk I (2014) Regional differences in the dynamic linkage between CO2 emissions, sectoral output and economic growth. *Renew Sust Energy Rev* 38:1–11. <https://doi.org/10.1016/j.rser.2014.05.091>

Alam MM, Murad MW, Noman AHM, Ozturk I (2016) Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. *Ecol Indic* 70:466–479. <https://doi.org/10.1016/j.ecolind.2016.06.043>

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. *Energy* 84:382–389. <https://doi.org/10.1016/j.energy.2015.03.004>

Al-Mulali U, Solarin SA, Ozturk I (2016) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. *Nat Hazards* 80: 1729–1747. <https://doi.org/10.1007/s11069-015-2050-x>

Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Sci Total Environ* 685:702–709. <https://doi.org/10.1016/j.scitotenv.2019.05.139>

Altıntaş H, Kassouri Y (2020) Is the environmental Kuznets curve in Europe related to the per-capita ecological footprint or CO2 emissions? *Ecol Indic* 113:106187. <https://doi.org/10.1016/j.ecolind.2020.106187>

Baz K, Xu D, Ali H, Ali I, Khan I, Khan MM, Cheng J (2020) Asymmetric impact of energy consumption and economic growth on ecological footprint: using asymmetric and nonlinear approach. *Sci Total Environ* 718:137364. <https://doi.org/10.1016/j.scitotenv.2020.137364>

Bekhet HA, Othman NS (2017) Impact of urbanization growth on Malaysia CO2 emissions: evidence from the dynamic relationship. *J Clean Prod* 154:374–388. <https://doi.org/10.1016/j.jclepro.2017.03.174>

Bilgili F, Ulucak (2019) Implications of environmental convergence: continental evidence based on ecological footprint, green energy and technology. https://doi.org/10.1007/978-3-030-06001-5_6

Charfeddine L (2017) The impact of energy consumption and economic development on ecological footprint and CO2 emissions: evidence from a Markov Switching Equilibrium Correction Model. *Energy Econ* 65:355–374. <https://doi.org/10.1016/j.eneco.2017.05.009>

Charfeddine L, Ben Khediri K (2016) Financial development and environmental quality in UAE: cointegration with structural breaks. *Renew Sust Energy Rev* 55:1322–1335. <https://doi.org/10.1016/j.rser.2015.07.059>

- Charfeddine L, Mrabet Z (2017) The impact of economic development and social-political factors on ecological footprint: a panel data analysis for 15 MENA countries. *Renew Sust Energ Rev* 76:138–154. <https://doi.org/10.1016/j.rser.2017.03.031>
- Chen H, Jia B, Lau SSYL (2008) Sustainable urban form for Chinese compact cities: challenges of a rapid urbanized economy. *Habitat Int* 32:28–40. <https://doi.org/10.1016/j.habitatint.2007.06.005>
- Cole MA, Neumayer E (2004) Examining the impact of demographic factors on air pollution. *Popul Environ* 26:5–21
- Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. *Glob Environ Chang* 26:152–158. <https://doi.org/10.1016/j.gloenvcha.2014.04.002>
- Danish, Hassan ST, Baloch MA, Mahmood N, Zhang JW (2019) Linking economic growth and ecological footprint through human capital and biocapacity. *Sustain Cities Soc* 47:101516. <https://doi.org/10.1016/j.scs.2019.101516>
- Danish, Ulucak R, Khan SUD (2020) Determinants of the ecological footprint: role of renewable energy, natural resources, and urbanization. *Sustain Cities Soc* 54:101996. <https://doi.org/10.1016/j.scs.2019.101996>
- Dong K, Hochman G, Timilsina GR (2020) Do drivers of CO2 emission growth alter overtime and by the stage of economic development? *Energy Policy* 140:111420. <https://doi.org/10.1016/j.enpol.2020.111420>
- Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. *Econ Model* 29:1450–1460. <https://doi.org/10.1016/j.econmod.2012.02.014>
- Eberhardt M, Teal F (2010) Productivity analysis in global manufacturing production. *Econ Ser Work Pap* 1–27
- Galli A, Lin D, Wackernagel M, Gressot M, Global SW (2015) Brief for GSDR 2015 Humanity's growing Ecological Footprint: sustainable development implications
- GFN (2019) Sector analysis, global footprint network, <https://www.footprintnetwork.org/our-work/sector-analysis/>
- Grossman G, Krueger A (1991) Environmental impacts of a North American Free Trade Agreement. *Natl Bur Econ Res*. <https://doi.org/10.3386/w3914>
- Grossman GM, Krueger AB (1995) Economic growth and the environment. *Q J Econ* 110:353–377
- Hassan ST, Xia E, Khan NH, Shah SMA (2019) Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environ Sci Pollut Res* 26:2929–2938. <https://doi.org/10.1007/s11356-018-3803-3>
- Hoekstra AY (2009) Human appropriation of natural capital: a comparison of ecological footprint and water footprint analysis. *Ecol Econ* 68:1963–1974. <https://doi.org/10.1016/j.ecolecon.2008.06.021>
- IEA (2019) Energy policies of IEA countries, 2019 Review Executive Summary
- Irfan M, Elavarasan RM, Hao Y, Feng M, Sailan D (2021a) An assessment of consumers' willingness to utilize solar energy in China: end-users' perspective. *J Clean Prod* 292:1–4. <https://doi.org/10.1016/j.jclepro.2021.126008>
- Irfan M, Hao Y, Ikram M, Wu H, Akram R, Rauf A (2021b) Assessment of the public acceptance and utilization of renewable energy in Pakistan. *Sustain Prod Consum* 27:312–324. <https://doi.org/10.1016/j.spc.2020.10.031>
- Jorgenson AK (2005) Unpacking international power and the ecological footprints of nations: a quantitative cross-national study. *Sociol Perspect* 48:383–402. <https://doi.org/10.1525/sop.2005.48.3.383>
- Khan I, Hou F (2020) The dynamic links among energy consumption, tourism growth, and the ecological footprint: the role of environmental quality in 38 IEA countries. *Environ Sci Pollut Res* 28:5049–5062. <https://doi.org/10.1007/s11356-020-10861-6>
- Khan I, Hou F (2021a) The impact of socio-economic and environmental sustainability on CO2 Emissions: a novel framework for thirty IEA countries. *Soc Indic Res* 155:1045–1076. <https://doi.org/10.1007/s11205-021-02629-3>
- Khan I, Hou F (2021b) Does multilateral environmental diplomacy improve environmental quality? The case of the United States
- Khan I, Hou F, Irfan M, Zakari A, Phong H (2021a) Does energy trilemma a driver of economic growth? The roles of energy use, population growth, and financial development. *Renew Sust Energ Rev* 146:111157. <https://doi.org/10.1016/j.rser.2021.111157>
- Khan I, Hou F, Le HP (2021b) The impact of natural resources, energy consumption, and population growth on environmental quality: fresh evidence from the United States of America. *Sci Total Environ* 754:142222. <https://doi.org/10.1016/j.scitotenv.2020.142222>
- Khan I, Hou F, Phong H, Ahtsham S (2021c) Do natural resources, urbanization, and value-adding manufacturing affect environmental quality? Evidence from the top ten manufacturing countries. *Res Policy* 72:102109. <https://doi.org/10.1016/j.resourpol.2021.102109>
- Khan I, Hou F, Zakari A, Konadu V (2021d) The dynamic links among energy transitions, energy consumption, and sustainable economic growth: a novel framework for IEA countries. *Energy* 222:119935. <https://doi.org/10.1016/j.energy.2021.119935>
- Koondhar MA, Shahbaz M, Memon KA, Ozturk I, Kong R (2021) A visualization review analysis of the last two decades for environmental Kuznets curve “EKC” based on co-citation analysis theory and pathfinder network scaling algorithms. *Environ Sci Pollut Res* 28:16690–16706. <https://doi.org/10.1007/s11356-020-12199-5>
- Le HP, Ozturk I (2020) The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. *Environ Sci Pollut Res* 27:22680–22697. <https://doi.org/10.1007/s11356-020-08812-2>
- Li G, Zakari A, Tawiah V (2020) Does environmental diplomacy reduce CO2 emissions? A panel group means analysis. *Sci Total Environ* 722:137790. <https://doi.org/10.1016/j.scitotenv.2020.137790>
- Lu WC (2017) Greenhouse gas emissions, energy consumption and economic growth: a panel co-integration analysis for 16 Asian countries. *Int J Environ Res Public Health* 14. <https://doi.org/10.3390/ijerph14111436>
- Marti L, Puertas R (2020) Analysis of the efficiency of African countries through their ecological footprint and biocapacity. *Sci Total Environ* 722:137504. <https://doi.org/10.1016/j.scitotenv.2020.137504>
- McGranahan G, Jacobi P, Songsore J, Surjadi C, Kjellén M (2001) The citizens at risk: from urban sanitation to sustainable cities
- Mol APJ, Spaargaren G (2014) Ecological modernisation theory in debate: a review. *Ecol Mod Around World Perspect Crit Debates*:17–49
- Murshed M, Dao NTT (2020) Revisiting the CO2 emission-induced EKC hypothesis in South Asia: the role of Export Quality Improvement. *GeoJournal* 9. <https://doi.org/10.1007/s10708-020-10270-9>
- Murshed M, Ali SR, Banerjee S (2020a) Consumption of liquefied petroleum gas and the EKC hypothesis in South Asia: evidence from cross-sectionally dependent heterogeneous panel data with structural breaks. *Energy. Ecol Environ* 6:353–377. <https://doi.org/10.1007/s40974-020-00185-z>
- Murshed M, Nurmakanova M, Elhaddad M, Ahmed R (2020b) Value addition in the services sector and its heterogeneous impacts on CO2 emissions: revisiting the EKC hypothesis for the OPEC using panel spatial estimation techniques. *Environ Sci Pollut Res* 27:38951–38973. <https://doi.org/10.1007/s11356-020-09593-4>
- Nathaniel SP (2020) Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. *GeoJournal* 7. <https://doi.org/10.1007/s10708-020-10175-7>
- Nathaniel S, Abdul SKR (2020) The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries. *J Clean Prod* 122709:122709. <https://doi.org/10.1016/j.jclepro.2020.122709>

- Parikh J (1995) Urbanization, energy use and greenhouse effects in economic development study of developing countries 5
- Pesaran MH (2004) General diagnostic tests for cross section dependence in panels. IZA Discuss. Pap. No. 1240 August 2004 1–39
- Pesaran MH (2006) Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74:967–1012. <https://doi.org/10.1111/j.1468-0262.2006.00692.x>
- Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. *J Appl Econ* 21:1–21. <https://doi.org/10.1002/jae>
- Pesaran MH, Smith R (1995) Estimating long-run relationships from dynamic heterogeneous panels. *J Econ* 68:79–113. [https://doi.org/10.1016/0304-4076\(94\)01644-F](https://doi.org/10.1016/0304-4076(94)01644-F)
- Poumanyong P, Kaneko S (2010) Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. *Ecol Econ* 70:434–444. <https://doi.org/10.1016/j.ecolecon.2010.09.029>
- Rashid A, Irum A, Malik IA, Ashraf A, Rongqiong L, Liu G, Ullah H, Ali MU, Yousaf B (2018) Ecological footprint of Rawalpindi; Pakistan's first footprint analysis from urbanization perspective. *J Clean Prod* 170:362–368. <https://doi.org/10.1016/j.jclepro.2017.09.186>
- Rauf A, Liu X, Amin W, Ozturk I, Rehman OU, Hafeez M (2018) Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from belt and road initiative economies. *Environ Sci Pollut Res* 25:32066–32080. <https://doi.org/10.1007/s11356-018-3052-5>
- Rees W, Wackernagel M (1996) Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability introduction: transforming human ecology. *Environ Impact Assess Rev*:537–555. <https://doi.org/10.1007/978-0-387-73412-5>
- Rehman A, Ulucak R, Murshed M, Ma H, Işık C (2021) Carbonization and atmospheric pollution in China: the asymmetric impacts of forests, livestock production, and economic progress on CO2 emissions. *J Environ Manag* 294:113059. <https://doi.org/10.1016/j.jenvman.2021.113059>
- Saleem N, Rahman S, Jun Z (2019) The impact of human capital and biocapacity on environment: environmental quality measure through ecological footprint and greenhouse gases. *J Pollut Effect Control* 07:12. <https://doi.org/10.35248/2375-4397.19.7.237>
- Saud S, Danish, Chen S (2018) An empirical analysis of financial development and energy demand: establishing the role of globalization. *Environ Sci Pollut Res* 25:24326–24337. <https://doi.org/10.1007/s11356-018-2488-y>
- Sheng P, He Y, Guo X (2017) The impact of urbanization on energy consumption and efficiency. *Energy Environ* 28:673–686. <https://doi.org/10.1177/0958305X17723893>
- Södersten CJ, Wood R, Wiedmann T (2020) The capital load of global material footprints. *Resour Conserv Recycl* 158:104811. <https://doi.org/10.1016/j.resconrec.2020.104811>
- Solarin SA, Tiwari AK, Bello MO (2019) A multi-country convergence analysis of ecological footprint and its components. *Sustain Cities Soc* 46:101422. <https://doi.org/10.1016/j.scs.2019.101422>
- Tawiah VK, Zakari A, Khan I (2021) The environmental footprint of China–Africa engagement: an analysis of the effect of China–Africa partnership on carbon emissions. *Sci Total Environ* 756:143603. <https://doi.org/10.1016/j.scitotenv.2020.143603>
- Troster V, Shahbaz M, Uddin GS (2018) Renewable energy, oil prices, and economic activity: a Granger-causality in quantiles analysis. *Energy Econ* 70:440–452. <https://doi.org/10.1016/j.eneco.2018.01.029>
- Uddin GA, Gow J (2016) Does ecological footprint impede economic growth? An empirical analysis based on the environmental Kuznets curve hypothesis University of Southern Queensland and John Wiley & Sons Australia, Ltd Aust Econ Pap <https://doi.org/10.1111/1467-8454.12061>, 55, 301, 316
- Udemba EN (2020) Jo The author hereby declares that there is no form of funding received for this study of *Sci Total Environ* 139270. <https://doi.org/10.1016/j.scitotenv.2020.139270>
- Wackernagel M, Galli A (2012) Ecological footprint: economic performance and resource constraints, https://www.footprintnetwork.org/content/images/article_uploads/Wackernagel_and_Galli_2012.pdf. *Glob Footpr Netw*
- Wang Z, Rasool Y, Zhang B, Ahmed Z, Wang B (2020) Dynamic linkage among industrialisation, urbanisation, and CO2 emissions in APEC realms: evidence based on DSUR estimation. *Struct Chang Econ Dyn* 52:382–389. <https://doi.org/10.1016/j.strueco.2019.12.001>
- Westerlund J (2007) Testing for error correction in panel data. *Oxf Bull Econ Stat* 69:709–748. <https://doi.org/10.1111/j.1468-0084.2007.00477.x>
- Wood R, Hertwich EG (2017) Environmental impacts of capital. *J Ind Ecol* 00:1–13. <https://doi.org/10.1111/jiec.12532>
- Zhang YJ, Yi WC, Li BW (2015) The impact of urbanization on carbon emission: empirical evidence in Beijing. *Energy Procedia* 75:2963–2968. <https://doi.org/10.1016/j.egypro.2015.07.601>
- Zhou C, Wang S, Feng K (2018) Examining the socio-economic determinants of CO2 emissions in China: a historical and prospective analysis. *Resour Conserv Recycl* 130:1–11. <https://doi.org/10.1016/j.resconrec.2017.11.007>

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