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Research article

Impact of urbanization and human development on ecological footprints in OECD and non-OECD countries

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A B S T R A C T

Ecological footprints play a crucial role in assessing how human activities impact the environment, serving as key indicators. This study investigates the influence of urbanization and human development controlling for GDP and industrialization on ecological footprints, focusing on both OECD and non-OECD countries during the period from 1990 to 2018. The investigation employs an open-access solution framework and utilizes the Generalized Method of Moments approach for analysis. The findings highlight distinct patterns between OECD and non-OECD countries. In OECD countries, ecological footprints are increasing with urbanization and GDP growth while showcasing a negative impact of the Human Development Index (HDI) and industrialization on ecological footprint. Conversely, non-OECD countries demonstrate a positive impact of GDP and HDI on ecological footprints, while there is a negative impact of industrialization and urbanization on ecological footprints. These disparities underscore the need for tailored environmental strategies based on a country's economic and developmental status. The results underscore the importance of investing in the renewable energy sector and implementing stringent environmental policies to mitigate the environmental impact of human activities. This evidence reinforces the urgency for countries, irrespective of their OECD status, to take proactive measures to safeguard the planet from further environmental hazards.

1. Introduction

In recent years, the global environment has faced significant challenges stemming from ecological imbalances and the relentless pace of economic activities [1]. This has led to widespread environmental degradation characterized by phenomena such as global warming and various forms of pollution, posing considerable challenges to sustainable development [2]. Amidst these concerns, the concept of environmental footprints has emerged as a crucial framework for assessing the impact of human activities on ecosystems [3]. Environmental footprints encompass diverse dimensions including agricultural footprints, fisheries footprints, construction footprints, carbon footprints, and forest land footprints [4].

Central to the evaluation of environmental footprints is the ecological footprint (EF), a sustainability indicator developed by Wackernagel and Rees in the early 1990s [5]. The EF provides a quantitative measure of an individual's ecological impact by gauging the rate at which resources are consumed and waste is generated in comparison to the Earth's capacity for resource regeneration [6]. The EF is typically measured in global hectares (gha), with consumption statistics serving as the foundation for its calculation. Consequently, an increase in consumption correlates with an augmentation of the ecological footprint.

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Agricultural footprints quantify the land and resources utilized for crop production and livestock feed, while fisheries footprints estimate the primary production consumed by marine species over their lifetimes. Construction footprints assess the land required for infrastructure development, transportation, and industrial activities. Carbon footprints measure the total greenhouse gas emissions associated with specific entities, while forest land footprints evaluate the impact of certain products on forest cover [7].

Complementing the EF is the concept of biocapacity (BC), which denotes nature's capacity for resource replenishment. The relationship between EF and BC is crucial in determining environmental sustainability, with an ecological surplus indicating sustainable practices and an ecological deficit signifying unsustainable resource consumption [8].

Despite its significance, the assessment of environmental footprints presents challenges, particularly in the context of valuation techniques. Direct methods, such as monetary conversions of environmental preferences, often exhibit biases and limitations [9].

Table 1
Empirical literature review.

Author(s)	Country(s)	Time Period	Variables	Methodology	Results
Chen et al. (2021)	110 countries	1990–2016	Human capital, urbanization, and the ecological footprints	Tree regression, boosting, and the random forest	To improve the environment, increased levels of urbanization call for higher levels of human capital.
Álvarez-García et al. (2022)	Global level	1995 to 2017	Economic development, renewable energy, urbanization, industrialization, and FDI	Westerlund co-integration and quantile regressions	Globally, urbanization and renewable energy had the opposite effect, with the biggest impact shown in the upper quantiles, while economic development contributed to environmental degradation across all quantiles.
Christoforidis and Katrakilidis (2021)	29 OECD countries	1984 to 2016	Renewable and non-renewable energy consumption, economic growth, institutional quality, and the EF	Feasible Generalized Least Squares (FGLS) and the Panel Corrected Standard Error (PCSE)	Environmental harm is caused by economic expansion and with usage of non-renewable energy sources, whereas the quality of institutions has a positive relationship with ecological sustainability.
Chang and Chen (2016)	99 countries	1981 to 2006	GDP per capita, ecological footprint and urbanization	Generalized method of moments (GMM) estimator	The environment will be impacted as nations strive for economic progress, and developed nations may participate in more environmentally destructive activities.
Gorus and Karagol (2022)	27 OECD countries	1971–2016	Income level, divided energy consumption, types of globalization level, urbanization, and the ecological footprint.	Tree regression, boosting, bagging, and the random forest.	The partial dependence charts show that the ecosystem suffers from economic growth, especially when it is driven by fossil fuels.
Radmehr et al. (2022)	Seven (G7) countries	1990 to 2018	Ecological Footprint (EFP), renewable energy consumption (REC), and income	Generalized method of moments (GMM) estimator	GDP and renewable energy are symbiotically linked, and a reciprocal relationship is observed between EFP and both renewable energy and outcome.
Zhang et al. (2021)	Pakistan	1985 to 2018	Natural resources, economic growth, human capital, ecological footprints, and carbon emissions	Dynamic autoregressive distribution lag (DARDL) approach	Natural resources and economic growth have a negative relationship with ecological footprint in the short and long term. However, human capital and human growth have a positive relationship. EKC is present in Pakistan.
Pata et al. (2020)	Top ten countries having highest ecological footprint	1992 to 2016	Globalization, REC, natural resource abundance, human development index and environmental degradation	Panel co-integration test and augmented mean group estimator	Increased REC and human progress have a harmful impact on the environment. While globalization has little effect on environmental strain, the abundance of natural resources lowers environmental quality.
Chu and Tran (2022)	27 OECD countries	1990–2015	Environmental policy stringency and ecological footprint	Panel quantile regression	Environmental regulation plays a positive function in lowering the ecological footprint at quantiles below the 80th, but it starts to have a negative impact at extremely high quantiles. At numerous quantiles of ecological footprint, the influence of additional driving factors, including income, global trade, energy efficiency, and renewable energy, are varied.

Nevertheless, the EF remains a valuable tool for evaluating changes in land use patterns and facilitating environmental management efforts.

Urbanization profoundly influences ecological footprints due to its significant impacts on resource consumption, land use, and waste generation. As populations migrate from rural to urban areas, the concentration of people in cities escalates the demand for resources such as water, energy, and food, thereby intensifying ecological footprints [10]. The expansion of urban infrastructure necessitates the conversion of natural habitats into built environments, leading to habitat loss and fragmentation, which further exacerbates ecological footprints [11]. Moreover, the compact nature of cities often results in increased energy consumption for transportation, heating, and cooling, contributing to greenhouse gas emissions and climate change [12]. Additionally, urban areas generate vast amounts of waste, including solid waste and wastewater, which require significant energy and resources for disposal and treatment, adding to ecological footprints [13].

Human development intricately intertwines with ecological footprints, as advancements in living standards and quality of life often correspond with increased resource consumption and environmental impact. As societies progress economically, access to goods and services improves, leading to elevated levels of consumption per capita [5]. This heightened consumption encompasses various resources such as energy, water, land, and materials, contributing significantly to ecological footprints. Moreover, human development is frequently accompanied by urbanization and industrialization, further amplifying resource demands and environmental pressures [14,15]. Additionally, as individuals attain higher levels of income and prosperity, lifestyles tend to become more resource-intensive, with increased reliance on transportation, technology, and consumer goods, consequently expanding ecological footprints [16].

The objective of this study is to examine the impact of urbanization and human development controlling GDP and industrialization on the ecological footprints focusing on both OECD and non-OECD countries. Also, this study aims to provide insights for policymakers and practitioners to promote sustainable development by making strict environmental policies. Further, this study aims to contribute to a better understanding of the relationship between urbanization, human development, and ecological footprint in OECD and non-OECD countries. Previous studies have mainly discussed developed countries, but here, the comparison of OECD and non-OECD nations has been studied in the context of ecological footprints, urbanization, and human development. Also, the current study uses open-access solutions from resource economics in its theoretical framework and in this way, it adopts an inter-disciplinary approach emphasizing the importance of evaluating economic activities in the context of their environmental implications.

2. Literature review

The ecological footprint (EF) has emerged as a prominent metric for evaluating human impact on the environment [17]. A growing body of research explores the multifaceted determinants of EF, emphasizing the intricate interplay between economic factors, human development, and environmental quality. Table 1 shows the empirical literature review.

Several studies highlight the environmental consequences of economic expansion [18]. documents a positive association between economic growth and ecological footprint, implying that economic activity comes at the expense of environmental degradation. However, the relationship appears nuanced and it is observed an inverted U-shaped curve [17], suggests that the environmental impact intensifies at initial development stages but tapers off as economies mature [19]. This aligns with the Environmental Kuznets Curve (EKC) hypothesis [20].

Urbanization presents a complex picture. While [21,22] report the opposite. This discrepancy underscores the potential for urbanization to foster innovation and resource efficiency [23]. However [24], caution against overexploiting natural resources, which can exacerbate environmental strain despite advancements in human development.

Human capital plays a crucial role. Studies by Refs. [20,25] show that a skilled population fosters environmental sustainability. Investment in human capital may lead to the development of green technologies and eco-conscious practices. However [24], challenge the universality of the Human Capital Kuznets Curve (HCKC) hypothesis, indicating that the relationship between human development and ecological footprint might be more complex than previously assumed.

The impact of globalization on the environment remains debated. While [25] finds that financial globalization has a detrimental effect, economic and social globalization appear less impactful [22]. emphasize the significance of foreign direct investment (FDI) but caution that its environmental consequences vary depending on the level of development.

Renewable energy offers a promising path towards sustainability. Studies by Refs. [24,26,27] highlight the positive influence of renewable energy consumption on ecological footprint reduction. This underscores the importance of transitioning away from fossil fuels.

Environmental regulations play a critical role in curbing ecological degradation. Further demonstrated that stricter environmental regulations can effectively minimize the ecological footprint, particularly for consumption-related activities. However, the effectiveness may vary depending on the level of economic development [28].

Despite these advancements, knowledge gaps remain. Prior research has primarily focused on developed nations, limiting the generalizability of findings [29]. Furthermore, a comprehensive understanding of the complex interplay between economic development, human capital, and ecological footprints, including potential feedback loops and trade-offs, is needed. Additionally, comparisons between OECD and non-OECD countries regarding the influence of urbanization and human development on ecological footprints while controlling for GDP and industrialization are yet to be explored extensively.

Future research should aim to bridge these gaps by incorporating data from a wider range of countries and employing sophisticated econometric techniques to untangle the intricate relationships between the aforementioned factors. A focus on developing sustainable development strategies that balance economic growth with environmental protection is paramount.

3. Methodology

3.1. Theoretical framework

In 1954, Schaefer and Gordon laid the foundation for the modern understanding of the open-access solution and developed a standard model of resource economics that is called the Gordon-Schaefer model. This model is applicable to maximum sustainable yield and open access and here we say that Ecological Footprints (EFP) is a natural good.

From Fig. 1, point Em is economically efficient, point Eb is biologist-efficient, and Ec is the free usage point.

As Ec is the free usage point, here, nations excessively exploit the natural resources to a level where there is a risk of complete exhaustion. Marked by rampant urbanization and industrialization with excessive emissions of carbon dioxide, the environment and its resources are eventually depleted. Hence, the ecological footprints are remarkably high at this point, as people are freely overusing resources without any checks and balances.

Point Eb is the solution for a biologist to allocate natural resources, and it is the optimal usage point where the marginal benefit is lower than the marginal cost. Here, nations are overusing the resources but not as much as they were utilizing in the free usage point. Urbanization and industrialization are taking place, accompanied by carbon dioxide emissions and marginal advancements in human development. Hence, at this point, the environment is on its way to degradation, and ecological footprints are increasing rapidly.

The efficient level is the Economist's solution denoted by point Em, where the marginal benefit is equal to the marginal cost. With escalating trends of urbanization and industrialization, there are technological improvements that foster human development and facilitate efficient ways of sustainable production. This sustainability serves to curtail pollution and mitigate carbon dioxide emissions from industrial and vehicular sources. Hence at this point, the environment is protected as people are not overusing natural resources, so the ecological footprints are relatively low.

3.2. Conceptual framework

From Fig. 2, initially, our planet Earth had abundant natural resources, with a sparse human population. Consumption by humans exerted minimal impact on the available resources but with the passage of time, the population started to increase. Over several decades, growth escalated markedly as people started innovating and became efficient in technological terms, and for that, natural resources were massively utilized. Deforestation prevailed to accommodate expanding human habitats, and demand for crops, lands, and livestock escalated during the 18th century. Later, there was a transition towards the area of the Industrial Revolution. This period of industrialization required the utilization of fossil fuels, clear lands for the construction of buildings and infrastructure development. Also, due to industrialization, people from rural areas started migrating in search of better facilities and advanced lifestyles, which resulted in urbanization as well as human development. However, there was an adverse impact on the natural environment due to this rapid urbanization and industrialization. Industrial advancements influenced the air and water in the form of severe pollution due to the extensive discharge of factory waste material into our environment. It caused widespread deforestation, degradation of land, depletion of crops, decline in animal population, and water deterioration. Consequently, ecological footprints, i.e., measures of how fast humans consume natural resources and produce waste as compared to the speed at which nature absorbs the waste and re-

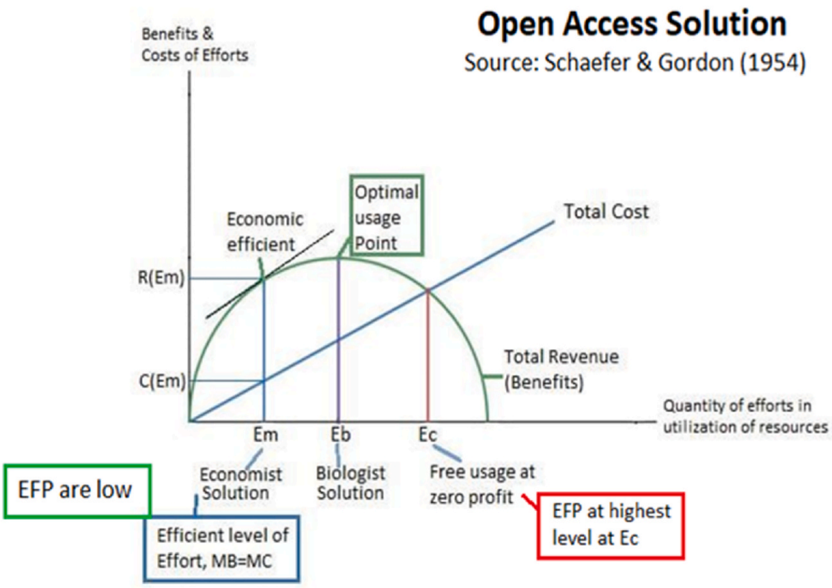

Fig. 1. Theoretical framework.

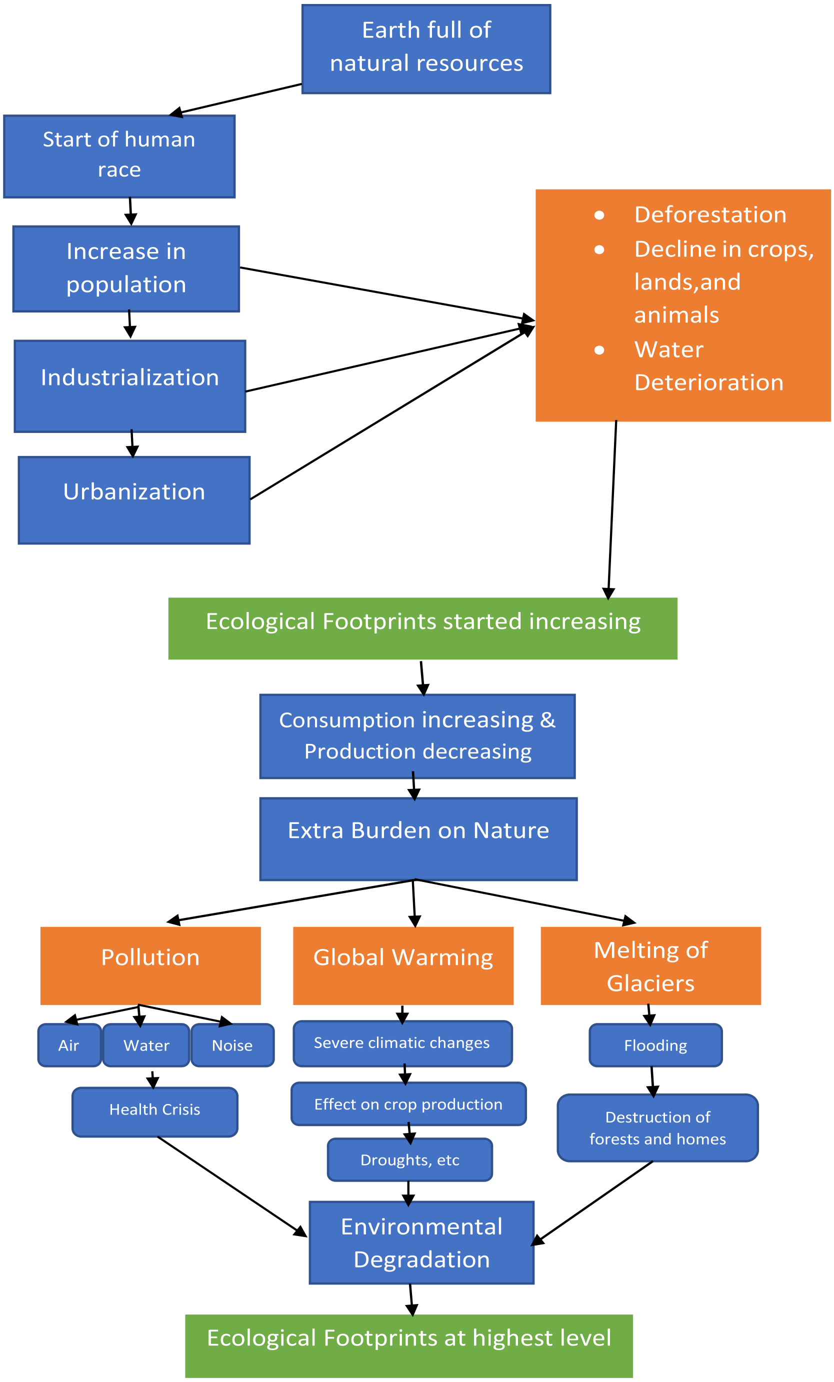

Fig. 2. Ecological footprints conceptual framework.
Source: Authors' Estimates

produces natural resources, started escalating rapidly.At that point, human consumption surged in a greater proportion than production, imposing an extra burden on nature, which resulted in further challenges. This burden caused global warming that is contributing towards the gradual melting of glaciers. As a result of human activities, many species have become extinct and some of them are endangered due to the loss of their habitat. Presently, the drastic change in climate is evident and is accompanied by health crises. Heat waves, for instance, are contributing to mortality and deterioration of arable lands. Hence, the health sector is under a great burden, and countries are also facing formidable economic pressures. Agricultural and industrial activities are further harming the economy of a country. This all adds up and creates chaos as survival on the earth is becoming more difficult, given the relentless escalation of ecological footprints.

It is shown in Fig. 3.

Natural resources serve a dual role in human activities, acting both as direct consumables and as important raw materials in production processes. The utilization of these resources in both processes generates waste that is eventually discharged into the environment. Also, the production processes that use natural resources as inputs yield by-products, leading to pollution. The waste generated by human activities is absorbed by nature to a certain extent, but an excess quantity surpassing the natural absorption capacity persists within the environment. This surplus waste remains as air, water, or land pollution, indicating an escalation in ecological footprints and contributing to an undesirable environmental state.

3.3. *Theory of ecological footprint*

Given current technology and resource management practices, the ecological footprint is a technique to quantify how much biologically productive land and water an individual, group, or activity needs to produce the resources they consume and dispose of the trash they generate. It is described as a total of six elements by The Global Footprint Network consisting of carbon footprints, farmland, grazing land, fishing grounds, forest land, and built-up land. Since the ecological footprint takes a variety of resource supplies into account, using it as a foundation for policymaking can be more advantageous than relying solely on one ecological indicator.

Environmental debates have long centred on climate change and global warming. One of the major causes of serious environmental issues is global warming, and according to natural scientists, it is mostly caused by carbon dioxide ($CO2$) emissions and greenhouse gases that arise due to fossil fuel combustion. As a result, researchers are now concentrating on how production-related economics and environmental concerns are related. As a result, environmental economics has recently become a well-liked area of study in the field of

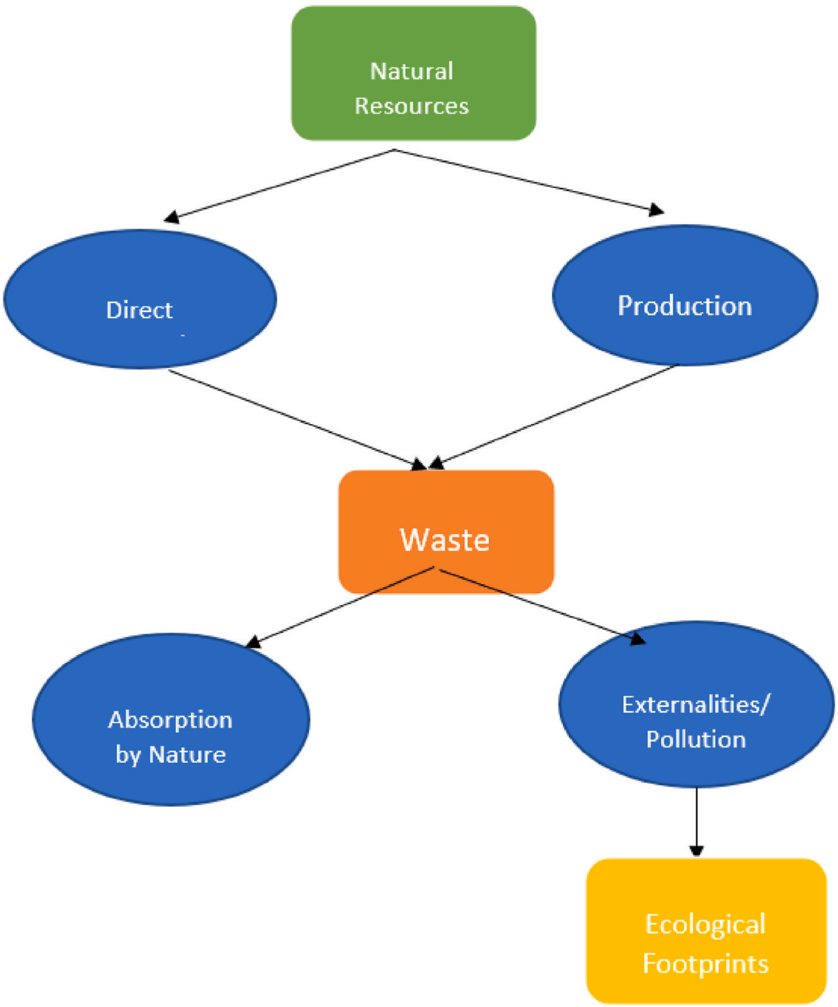

Fig. 3. Ecological footprints framework.
Source: Authors' estimates

economics.

This study compares 20 OECD (Organization for Economic Co-operation and Development) and 20 non-OECD countries from 1990 to 2018. These countries, and this time, were chosen for several significant reasons.

Recent studies have looked at elements such as CO2, Sulphur dioxide, and suspended particulate matter as well as ecological footprints to evaluate environmental deterioration. To examine the viability of the EKC theory [30], performed research on 93 nations between 1980 and 2008 using the ecological footprint as a measure of deterioration of the environment. In panel settings, the study made use of fixed effects and the generalized method of moments. The results demonstrated that ecological footprint and GDP growth had an inverted U-shaped link in upper-middle and high-income countries but not in low and lower-middle-income ones. The cointegration test results showed a consistent upward trend in environmental impact, energy use, urbanization, industrial development, and political stability throughout time. Studies on Granger causality have shown a connection between ecological footprint and other factors. Similar research was conducted by Refs. [31,32], who used the ecological footprint as an ecological indicator and output from tourism as an economic metric to evaluate the EKC hypothesis for 144 countries between 1988 and 2008. The results of the generalized method of moments (GMM) showed that mainly in high and upper-middle-income countries, ecological footprint and its drivers were negatively associated.

In this work, we looked at the stationarity of the ecological footprint and reviewed related literature. The first study, by Ref. [33] offered policy suggestions based on the stationary nature of the ecological footprint and other environmental indicators. The ecological footprint and its constituent parts were studied using Fourier unit root tests, and it was discovered that while the ecological footprint, carbon footprint, grazing land footprint, forest footprint, built-up land footprint, fishing grounds footprint, and ecological deficit were not stationary, the cropland footprint and biocapacity were. The findings imply that environmental footprint-related actions will have long-term implications. Between 1961 and 2013 [34], examined the stationarity of the ecological footprint for 128 nations. Their research showed that the ecological footprint for 96 countries was not constant, indicating that environmental actions can have long-lasting effects. In addition [32], looked at the ecological footprint stationarity for low-, middle-, and high-income nations between 1961 and 2013. According to their unit root tests, the ecological footprints of all high-income countries demonstrated mean-reverting behaviour, but only around half of the ecological footprints of lower- and middle-income countries were stationary. However, the ecological footprint for lower-middle-income nations was not constant.

3.4. Empirical model

This study aims to investigate the impact of urbanization and human development on the ecological footprints in the selected OECD and non-OECD countries. It also adds industrialization and GDP (Gross Domestic Product) as control variables. The following equation shows the research model of the study and explains the association between the variables.

$$EFP_{i,t} = \alpha_i + \gamma_t + \beta_1 URB_{i,t} + \beta_2 HDI_{i,t} + \beta_3 IND_{i,t} + \beta_4 GDP_{i,t} + \varepsilon_{i,t}$$

Here, i = 1, 2, …, N is for the individual country while t = 1, 2, …,T refers to the time period. β_1 to β_4 are the coefficients that are to be estimated. $\varepsilon_{i,t}$ represents the error term. EFP is Ecological Footprints and is a dependent variable. The independent variables include URB which represents Urban population (percent of total population), HDI which is human development index, IND shows Industry (that includes construction, and is value-added, percentage of GDP), and GDP represents GDP (current US$). To avoid any issue of heteroskedasticity, all the variables were converted into log form using a logarithmic scale.

$$lEFP_{i,t} = \alpha_i + \gamma_t + \beta_1 lURB_{i,t} + \beta_2 lHDI_{i,t} + \beta_3 lIND_{i,t} + \beta_4 lGDP_{i,t} + \varepsilon_{i,t}$$

3.4.1. Data and variable description

Two balanced panel datasets of twenty countries each were used over the period of 1990–2018 taken from the World Bank (World Development Indicators), United Nations Development Program (UNDP), and Global Footprints Network. The list of countries included OECD nations (Australia, Belgium, Chile, Colombia, Costa Rica, Denmark, Estonia, Germany, Greece, Hungary, Ireland, Israel, Italy, Netherlands, Norway, Poland, Spain, Türkiye, United Kingdom, United States) and 20 non-OECD nations (Argentina, Brazil, China, India, Indonesia, Kazakhstan, Malaysia, Pakistan, Philippines, Russian Federation, South Africa, Thailand, Tunisia, Zimbabwe, Morocco, Nepal, Nigeria, Kenya, Panama, Paraguay). The countries were selected based on reliable data availability and geographical locations. It was also made sure that the key economies are included in the list. The period was selected from 1990 to 2018 because there was limited data available on the sources.

The ecological footprint (EFP) serves as a crucial measure, indicating the rate at which humans are utilizing natural resources and generating waste compared to the capacity of nature to replenish those resources and absorb waste. It acts as the dependent variable in our analysis, reflecting the impact of human activity on the environment. This data, derived from the Global Footprints Network, underscores the urgency of sustainable practices to maintain ecological balance.

On the other hand, urbanization (URB), representing the shift of population from rural to urban areas, stands as an independent variable. Calculated as a percentage of the total population, it signifies the growing trend of urban settlement and its potential influence on ecological footprints. Data for this variable is sourced from the World Bank, highlighting the global perspective on urbanization trends.

The Human Development Index (HDI) offers a comprehensive assessment of societal progress, encompassing factors like life expectancy, education, and Gross National Income (GNI). Classified into distinct levels ranging from excessive to low human development, HDI serves as another independent variable in our study. This index, provided by the Human Development Reports (UNDP), reflects the multidimensional nature of human development and its implications for ecological sustainability.

Gross Domestic Product (GDP) serves as an additional independent variable, representing the monetary value of goods and services produced within a country. Calculated in current US dollars, GDP provides insights into economic activity and its potential correlation with ecological footprints. The World Bank serves as the primary data source for GDP figures, ensuring consistency and reliability in our analysis.

Finally, industrialization (IND) emerges as a significant factor influencing ecological footprints. This variable, measured as a percentage of GDP, signifies the degree to which a country transitions from agrarian to industrial economic structures. With sectors such as manufacturing, construction, and transportation contributing to industrial output, IND sheds light on the impact of economic development patterns on environmental sustainability. Data for this variable is also sourced from the World Bank, enabling a holistic examination of industrialization's role in shaping ecological footprints. The variable and the data source are mentioned in Table 2. The descriptive statistics for OECD and Non-OECD are provided in Tables 3 and 4 respectively.

4. Results and discussion

4.1. Panel unit root test and endogeneity test

For checking the stationarity of all variables, unit root tests were conducted on both sets of panel data. The regression result becomes spurious and unreliable if the data is non-stationary [22]. The null hypothesis states that a unit root exists, while the alternate hypothesis assumes that no unit root exists, indicating stationary data. Tables 5 and 6 show the results of the panel unit root tests for both, at the level and at the first difference for OECD and non-OECD countries, respectively. It can be seen from these tables that for some variables in both panel data sets, null hypothesis is rejected at level and for other variables rejection took place at the first difference.

Parentheses contain the p-value, and the null hypothesis was rejected at a 5 % level of significance.

When there is a correlation of the independent variable with the error term, the problem of endogeneity arises in the regression model. This endogeneity bias leads towards misleading results and wrong interpretations. Hence, it is useful to conduct endogeneity tests. The null hypothesis states that endogeneity does not exist, and the alternate hypothesis assumes that endogeneity exists [35]. The following Tables 7 and 8 show the results of the endogeneity test for OECD and non-OECD nations, respectively. Here, the null hypothesis was rejected indicating that endogeneity existed. So, the panel GMM model was used as it removes the endogeneity bias efficiently.

Hausman's test is implemented to select between fixed effects and the random effects model, to determine which one is efficient for the analysis of panel data before conducting the regression. In his paper, Hausman first proposed this test in 1978 [36], and the null hypothesis states that the random effects model is more efficient than the fixed one, while the alternate hypothesis states that the fixed effects model is comparatively more consistent [37]. In this study, the null hypothesis was rejected for both panel data sets, indicating that the fixed effects model is appropriate for both. Results are given below in Table 9.

4.2. GMM analysis

This paper uses the GMM (Generalized Methods of Moments) approach, initially developed by Ref. [38], that solves all the problems related to the endogeneity of explanatory variables, heteroskedasticity, and any measurement error as compared to the other techniques [39]. GMM technique also uses lagged and differenced forms of independent variables as instruments in the model to obtain coefficient estimates [14,40].

4.3. Discussion

From Table 10, regression results for OECD nations indicate that if GDP increases by 1 %, Ecological Footprints will increase by 0.03 %. It was found that if HDI increases by 1 %, Ecological Footprints will decrease by 20 %, and if IND increases by 1 %, ecological

Table 2
Variables and data source.

Variables	Data Source
Ecological footprint (EFP)	Global Footprints Network https://www.footprintnetwork.org/
Urbanization (URB)	World Bank https://data.worldbank.org/
Human Development Index (HDI)	Human Development Reports (UNDP) https://hdr.undp.org/
Gross Domestic Product (GDP)	World Bank https://data.worldbank.org/
Industrialization (IND)	World Bank https://data.worldbank.org/

Table 3
Descriptive statistics for OECD countries.

Variable Name	Range		Mean	Standard Deviation
	Minimum	Maximum		
Ecological Footprints	20.53176	2168.645	868.004	595.9966
Urbanization (% of total population)	50.003	98.001	76.18608	10.30336
Human Development Index	0.6	0.962	0.8372879	0.0793344
Industrialization (%age of GDP)	13.62844	40.29481	25.45106	4.864711
GDP (current US$)	4.50e+09	2.05e+13	1.22e+12	2.86e+12

Table 4
Descriptive statistics for non-OECD countries.

Variable Name	Range		Mean	Standard Deviation
	Minimum	Maximum		
Ecological Footprints	4.706388	1611.292	616.5433	399.5395
Urbanization (% of total population)	8.854	91.87	50.21595	19.76332
Human Development Index	0.294	0.851	0.6276828	0.1175796
Industrialization (%age of GDP)	12.65542	48.53032	29.73341	8.707085
GDP (current US$)	3.40e+09	1.39e+13	4.88e+11	1.37e+12

Table 5
Unit root (test type: summary) OECD.

Variables	At level	At the first difference
LnEFP	−1.433	−13.41
	(0.07)	(0.00)
LnGDP	−2.765	−10.245
	(0.00)	(0.00)
LnHDI	−9.717	−8.249
	(0.00)	(0.00)
LnIND	−1.975	−9.754
	(0.02)	(0.00)
LnURB	−2.389	−3.778
	(0.01)	(0.00)

Parentheses contain the p-value, and null hypothesis was rejected at 5 % level of significance.

Table 6
Unit root (test type: Summary) Non-OECD.

Variables	At level	At the first difference
LnEFP	−0.309	−9.98
	(0.37)	(0.00)
LnGDP	0.343	−9.27
	(0.63)	(0.00)
LnHDI	−6.056	−2.732
	(0.00)	(0.00)
LnIND	−1.867	−10.139
	(0.03)	(0.00)
LnURB	−0.451	−0.366
	(0.32)	(0.05)

Table 7
Endogeneity test OECD.

Variable	Coefficient	Prob.
RES_LnGDP	0.005771	0.9242
RESI_LnHDI	0.962776	0.0661
RESID_LnIND	3.24E+14	0.1796
RESID_URB	0.858276	0.0106

Table 8
Endogeneity Test non-OECD.

Variable	Coefficient	Prob.
RES_LnGDP	0.915092	0.000
RESI_LnHDI	−3.790971	0.000
RESID_LnIND	−0.441437	0.063
RESID_LnURB	1.373929	0.000

Table 9
Hausman Test OECD and non-OECD.

	OECD	NON-OECD
Value of P	0.0448	0.0126

footprints will decrease by 3.9 %. Also, if URB increases by 1 %, ecological footprints will increase by 12 %. The p-value of J-statistic was 0.4552, that is insignificant (greater than 0.05), indicating the validity of GMM model.

From Table 11, regression results for non-OECD nations indicate that if GDP increases by 1 %, Ecological Footprints will increase by 0.4 %. Also, if HDI increases by 1 %, the ecological footprints will increase by 5 %. We found if IND increases by 1 %, ecological footprints will decrease by 2 %, and if URB increases by 1 %, Ecological Footprints will decrease by 6 %. The p-value of the J-statistic was 0.149 which is insignificant (greater than 0.05), indicating the validity of the GMM model.

This section shows the description of the results and their consequences in greater depth. It is observed that the ecological footprints (emissions of CO2) are used for measuring environmental degradation. We analysed the relationship of environmental quality by taking GDP as an independent variable. In the case of OECD countries, it shows positive and low magnitude, while in the case of non-OECD countries, there is positive and high magnitude that represents a decline in the quality of the environment. This shows that both OECD and non-OECD nations have shifted towards clean resources of GDP production, and with the increase in GDP growth, they invest in environmental sustainability as well. There is a low magnitude of variable GDP in non-OECD countries, which showcases that if countries use clean energy for the production processes, they may improve environmental quality [41]. Some studies contradict these findings, such as Usman et al. (2020a) determined that the growth of the economy has a significant negative impact on the ecological footprint, specifically in upper-income countries, and GDP boosts the standard and quality of the environment. Some other studies indicate that with the increase in GDP, countries demand or consume more natural resources (fossil fuel, water, land, and forests etc.) to meet the high demand that is more than the absorption capacity of nature [42–45].

Further, urbanization exhibits a positive and significant correlation with environmental degradation in OECD countries, i.e., it causes an increase in ecological footprints regardless of more or less developed countries. This states that in most of the countries, the conditions of the people living in the urban areas have changed a lot. People from rural areas migrate towards the urban areas for an advanced lifestyle and a better job, which leads towards the overcrowding of the urban population and exploitation of resources against the environmental capacity. As poor rural infrastructure is majorly held responsible for the rural-urban flow, the government needs to improve the rural infrastructure. Once done, urban challenges such as waste management, overcrowding and even deterioration of the ecosystem would be controlled, and these findings are supported by Refs. [46,47]. Some research like [33], are contrary to our results of OECD countries and support the results of non-OECD countries that have a negative impact on ecological footprints. These studies state that urbanization negatively impacts the ecological footprint in BRICS countries. They claimed that the inhabitants of urban areas are comparatively more productive and conscious and tend to be more environmentally friendly. As our findings show the impact of urbanization is opposite in OECD and non-OECD countries, it may be because of the fact that OECD and other developed countries have almost completed the process of urbanization and now it is very less likely that any further urbanization will have positive impact on environment sustainability, but non-OECD and other developing countries still have opportunities of urbanization and most of these countries still have almost more than 50 percent of population living in rural areas that will gradually shift to cities. Hence, it will increase the chances of benefiting from the outcomes of urbanization.

However, industrialization is causing improvement in environmental quality by decreasing the ecological footprints in both OECD and non-OECD countries. Nowadays, industrialization is growing at a high rate. Our finding shows that the negative impact of industrialization on ecological footprints is not that high, but it is being negative is appreciable. It is because nowadays, a lot of effort

Table 10
GMM regression results OECD countries.

Variable	Coefficient	Prob.
LnEFP (-1)	0.8331***	0.00
LnGDP	0.0003**	0.043
LnHDI	−0.2087***	0.00
LnIND	−0.0391***	0.00
LnURB	0.1228***	0.00
Prob(J-statistic)	0.4552	

Table 11
GMM regression results Non-OECD countries.

Variable	Coefficient	Prob.
LnEFP (-1)	0.5945***	0.00
LnGDP	0.0042***	0.00
LnHDI	0.0552***	0.00
LnIND	−0.0296***	0.00
LnnURB	−0.0633***	0.00
Prob(J-statistics)	0.149	

and attention has been given to reducing the externalities of industrialization. Patents, licenses, and restrictions have played a positive role in making industrialization an environmental-friendly process. Also, industries have been made technologically efficient. For instant, diesel automobiles are enfolded to cycle, electric cars and vehicles that use stop-start technology and hence efficiency of fuel increases [48]. Furthermore, industries are making efforts to improve the oxidation cycle of fuel in moving vehicles by consuming additives, hence production process of industries that use these vehicles becomes clean and efficient towards the environment. Our findings are supported by some of the past research [49,50] which show that due to the advancement in technology, industries have become more productive, and more products are generated with the available natural resource because it minimizes the energy consumption such as the CFL and LED bulbs consume less energy than traditional bulbs. Some other studies also support our findings like [46,51]. The findings show that industrialization has a negative magnitude in the case of OECD countries as these countries are more technologically advanced countries.

The larger the HDI the higher the level of human well-being and development described by HDI, while lower the ecological footprints, the less natural resource consumption. Hence, high HDI and Low EFP lead to an ideal sustainable environment.

Because the different developed economies of the world have been attaching immense importance to human and livelihood development, they are making great efforts for the provision of high levels of medical and health facilities, medical security policies and education. This is reflected in the findings of this study as well, where it was found that OECD countries show a positive impact of HDI towards a green environment as there is a negative correlation between HDI and ecological footprints in these countries. Results for non-OECD countries showcase a positive and significant relationship of HDI with ecological footprints which indicates that these countries are not working effectively to increase HDI by providing better facilities and opportunities and using it to improve the environment. So, when we invest in human development, a productive labour force is produced that is well-educated and skilled. Such kind of people are more aware of environmental hazards, and hence, they become conscious of their acts that could degrade the environment. They use their skills to produce energy-efficient devices that reduce pollution. So, well-educated people are not just careful regarding the quality of the environment but also make innovations that help other people to shift towards efficient ways of sustainable production and consumption. This mechanism in which the positive impact of HDI is transmitted on the quality of the environment is true for only OECD countries because in non-OECD countries, the impact is the exact opposite. In these countries when people are provided with better education and skills, they use it for over extraction of natural resources. Hence, they move towards the exploitation of land, forest, and natural oil, escalating air, water, and soil pollution. Hence, education, technology, health, and skills improve productivity but also increase the pollution and consumption rate in non-OECD countries because these countries are less restricted with environment-sustainable policies.

5. Conclusion & policy implications

This paper studied the impact of major independent variables urbanization, HDI, and some other control variables like GDP and industrialization on ecological footprints in 20 OECD and 20 non-OECD countries from 1990 to 2018 using GMM analysis. The results revealed that in the case of OECD countries, ecological footprints have a direct relation with urbanization and GDP, while there is an inverse relation with HDI and IND. With the increase in GDP, Ecological footprints also boost, but with a lower magnitude, as these countries have already switched towards sustainability. Here, urbanization has a positive relation with ecological footprints because it might be possible that these countries have already completed the process of urbanization and now further urbanization will not positively impact the environment. So, OECD nations should keep their rural areas in view during planning and policymaking. HDI and IND are inversely proportional to the EFP, as with technological advancement, these countries are spending on the education and development of their people, and this highly productive labour force improves the manufacturing processes in industries by using sustainable sources of production. Hence ecological footprints decline.

In the case of non-OECD countries, ecological footprints have a direct relation with GDP and HDI while having an inverse relation with industrialization and urbanization. As GDP increases, ecological footprints also rise with a higher magnitude as these nations are trying to convert their production process towards sustainability. As HDI is high, these countries are investing in the development of their people, but the people are not taking environmental policies and restrictions seriously. As a result, they consume their income for extraction and exploitation of natural resources, due to which ecological footprints keep on rising. To achieve a green economy, non-OECD countries should re-evaluate their policies towards the environment so that people would obey them and work towards technological improvement and use efficient renewable energy sources so that CO_2 emissions will also be reduced. With increasing industrialization, ecological footprints decrease in these countries because the patents and licenses have played an important role in making industrialization an environment-friendly process. Ecological footprints decrease when urbanization increases in non-OECD countries because these countries still have room for urbanization and most of the population lives in rural areas.

The findings showed that the impact of HDI and urbanization on ecological footprints was different in OECD countries as compared to non-OECD countries. The coefficient of industrialization was negative while that of GDP was positively related to ecological footprint for both types of countries. The study found that countries should invest more in the sector of renewable energy and make strict environmental policies for maintaining the atmosphere from environmental hazards. The circular economy should be promoted that includes reduction, reuse, and recycling of the materials to minimize waste generation. Awareness campaigns must be launched in countries with increased ecological footprints to educate people about the environmental impact of their choices. Governments should provide financial incentives, tax breaks, and some research grants to industries and businesses that invest in eco-friendly innovations, and they must also be monitored and evaluated from time to time.

5.1. Practical implications

The empirical result of this research enables us to focus on environmental regulations and improvement in the energy transition policies that decrease environmental degradation. Particularly, policymakers should modify previous policies to replace fossil fuel utilization in industries by using green energy technologies. For incorporating uncertainties attached to climatic changes in the policy-making process, resilience-building measures should be taken and a framework for integrated risk assessment should be established. Moreover, the policymakers must introduce strategies to encourage institutions to promote environmental laws that restrict the introduction of polluting processes by industries.

5.2. Limitations

This study is limited to the sample countries, timeline, and variables used. Future studies can include some other interesting relevant factors or variables such as innovation, tourism, and trade in their research.

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The authors report there are no competing interests to declare.

Ethical consideration

No animal or human experiment and primary data is involved in this study.

Data availability statement

Data is obtained from secondary sources and can be accessed from following sources: https://www.footprintnetwork.org, https://data.worldbank.org; https://hdr.undp.org/

CRediT authorship contribution statement

Naima Sarwar: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Fazal un Nisa Bibi:** Writing – original draft, Visualization, Validation, Software, Resources, Investigation, Formal analysis, Data curation. **Ahmed Junaid:** Writing – review & editing, Software, Methodology, Investigation, Data curation. **Shahzad Alvi:** Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

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

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