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From finance to sustainability: Understanding the financial development-environment nexus with the environmental Kuznets curve in East-Asia and Pacific economies

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ABSTRACT

This study examines the effect of financial development on environmental quality in East Asia and the Pacific (EP) countries from 1995 to 2020. A unique technique, Dynamic Common Correlated Effects, is utilized to resolve cross-sectional dependence and heterogeneity. The Pooled Mean Group technique is also applied to verify the robustness of the results. The long-run analysis confirms financial development's positive and significant impact on CO_2 and CH_4 emissions while exhibiting an inverse impact on ecological footprint and N_2O emissions in overall and developed EP countries. The study confirms the presence of an inverted U-shaped environmental Kuznets curve (EKC) when analyzing ecological footprint, CO_2, and CH_4 across all groups of selected countries. However, for N_2O emissions, a U-shaped EKC pattern emerges specifically in less-developed and overall EP economies. It is proposed that governments of EP economies should maintain financial development while promoting sustainable environmental management to address climate challenges.

1. Introduction

The role of financial development (FD) in environmental quality (ENQ) is a topic of significant concern and interest in today's world. FD refers to the growth and expansion of financial institutions and markets, including banking, stock markets, and other financial intermediaries (Al-Mulali, Ozturk, & Lean, 2015). One of the key ways in which FD can affect ENQ is through its influence on investment decisions. Financial institutions are crucial in allocating capital to different economic activities, including those that impact the environment (Jahanger et al., 2023). For example, if financial institutions primarily allocate funds to industries with high levels of pollution or unsustainable practices, it can result in environmental degradation and a decline in ENQ. On the other hand, if financial institutions promote and invest in environmentally friendly and sustainable projects, it can contribute positively to ENQ (Khan, Khan, Ahmed, & Khan, 2022; Zafar, Saud, & Hou, 2019). Moreover, FD can also impact ENQ by facilitating technological advancements. As financial markets and institutions grow, they provide more opportunities for entrepreneurs and innovators to access funding for R&D of environmentally friendly technology. These technologies can range from renewable energy sources to sustainable farming practices. With adequate financial support, these innovations can be scaled up and deployed more widely, leading to improvements in ENQ (Zafar et al., 2019; Renzhi & Baek, 2020; Ahmad et al., 2022).

However, it is essential to acknowledge that FD can also have negative implications for ENQ. Rapid financial expansion can increase resource consumption, energy use, and waste generation (Xing, Jiang, & Ma, 2017). The demand for natural resources rises, promoting unsustainable extraction and habitat loss. Urbanization expands, encroaching on natural habitats and causing biodiversity decline. Consumerism rises, generating more waste and environmental pollution. Additionally, financial institutions' pursuit of short-term profits may prioritize economic growth over environmental considerations, leading to natural resource exploitation and a decline in ENQ (Hussain, Ahmad, & Shahzad, 2021). Environmental Kuznets curve (EKC) recommends an inverted U-shaped association between income and pollution. In the initial

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stages of growth, pollution levels tend to rise due to increased industrialization and energy consumption. However, as countries reach a certain income level, they invest in cleaner technologies and adopt more sustainable practices, improving ENQ (Udeagha & Breitenbach, 2023). FD enhances access to credit and investment capital. This enables businesses and industries to fund research and development initiatives focused on developing cleaner technologies and adopting environmentally friendly practices to improve ENQ (Hussain et al., 2021; Udeagha & Breitenbach, 2023).

The East Asia and Pacific (EP) region comprises 38 economies. The region's industrial production has risen due to trade openness (TOP), leading to a surge in energy consumption and utilization of natural resources. Unfortunately, this growth has also resulted in heightened pollution levels (Liu, Pang, Fang, Ali, & Anser, 2022). The EP region was selected as the focus of this study due to its status as one of the utmost-emitting regions globally. EP economies generate 6.5 metric tons of carbon dioxide emissions (CO_2) per capita, exceeding the world average of 4.7 metric tons (World Bank, 2020). Within this zone, some of the world's largest contributors to CO_2 can be found. China holds the position of the highest emitter globally, followed by Japan in fifth place, South Korea in eighth place, Indonesia in ninth place, and Australia in fifteenth place. Notably, China alone is responsible for 28% of total global CO_2, while Japan contributes 3%, Indonesia 2%, and Australia and South Korea each contribute 1% to the overall emissions (World Bank, 2020). Within this region, some of the most environmentally damaging countries can be found in terms of Ecological Footprint (ECF). China ranks first, followed by Japan in fifth place, Indonesia in seventh place, and South Korea in tenth place (Global Footprint Network, 2020). The economies in the EP region have an average per capita ECF of 3.8 global hectares (gha), surpassing the global medium of 2.8 gha (Global Footprint Network, 2020).

While numerous empirical studies have observed the FD-ENQ nexus in various regions or country groups, the attention given to the EP countries has been notably limited (Javid & Sharif, 2016; Katircioğlu & Taşpinar, 2017; Zafar et al., 2019; Farooq, Yusop, Chaudhry, & Iram, 2020; Wang, Zhang, Wang, Chen, & Li, 2023; Huang & Guo, 2023). Consequently, the present work aims to impart in the ongoing body of literature by addressing gaps in the following ways: (i) Despite limited studies on the association between FD and ENQ, the precise connections between these factors remain unclear and warrant further exploration. (ii) Previous studies have commonly employed methodologies such as random effect, fixed effect models, and the GMM,[1] for analyzing panel data. Additionally, the ARDL,[2] NARDL,[3] and VAR[4] methods have been utilized for investigating time series data in past research endeavors. The conventional methodologies used in previous studies suffer from several limitations, including problems related to heterogeneity, heteroscedasticity, and cross-sectional dependence (CSD) between countries. In contrast, this research employs a more advanced approach, Dynamic Common Correlated Effects (DCCE), offering more sophisticated and robust outcomes by effectively tackling the abovementioned challenges. (iii) A significant gap in previous research is the reliance on CO_2 as the sole indicator of ENQ. Relying on just a single indicator of ENQ (like CO_2) can be misleading and insufficient for capturing the full extent of ENQ (Ali, Yusop, Kaliappan, & Chin, 2020). Therefore, this study adopts a novel framework that incorporates multiple proxies (including greenhouse gas emissions (GHG): methane emissions (CH_4), nitrous oxide emissions (N_2O), and CO_2, together with ECF to appraise ENQ. This comprehensive approach gives a more holistic and accurate assessment of ENQ, enriching the quality of our results and insights. (iv) Rather than adopting a sole proxy for FD, this study constructs a composite index through principal component analysis (PCA) by combining various indicators of FD. (v) Furthermore, this study also analyzes the FD-ENQ nexus under the EKC hypothesis for EP nations. The inclusion of EP economies in the present work holds relevance for governments, policymakers, and researchers, as such economies represent approximately one-fourth of the worldwide inhabitants and are responsible for high emission ranks compared to non-EP nations. (vi) Ultimately, the findings of the present work would provide valuable insights and recommendations, offering an opportunity for prospective research on the nexus between FD and ENQ and their implications in EP economies. Hence, the present study enhances the comprehensiveness by addressing a significant gap in existing literature. This research broadens the understanding of the FD-ENQ nexus by employing a methodological precedent for future investigations in this field.

The succeeding sections of the present article are framed along these lines: Section 2 exhibits a review of previous studies concerning the nexus between FD and ENQ. Section 3 defines the data description, while Section 4 clarifies the econometric method employed in this research. Section 5 specifies the outcomes and engages in a detailed discussion of the findings. Finally, in section 6, the research concludes by summarizing the main outcomes and providing policy recommendations from the findings.

2. Literature review

This section gives the empirical review of prior studies about the impact of FD on ENQ. Through an evidence-based examination of the existing literature, we aim to shed light on the potential opportunities and challenges in aligning financial systems with sustainable environmental outcomes. Grossman and Krueger (1991) conducted a pioneering study that explored the bond between income and environmental deterioration, specifically focusing on the inverted U-shaped EKC. Depending on this research, Frankel and Romer (1999) and Jensen (1996) detected that all-encompassing financial systems could contribute to raised economic activities, leading to a higher demand for polluting energy sources and resulting in elevated GHG. Numerous studies have identified that FD has a significant impact on ENQ. For example, Al-Mulali et al. (2015) assessed the alliance between FD, TOP, pollution, renewable energy, and economic growth in European economies from 1991 to 2014. The outcomes specified that, except TOP, all the variables mentioned above were found to decrease ENQ. Shahbaz, Shahzad, Ahmad, and Alam (2016) examined how FD affected the environment in Pakistan between 1985Q1 and 2014Q4 using a comprehensive FD index from banking and stock market data. The results showed that inefficient energy use harmed the environment, emphasizing the importance of energy-efficient technology for production and consumption. In the same way, Javid and Sharif (2016) probed the impact of FD and GDP growth on CO_2 in Pakistan, adopting a yearly dataset spanning from 1973 to 2014. By employing the ARDL technique, the study revealed that both independent variables were associated with a decrease in ENQ. Tsurumi and Managi (2014) executed a study examining the nexus between TOP and deforestation in both OECD and non-OECD nations. The work adopted details extending from the year 1990–2003. The outcomes revealed that deforestation in non-OECD countries increased due to TOP, while in OECD economies, it decreased.

Shahbaz, Dube, Ozturk, and Jalil (2015) evaluated the Indian economy, and it was found that FD, energy consumption, globalization, and GDP growth were significant factors contributing to environmental degradation. The study also provided evidence supporting the EKC hypothesis. Xing et al. (2017) employed the ARDL and STIRPAT tools to assess the association between FD and ENQ in China. Their study revealed that FD had an adverse effect on ENQ, implying a decline in ENQ. Ashraf, Nguyen, and Doytch (2022) investigated the effects of FD on ECF in 124 economies using a method to address potential endogeneity and found that financial institutions' development had an inverse-U-shaped association with ECF, initially harming the

[1] Generalized method of moments.
[2] Autoregressive distributed lag.
[3] Nonlinear autoregressive distributed lag.
[4] Vector autoregression.

environment but later became beneficial. This differed from financial markets, which didn't show the same pattern, and was attributed to changing effects of FD. Similarly, Wang et al. (2023) analyzed the link between FD and ENQ in 234 Chinese cities from 2010 to 2019. Surprisingly, it was found that improvements in financial interrelations ratio and financial efficiency did not lead to better ENQ. Instead, FD boosted economic growth and had negative consequences for industrial structure optimization, increasing pollution and environmental deterioration, especially in central and western regions. In another study, Huang and Guo (2023) investigated how FD influenced carbon emissions decoupling across regions, employing the Tapio decoupling model and FMOLS. It was found that FD had mixed effects: it promoted decoupling in Europe and Central Asia but increased emissions in EAP, Sub-Saharan Africa, South Asia, and MENA. Additionally, the effect of FDI, urbanization, infrastructure, and population on pollution varied across regions, with the European and Central Asian regions achieving strong decoupling.

Dogan and Seker (2016) and Salahuddin, Gow, and Ozturk (2015) realized a positive correlation between financial stability and ENQ. Furthermore, Zafar et al. (2019) explored the impact of FD and globalization in OECD nations. The study utilized the CUP-FM and CUP-BC procedures and found that globalization and FD had a long-run mitigating influence on pollution. In another investigation, Renzhi and Baek (2020) identified a positive effect of FIN on emissions and confirmed the presence of an EKC across 103 nations. They observed an inverted U-shaped bond across FIN and pollution, employing various indicators to measure FIN. Udeagha and Breitenbach (2023) investigated the impact of FD on ENQ in South Africa from 1960 to 2020. Ecological footprint (ECF) is used as an indicator of ENQ. The empirical analysis was based on the novel ARDL simulation approach. The results, which utilized five FD measures, demonstrated that FD boosted ecological sustainability and ENQ by confirming EKC.

Despite the extensive literature on FD's impact on ENQ, some gaps still require further exploration. While numerous studies have identified a significant impact of FD on ENQ, as evidenced by increased GHG, pollution, and environmental degradation, some studies suggest that FD improves ENQ. The existing literature mainly focuses on the FD-ENQ nexus in Europe, Pakistan, China, India, and some OECD and non-OECD nations. However, there needs to be more comprehensive studies specifically targeting EP countries, which may have unique characteristics and challenges in terms of environmental policies, energy sources, and economic activities. Furthermore, some investigations have observed an inverse U-shaped EKC, which suggests that pollution initially increases with economic development but ultimately declines as countries reach a specific income level; its applicability to EP countries remains unclear. There is a need for more research to investigate the existence and shape of the EKC in this specific region and how FD interacts with it.

3. Data

The present work evaluates the connection between FD and ENQ in the EP countries from 1995 to 2020. Four environmental models are employed, utilizing different indicators (CO_2, N_2O, ECF, and CH_4) as dependent variables. The independent variables in our outlines include FD, TOP, urban population, per capita GDP, and square of per capita GDP. The selection of CO_2, N_2O, and CH_4 as environmental proxies is based on their notable contribution to GHG. Among these pollutants, CO_2 is the most vital contributor to GHG, pursued by N_2O and CH_4. CO_2 arises majorly from transportation, energy usage, and manufacturing (Udeagha & Breitenbach, 2023). Agricultural activities contribute to N_2O, as indicated by Xue et al. (2021), while CH_4 stems from using natural gas, coal, and oil (Yusuf, Abubakar, & Mamman, 2020). ECF measures the ecological and biological attributes of the environment and serves as a proxy for assessing ENQ (Udeagha & Breitenbach, 2023).

The empirical analysis in this paper is performed by adopting data from 30 countries in the EP region, limited by data availability. According to the categorization of World Bank, these nations are divided into different income classes, including low-income, lower-middle-income, upper-middle-income, and high-income economies. Pursuing the World Bank categorization and the research conducted by Farooq et al. (2020), our study organizes the countries into three main panels, as outlined in Appendix-Table. The first panel comprises all EP countries, called 'overall-EP countries'. The second panel comprises lower-middle-income and low-income EP nations, collectively denoted as 'less-developed EP countries'. The third panel comprises upper-middle-income and higher-income EP economies, collectively identified as developed EP economies. Table 1, at the study's outset, provides a comprehensive list of the symbols and abbreviations utilized in this research.

Previous studies have encountered a significant limitation by utilizing a single proxy to represent FD, which leads to deceptive or biased results (Latif et al., 2023). Moreover, integrating the whole proxies into one equation poses considerable challenges. To overcome this issue, we have adopted the method of PCA to derive a comprehensive variable called the FD index from five FD indicators, including liquid liabilities to GDP ratio, total bank deposit to GDP ratio, domestic credit to the private sector, domestic credit provided by the financial sector, and financial system deposits to GDP ratio. The PCA allows us to condense all the original FD data into a single index with minimal data loss. The construction of the PCA follows the approach outlined in the study conducted by Ali et al. (2020). In PCA, the jth element exponents are stated like:

$$FD_{j=}W_{j1}X_1 + W_{j2}X_2 + W_{j3}X_3 + W_{j4}X_4 + W_{j5}X_5 \quad (1)$$

Here, FD_j embodies the FD index. The five FD indicators, as explained earlier, are shown by X_1, X_2, …. X_5. The weights assigned to each FD indicator are represented by $W_{j1,}$ $W_{j2,}$ … …..,W_{j5}.

Table 2 gives the variables' description and their data sources.

4. Methodology

The methodology for this study includes CSD tests, unit root test, slope homogeneity test, and cointegration test along with econometric techniques. For econometric analysis, we have applied the DCCE approach. To assess the robustness of our findings, we also employ the PMG estimation technique for our models.

4.1. Dynamic Common Correlated Effects (DCCE)

Multiple studies have found that globalization, economic shocks, TOP, and other unperceived components contribute to CSD in many

Table 1
The nomenclature of abbreviations and symbols.

Symbols or Abbreviations	Explanation	Symbols or Abbreviations	Explanation
EP	East-Asia and Pacific	GHG	Greenhouse gas emissions
FD	Financial development	ECF	Ecological footprint
ENQ	Environmental quality	EKC	Environmental Kuznets curve
CSD	Cross-sectional dependence	GDP	Gross domestic product per capita
DCCE	Dynamic Common Correlated Effects	SDGs	Sustainable development goals
PCA	Principal component analysis	TOP	Trade openness
CO_2	Carbon dioxide emissions	OLS	Ordinary least squares
CH_4	Methane emissions	FIN	Financial inclusion
N_2O	Nitrous oxide emissions	PMG	Pooled mean group

Table 2
Variables and data sources description.

Variables	Narration	Measurement Unit	Data Sources
CH_4	Methane emissions	kt of CO_2 equivalent	World Bank
FD	Financial development	index	IMF Financial Access Survey
CO_2	Carbon dioxide emission	Kilo ton (kt)	World Bank
GDP	GDP per capita	Constant 2010 US$	World Bank
ECF	Ecological footprint	Global hectares (gha)	Global Footprint Network
N_2O	Nitrous oxide emission	Thousands of CO_2e metric tons	World Bank
UP	Urban population	People living in urban areas	World Bank
TOP	Trade openness	Imports plus exports divided by GDP	World Bank

nations. In the current era of modernization, every nation is influenced by economic fluctuations occurring in other economies (Ali et al., 2020; Chaudhry et al., 2021). To tackle this concern of CSD, Chudik and Pesaran (2015) have developed a novel technique called "Dynamic Common Correlated Effects (DCCE)." According to this approach, CSD across units arises from an unobserved common factor. The DCCE technique incorporates elements from the mean group (MG), PMG, and common correlated effects (CCE) methods and offers a practical solution. In order to capture the unperceived familiar components, the CCE method practices cross-sectional averages for each dependent and independent variable. While the CCE demonstrates resilience against structural changes, autocorrelation, CSD, and autocorrelation, it is unsuitable for dynamic panel models due to the lack of complete exogeneity in the dependent variable (Latif et al., 2023). The PMG estimation approach allows for variability in short-run coefficients, encompassing adjustment speed and intercepts across different countries. Nevertheless, it enforces a condition requiring long-run slope coefficients to be uniform across countries, as Chudik and Pesaran (2015) elucidated.

Alternatively, when incorporating added lags of cross-sectional moderates, the predictors within the DCCE approach exhibit greater persistence. Ditzen (2019) has modified the DCCE technique, enabling it to generate short and long-run dynamic predictions for heterogeneous panel data. The DCCE approach deals with several significant issues that traditional methodologies fail to address. Firstly, it resolves the consequence of CSD by retrieving lags and moderates from whole cross-sectional units (Latif et al., 2023). Second, the DCCE methodology effectively deals with parameter heterogeneity by leveraging the characteristics of MG estimation, which are intrinsic to its framework. Thirdly, calculating vigorous familiar interconnected affects considers heterogeneity and assumes that a single factor can account for all regression variables. Moreover, the DCCE tool can be adjusted for small datasets by utilizing the Jackknife command (Chudik & Pesaran, 2015). Lastly, this approach yields reliable outcomes even when dealing with unbalanced panel data and situations involving structural breaks (Ditzen, 2019).

When formulating our empirical models, we have relied on the studies conducted by Renzhi and Baek (2020) & Usman, Makhdum, and Kousar (2020), which emphasize the importance of FD in the environment. To address the potential issue of omitted variable bias, we have also covered more essential variables, like urban population, GDP per capita, and TOP.

According to the above characteristics, the DCCE model can be represented as follows:

$$Y_{it} = \alpha_i Y_{it-1} + \delta_i X_{it} + \sum_{p=0}^{p_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{p=0}^{p_T} \gamma_{yip} \overline{Y}_{t-p} + \mu_{it} \tag{2}$$

Here, the subscript 'i' shows countries, and 't' denotes time. The dependent variable is denoted by Y $_{it}$, while its lagged value is represented as Y_{it-1}. The lagged cross-sectional mean is denoted by P_T. The collection of additional illustrative factors is designated by X_{it}. The error component is signified by X_{it}. μ_{it}. The unobserved common factors for the explanatory and the dependent variables are represented by γ_{xip} and γ_{yip}, respectively.

4.2. Pooled Mean Group (PMG) estimation

Unlike alternative methods like dynamic panel GMM, which eliminates any potential long-run relationships among variables, the Pooled Mean Group (PMG) technique enables the estimation of dynamic heterogeneous panels to consider long-run equilibrium connections (Jouini, 2015). This is particularly pertinent in our empirical investigation because a shared trend might influence the co-movements of FD and environmental proxies over an extended period. As illustrated in the model, the PMG technique allows for variations in time trends, intercepts, and short-run parameters across groups, while it imposes the constraint of identical coefficients in long-run (Wang, Rasool, Asghar, & Wang, 2019). Pesaran, Shin, & Smith (1999) highlight that the presumption of uniform long-run equilibrium associations among variables across different groups can be attributed to factors such as solvency and budget limitations, common technologies, or arbitrage conditions that exert an equivalent impact on all groups. It is also emphasized that presuming uniform short-term coefficients and error variances across groups lacks persuasiveness while permitting heterogeneity in these coefficients enables variations in the dynamic specification among different groups. Consequently, the PMG method permits the imposition of identical long-run coefficients without requiring the assumption of uniform short-run parameters (Islam, 2022; Raheem, Tiwari, & Balsalobre-Lorente, 2020).

The PMG specification can be written as follows:

$$Y_{it} = \varphi_i + \sum_{j=1}^{p} \lambda_{ij} Y_{it-j} + \sum_{j=0}^{q} \delta_{ij} X'_{it-j} + \varepsilon_{it} \tag{3}$$

Here, i and t represent cross-sectional and time aspects, respectively. j shows optimum time lag. φ_i is the fixed effect. The independent variables of the regression are represented by X_{it}.

4.3. Model specification

Depending on the empirical research conducted by Grossman and Krueger (1991) and Shahbaz et al. (2015), we can formulate a fundamental pattern for the hypothesis of an inverted U-shaped or U-shaped EKC as under:

$$EI = a_0 + a_1 GDP + a_2 GDP^2 + \mu \tag{4}$$

In this context, EI represents an indicator of ENQ, such as CO_2, N_2O, SO_2, and ECF. GDP represents the level of income. Based on Equation (4), we can derive specific functional forms that describe the association between GDP and ENQ, which are presented as follows.

$a_1 = a_2 = 0$; no income-ENQ association
$a_1 > 0, a_2 = 0$; linearly increasing income-pollution nexus
$a_1 < 0, a_2 = 0$; linearly decreasing income-pollution nexus
$a_1 > 0, a_2 < 0$; inverted U-shaped GDP-pollution nexus
$a_1 < 0$, $a_2 > 0$; U-shaped/monotonically increasing GDP-pollution nexus

Next, we differentiate Equation (4) regarding GDP to assess the significant circumstances of the EKC:

$$\frac{dEI}{dGDP} = a_1 + 2a_2 GDP \tag{5}$$

Now, getting the second derivative of Equation (5):

$$\frac{d^2EI}{dGDP^2} = 2a_2 \tag{6}$$

Wherever.

$a_2 < 0$, depicts the presence of local maxima that guide to an inverted-U type relationship).
$a_2 > 0$, states the local minima that guide to U-type EKC.

To determine the threshold (turning) point of the EKC, we determine the GDP value by equating the first derivative, as indicated in Equation (6), tied to zero. This allows us to identify the specific value at which the turning point occurs.

$$a_1 + 2a_2GDP = 0 \tag{7}$$

$$GDP* = \frac{-a_1}{2a_2} \tag{8}$$

Where, GDP* embodies a turning (threshold) point of GDP.

Expanding upon the basic model of the EKC hypothesis, we introduce five additional models by incorporating additional variables. These models utilize different proxies for ENQ as the dependent variables, building upon the study of Chaudhry, Yusop, and Habibullah (2022).

$LNCO_{2it} = \alpha_i LNCO_{2it-1} + \delta_i X_{it} + \sum_{p=0}^{p_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{p=0}^{p_T} \gamma_{yip} \overline{Y}_{t-p} + \mu_{it}$ (Model A)
$LNCH_{4it} = \alpha_i LNCH_{4it-1} + \delta_i X_{it} + \sum_{p=0}^{p_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{p=0}^{p_T} \gamma_{yip} \overline{Y}_{t-p} + \varepsilon_{it}$ (Model B)
$LN\,N_2O_{it} = \alpha_i\, LN\,N_2O_{it-1} + \delta_i X_{it} + \sum_{p=0}^{p_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{p=0}^{p_T} \gamma_{yip} \overline{Y}_{t-p} + e_{it}$ (Model C)
$LNECF_{it} = \alpha_i LNECF_{it-1} + \delta_i X_{it} + \sum_{p=0}^{p_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{p=0}^{p_T} \gamma_{yip} \overline{Y}_{t-p} + \nu_{it}$ (Model D)

In the analysis, the variables $LNCO_2$, $LNCH_4$, LNN_2O, and LNECF represent the logarithmic values of CO_2 emissions, CH_4 emissions, N_2O emissions, and ECF, respectively. Lagged values of these dependent variables are included as explicative variables. Additionally, FD, TOP, GDP per capita, urban population, and GDP per capita squared (all in logarithmic form, except FD) are considered independent variables designated by X_{it}. The error components in the patterns are embodied by μ_{it}, ε_{it}, e_{it}, and v_{it}.

5. Findings and discussion

Table 3 displays the descriptive statistics values of our variables. The variables CO_2, CH_4, N_2O, FD, ECF, GDP, TOP, and UP illustrate CO_2 emissions, methane emissions, nitrous oxide emissions, financial development, ecological footprint, per capita GDP, trade openness, and urban population, respectively.

The findings of several tests examining CSD across the countries are presented in Table 4. These tests are essential for determining the appropriate estimation approach and deciding whether to use first-generation tests that assume CSD or second-generation unit root tests that account for CSD. The outcomes of these tests strongly indicate rejecting the null hypothesis and supporting the existence of CSD among countries.

Table 5 presents the CIPS test, a second-generation unit root test that gives the most exact findings when CSD exists. The outcomes of the CIPS test validate that $LNCO_2$ and LNUP become stationary at their first differences, while all other variables exhibit stationarity at their levels.

The outcomes of the Westerlund (2007) test, specifically the statistics values for Group-α, Group-Ʈ, and Panel-α, are displayed in Table 6, indicating their significance. This significance implies that the variables being investigated exhibit a long-run relationship. Our conclusions corroborate the outcomes of Xue et al. (2021), who utilized the same test and discovered a long-run interconnection between the variables.

The results of the slope homogeneity test ($\overline{\Delta}$), formulated by Pesaran, Ullah, and Yamagata (2008), are displayed in Table 7. The values of this test and its bias-corrected form ($\overline{\Delta}_{adj}$) demonstrate significant t-statistic values. The finding suggests that the null hypothesis of slope homogeneity is rejected, which indicates the evidence suggesting country-specific heterogeneity within the panel data of EP countries. Ignoring the existence of cross-sectional heterogeneity and assuming slope homogeneity in a panel data set can lead to inaccurate results (Xue et al., 2021). Therefore, this test is essential in determining whether the effects across different sections within the panel data are homogeneous or heterogeneous.

The results of the DCCE and PMG estimations for all EP economies are depicted in Table 8. Both short-run and long-run findings show a significant relationship between our independent variables and dependent variable.

The results of the DCCE and PMG estimation for developed EP economies are depicted in Table 9. Both short-run and long-run results show a significant relationship between our independent and dependent variables.

The estimation results of Tables 8–10 show that significant correlations exist between all dependent variables' lag values ($L.LNCO_2$, $L.LNN_2O$, L.LNECF, and $L.LNCH_4$) and their corresponding explanatory variables.

The analysis of short-run and long-run DCCE and PMG estimation reveals a positive and significant impact of FD on CO_2 and CH_4 in developed and overall EP countries. Likewise, in less-developed EP nations, FD positively and significantly impacts various environmental indicators, highlighting its contribution to ENQ. These findings are consistent with Shahbaz et al. (2015) and Javid and Sharif (2016), who assert that FD boosts commercial and industrial activities, leading to higher pollution levels. Additionally, FD induces FDI, which supports R&D and accelerates the growth process, consequently contributing to environmental degradation. Moreover, the augmented financial capacity permits buyers to buy energy-intensive items like refrigerators, air conditioning units, and cars, leading to noteworthy environmental concerns arising from amplified GHG (Udeagha & Breitenbach, 2023).

However, in the long run, DCCE estimation shows that FD negatively correlates with N2O and ECF in developed EP and whole EP economies, indicating its contribution to improving ENQ by reducing N2O and ECF.

Table 3
Descriptive statistics of variables.

	CO_2	CH_4	N_2O	ECF	FD	GDP	TOP	UP
Mean	5.39	37837.57	13535.26	57886498	3.00	7246.17	0.57	911.44
Median	2.61	12691.30	4478.44	22253592	2.66	2746.83	0.55	909.04
Minimum	0.08	945.68	71.75	1245639	0.77	339.14	0.41	605.40
Maximum	44.64	912858	369900.3	389000000	7.56	72444.08	0.75	1223.39
Skewness	2.14	5.78	6.08	1.97	0.67	2.65	1.90	2.68
Std.Dev.	7.51	68507.20	29192.30	72409720	1.59	10000.18	0.10	194.66
Kurtosis	7.35	57.20	54.86	6.96	2.82	11.79	3.89	9.77
Observations	600	600	600	600	600	600	600	600

* and ** shows 1 percent and 5 percent level of significance, respectively.

Table 4
Findings of cross-sectional dependence (CSD) tests.

Variables	Pesaran-CD		Pesaran-Scaled LM		Bias-Adjusted Scaled LM	
	Statistic	Probability	Statistic	Probability	Statistic	Probability
$LNCO_2$	30.71*	0.00	125.37 *	0.00	123.40*	0.00
LNN_2O	26.55*	0.00	129.20 *	0.00	128.13*	0.00
$LNCH_4$	80.84*	0.00	232.32 *	0.00	228.24*	0.00
LNECF	132.63*	0.00	383.07*	0.00	382.12*	0.00
FD	63.14*	0.00	152.40*	0.00	151.60*	0.00
LNGDP	48.60*	0.01	107.23*	0.00	106.15*	0.00
LNTOP	88.30*	0.01	274.35*	0.01	274.50**	0.02
LNUP	128.90*	0.00	397.57*	0.00	396.60*	0.00

*and ** indicate the significance level at 1 percent and 5 percent, respectively.

Table 5
Findings of CIPS test.

Difference	Level	First
$LNCO_2$	−1.88	−5.57 *
FD	−2.97 *	−4.17 *
LNTOP	−2.54 *	−4.70 *
LNN_2O	−2.16 **	−5.98 *
$LNCH_4$	−2.37 *	−5.18 *
LNECF	−2.95 *	−5.54 *
LNGDP	−2.72 *	−6.18 *
LNUP	−1.90	−5.65 *

Note: * and ** denotes 1% and 5% levels of significance, respectively.

This inverse relationship between FD and environmental indicators aligns with Dogan and Seker (2016), Salahuddin et al. (2015), and Renzhi and Baek (2020). One possible narration for this inverse influence of FD on N_2O and ECF is that N_2O emissions initially originate from agricultural activities and farming practices such as crop tillage, nitrogen fertilizers, and waterlogging (Ali et al., 2020). In this context, all-encompassing FD programs might have a positive environmental influence by enhancing availability, affordability, and the execution of environmentally friendly agriculture technologies that decrease N_2O from agricultural activities (Udeagha & Breitenbach, 2023). Similarly, FIN allows nations to adopt novel and sustainable technologies, benefiting both local and global climates and natural resources such as grazing and fishing areas, water, minerals, and biocapacity. On the other hand, PMG estimation reveals that FD is negatively correlated with only ECF in developed EP and overall EP groups in the long-run.

The findings obtained from comprehensive panels of EP nations demonstrate a significant and positive correlation between GDP and carbon emissions levels, CH_4, and ECF in the short-run and long-run. These results corroborate earlier research conducted by Al-Mulali et al. (2015) and Javid and Sharif (2016), which similarly emphasized the positive link between GDP and environmental indicators. As previously mentioned, during the initial phases of development, per capita GDP hurts the ENQ due to the scale effect resulting from factors such as FD, TOP, and energy consumption. Under the scale effect, expanded economic proceedings lead to environmental degradation because the focus primarily lies on growth rather than environmental preservation. Notably, GDP demonstrates an inverse and significant effect on N_2O in less-developed EP and whole EP countries while exhibiting a positive influence over N_2O in developed EP economies. This contrasting relationship between GDP and N_2O in less-developed EP and overall EP countries aligns with the outcomes of Renzhi and Baek (2020).

In the short and long-run, both DCCE and PMG outcomes achieved from whole panels of EP nations exhibit a significant and inverse interrelation between the squared value of GDP and CO_2, CH_4, and ECF levels. This indicates that there is a possibility of EKC or a U-shaped union between GDP and pollution. The presence of an EKC in existing patterns aligns with the empirical outcomes presented by Antweiler, Copeland, and Taylor (2001) and Katircioğlu and Taşpinar (2017). Following an initial development phase characterized by a positive interconnection between income and pollution, the subsequent phase reveals an inverse interconnection between income and pollution. This negative association can be attributed to composition or technique effects (Antweiler et al., 2001). During this phase, individuals strive for improved living standards, which encompass a preference for a cleaner environment (Grossman & Krueger, 1991). Furthermore, the composition effect occurs due to substituting polluting technologies with environmentally friendly alternatives or transitioning toward the services sector. This shift poses a positive effect on ENQ within EP economies.

The findings specify a positive and significant linkage between the squared value of GDP and N_2O in less-developed EP and overall EP economies in short-run and long-run. This positive relationship can be attributed to the fact that N_2O primarily originates from agricultural production, which holds significant economic importance in these countries (Xue et al., 2021). In contrast to other emissions, the increase in GDP results in higher N_2O rightful to expanded agricultural activity. In countries with lower incomes and overall EP nations, a U-shaped EKC pattern has been observed in the relationship between GDP and N_2O emissions. However, in developed EP economies such as China and others, where agriculture plays a minor role and sectors like oil and

Table 7
Findings of the slope homogeneity test.

	$\bar{\Delta}$	$\bar{\Delta}_{adj}$
Model A	5.82[a]	5.82[a]
Model B	7.10[a]	8.15[a]
Model C	5.96[a]	7.14[a]
Model D	6.34[a]	5.92[a]

[a] denotes a 1% significance level.

Table 6
Results of Westerlund panel cointegration test.

H_0: no cointegration	Model A		Model B		Model C		Model D	
Statistic	Value	Robust p-value	Value	Robust p-value	Value	Robust p-value	Value	Robust p-value
Group- τ	−4.12*	0.02	−4.71*	0.00	−4.97*	0.00	−5.37*	0.00
Group- α	−4.22*	0.00	−4.29*	0.00	−3.20*	0.00	−5.42*	0.00
Panel- τ	−7.37*	0.00	−3.47**	0.02	−9.18*	0.00	−5.65*	0.00
Panel- α	−4.21*	0.00	−3.52	0.00	−4.29*	0.01	−4.12*	0.01

Note: * and ** mention the significance level at 1% and 5%, respectively.

Table 8
Results of DCCE and PMG estimations (overall EP economies).

		DCCE Estimation				PMG Estimation			
	Regressor	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF
		Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients
Short-run Estimates	D.FD	0.220*	0.180*	−0.190	−0.170*	0.200*	0.160*	0.100	−0.150*
	D.LNGDP	0.820**	0.730*	−0.639*	0.995*	0.800**	0.720*	−0.625*	0.990*
	$D.LNGDP^2$	−0.063**	−0.054*	0.057***	−0.072*	−0.060*	−0.050*	0.053**	−0.070*
	D.LNTOP	−0.360*	−0.280*	−0.110*	0.190*	−0.320*	−0.270*	−0.100*	0.180*
	D.LNUP	0.750*	0.350*	0.212	1.150*	0.740*	0.355**	0.205	1.170*
	Turning Points	671.82	854.05	273.14	1002.25	660.50	852.10	270.10	980.20
Long-run Estimates	$L.LNCO_2$	−0.710**	–	–	–	−0.700*	–	–	–
	$L.LNCH_4$	–	.-0.690*	–	–	–	.-0.695*	–	–
	$L.LNN_2O$	–	–	−0.650*	–	–	–	−0.658*	–
	L.LNECF	.——	.——	–	−0.750*	.——	.——	–	−0.759*
	FD	0.200*	0.150*	−0.115**	−0.165*	0.205*	0.140*	0.110**	−0.170*
	LNGDP	0.794**	0.695*	−0.659*	0.982*	0.785**	0.690*	−0.670*	0.977*
	$LNGDP^2$	−0.059**	−0.051*	. 0.058***	−0.069*	−0.060**	−0.048*	. 0.053**	−0.065*
	LNTOP	−0.330*	−0.260*	−0.115*	0.176**	−0.325*	−0.250*	−0.118*	0.178**
	LNUP	0.770*	0.370*	0.266	1.100*	0.765*	0.375*	0.200**	1.010*
	Turning Points	835.13	904.85	290.93	1234.43	830.10	910.80	282.10	1205.30

Note: *,** and *** show the significance level at 1, 5, and 10% individually.

Table 9
Results of DCCE and PMG estimations (developed EP economies).

		DCCE Estimation				PMG Estimation			
	Regressors	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF
		Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients
Short-run Estimates	D.FD	0.270*	0.220*	−0.140**	0.260*	0.265*	0.225*	0.115**	−0.256*
	D.LNGDP	0.989**	1.030*	0.883*	0.930*	0.880**	0.930*	0.823*	0.920*
	$D.LNGDP^2$	−0.063**	−0.066**	−0.051	−0.052*	−0.060*	−0.059*	−0.045	−0.050*
	D.LNTOP	−0.370*	−0.298*	−0.076*	0.210*	−0.385*	−0.295*	−0.073*	0.210*
	D.LNUP	0.944**	0.473*	0.226	1.590*	0.940**	0.405	0.216	1.190*
	Turning Points	2565.20	2440.60	5767.53	7631.19	2460.50	2435.10	5720.50	7612.22
Long-run Estimates	$L.LNCO_2$	−0.790**	–	–	–	−0.772*	–	–	–
	$L.LNCH_4$	–	−0.641*	–	–	–	−0.635**	–	–
	$L.LNN_2O$	–	–	−0.740*	–	–	–	−0.735*	–
	L.LNECF	–	–	–	−0.590*	–	–	–	−0.593*
	FD	0.280*	0.230*	−0.149**	−0.265*	0.262*	0.220*	0.100*	−0.259*
	LNGDP	0.971**	0.998*	0.900*	0.910*	0.970**	0.990*	0.870*	0.900*
	$LNGDP^2$	−0.061**	−0.064*	−0.052**	−0.051*	−0.057*	−0.060*	−0.048*	−0.047**
	LNTOP	−0.350*	−0.283*	−0.061**	0.202*	−0.340*	−0.278*	−0.054**	0.190*
	LNUP	0.954**	0.493*	0.230	1.500*	0.650	0.400	0.232	1.520*
	Turning Points	3259.66	2438.58	5708.13	7478.06	3220.60	2420.50	5720.10	7458.15

Note: *,** and *** show the significance level at 1, 5, and 10%, respectively.

Table 10
Results of DCCE and PMG estimations (less-developed EP economies).

		DCCE Estimation				PMG Estimation			
	Regressors	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF	$LNCO_2$	$LNCH_4$	LNN_2O	LNECF
		Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients	Coefficients
Short-run Estimates	D.FD	0.160*	0.120*	0.142**	0.082*	0.155*	0.125*	0.135**	0.089*
	D.LNGDP	0.700**	0.560*	−0.725*	0.920*	0.720**	0.566*	−0.720*	0.910*
	$D.LNGDP^2$	−0.055**	−0.042*	0.061	−0.068*	−0.050*	−0.040**	0.055	−0.060*
	D.LNTOP	0.190*	0.223*	0.110*	0.175*	0.182*	0.220*	0.119*	0.166*
	D.LNUP	0.640*	0.316*	0.290	0.880*	0.634*	0.290*	0.297	0.887*
	Turning Points	578.26	780.55	380.01	862.64	566.20	775.50	370.28	851.60
Long-run Estimates	$L.LNCO_2$	−0.840**	–	–	–	−0.830*	–	–	–
	$L.LNCH_4$	–	−0.700*	–	–	–	−0.680**	–	–
	$L.LNN_2O$	–	–	−0.810*	–	–	–	−0.800*	–
	L.LNECF	.——	.——	–	−0.650*	.——	.——	–	−0.630*
	FD	0.174*	0.125*	0.159*	0.088*	0.154*	0.120*	0.140*	0.080*
	LNGDP	0.683**	0.545*	−0.738*	0.895*	0.672*	0.540**	−0.722*	0.880*
	$LNGDP^2$	−0.052**	−0.041*	0.062***	−0.066*	−0.045**	−0.048*	0.069**	−0.060*
	LNTOP	0.180*	0.216*	0.121**	0.162*	0.175*	0.215**	0.119*	0.155*
	LNUP	0.650*	0.310*	0.246	0.800**	0.642*	0.290*	0.200**	0.788**
	Turning Points	711.35	770.76	381.73	878.05	705.30	762.70	368.70	872.12

Note: *,** and *** show the ranks of significance at 1, 5, and 10%, respectively.

services are more prominent, the squared value of GDP reveals a significant and inverse bond with N_2O, referring to the occurrence of an inverted-U-shaped EKC. As a consequence of reduced agricultural activities, while income levels increase in these developed EP economies, N_2O declines.

The estimated turning points, representing the GDP levels at which pollution reaches its maximum, have been calculated for the EKC in EP economies. The formula used for calculating these turning points is defined in Equation 15. According to DCCE estimates, the turning points for CO_2 in the long-run are identified at GDP levels of US$835.13, US $3259.66, and US$711.35 for whole, developed, and less-developed EP nations, respectively. According to PMG estimates, the turning points for CO_2 in the long-run are observed at GDP levels of US$830.10, US $3220.60, and US$705.30 for whole, developed, and less-developed EP nations, respectively. According to DCCE estimates, the turning points of the EKC for ECF are estimated at GDP levels of US$1234.43, US $7478.06, and US$878.05 for overall, developed, and less-developed EP country panels in the long-run, respectively. According to PMG estimates, the turning points of the EKC for ECF are estimated at GDP levels of US$1205.30, US$7458.15, and US$872.12 for overall, developed, and less-developed EP country panels in the long-run, respectively.

Though, it is essential to note that due to lower GDP levels, low-income EP economies such as North Korea, Kiribati, and Guam cannot reach these turning points for ECF by 2020. Similarly, all developed EP economies fail to achieve their respective threshold points for ECF, with some less developed economies performing poorly compared to others. According to long-run DCCE estimation, for N_2O, the threshold levels for the U-shaped curve in less-developed and overall EP economies have been determined to be at the GDP level of US$381.73 and US$290.93, respectively. According to long-run PMG estimation, for N_2O, the threshold levels for the U-shaped curve in less-developed and overall EP countries have been determined to be at GDP levels of US$368.70 and US$282.10, respectively.

In overall and developed EP economies, a significant and inverse alliance is observed between TOP and all GHG, suggesting an enhancement in ENQ. These outcomes are corroborated by the findings of Tsurumi and Managi (2014). The inverse interrelation between TOP and GHG in these economies can be attributed to the prevailing influence of the technique influence, which outweighs both the level and configuration influence, as narrated by Antweiler et al. (2001). The effect level pertains to the deterioration of the ENQ due to increased economic proceedings, including industrialization, transportation, TOP, and energy consumption. Conversely, the technique effect emerges when individuals, as their per capita income rises, aspire to attain higher living standards in a cleaner environment. This leads to substituting polluting technologies with cleaner or more environmentally friendly alternatives or transitioning toward the service sector. This substitution, known as the composition effect, positively influences the environment (Antweiler et al., 2001; Grossman & Krueger, 1991). As long as the technique effect surpasses the composition and scale effects, TOP can increase ENQ (Antweiler et al., 2001). The outcomes of the study provide support for the Pollution Halo Hypothesis, which posits that overseas enterprises relocate innovative and purifier technologies to presenter economies, thereby contributing to an improvement in ENQ (Saqib, Ozturk, Usman, Sharif, & Razzaq, 2023). Additionally, in less-developed EP countries, TOP exhibits a positive correlation with whole environmental indicators, indicating that TOP contributes to the degradation of ENQ in these economies, persistent with the outcomes of Shahbaz et al. (2015). It is essential to acknowledge that less-developed EP economies tend to rely on traditional energy sources, which result in higher levels of GHG due to raised human activity and industrialization associated with TOP. This situation has detrimental effects on the ecological and biological capacities, as well as areas of forest, of these nations (Latif et al., 2023). In spite of that, when considering the ECF as an environmental element, TOP exhibits a positive correlation with ECF across complete panels of EP economies. This suggests that as TOP increases, the environment degrades in EP countries. The ecological ECF encompasses various factors involving carbon footprint, croplands, grazing lands, forest products, fishing waters, and biocapacity, collectively contributing to the overall ecological impact (Global Footprint Network, 2020). These components illustrate the ecological capability of a country that has been adversely influenced by human proceedings and industrialization resulting from TOP (Shahbaz et al., 2015). This provides a plausible explanation for the observed positive influence of globalization on ECF. Moreover, according to DCCE estimation, Urban population shows a significant and positive correlation with all environmental proxies except N_2O, suggesting that a rise in urbanization contributes to environmental decomposition in EP economies. These findings are consistent with the research of Ali et al. (2020), which also ascertained a positive bond between population and environmental indicators. Nevertheless, as per the PMG estimates, there is an unexpected finding: urban population exhibits an insignificant correlation with CO_2, N_2O, and CH_4 in developed EP economies.

Most estimates for DCCE and PMG calculations generally exhibit similar signs for coefficient values. However, the surprising finding of an insignificant correlation between urban population and GHG in developed EP countries in the PMG analysis could be attributed to the limitations of conventional methods, which do not account for the diversity and interdependence among cross-sectional units. DCCE emerges as the most appropriate technique in this context, as it effectively addresses these shortcomings, as explained in the methodology section.

6. Conclusion and policy recommendations

This study probes the relationship between FD and ENQ in EP economies from 1995 to 2020 by utilizing the DCCE and PMG approach. Different GHGs and ECF are utilized as indicators of ENQ. The long-run estimates reveal a positive impact of FD on CO_2 and CH_4, while FD is negatively interconnected with ECF and N_2O in both overall and developed EP nations. These outputs validate the EKC that exhibits an inverse U-shaped pattern for CO_2, CH_4, and ECF across all panels of EP economies. However, a U-shaped EKC pattern is evident for N_2O in less-developed and overall EP economies. The estimation of the DCCE reveals a positive and noteworthy influence of GDP on ECF, CO_2, and CH_4 across all groups of EP countries. GDP demonstrates a negative relationship with N_2O in less-developed and overall EP economies, while a positive interrelation is observed in developed EP nations.

Our results have important implications for EP nations, providing new insights into the FD-ENQ nexus. Policymakers should carefully consider the results of this research. Integrating FD into environmental change adaptation efforts can achieve significant reductions in emissions. For instance, the financial sector can assist in climate change mitigation through green credit financial services, supporting pollution reduction and sustainable development. Governments should align FD initiatives with environmental sustainability requirements. Inclusive financing should be promoted to support vulnerable populations while ensuring environmental sustainability. Moreover, enhancing accessibility to green financial services can encourage environmentally friendly practices among small and medium-sized enterprises (SMEs). Investments based on public-private partnerships can contribute to ENQ, aligning with the Sustainable Development Goals (SDGs). The study indicates that FD is inversely associated with ECF and N_2O in developed and overall EP countries but positively associated with developed EP economies. In this context, initiating inclusive financial programs can positively impact ENQ by improving accessibility, affordability, and implementing environmentally friendly agriculture technologies that reduce N_2O from agricultural activities. Governments should consider implementing regulations that mitigate N_2O in the agriculture, such as promoting minimum tillage, reducing nitrogen fertilizer usage, and utilizing nitrification inhibitors. Furthermore, FD allows countries to adopt updated environmentally sustainable technologies, benefiting local and global climates, natural resources, and forests.

TOP is highly advisable because of its beneficial effects on the ENQ through decreased GHG emissions in both developed and overall EP nations. Additionally, it enables the acquisition of composition effects and comparative advantages. To effectively align with the SDGs, these countries should adopt appropriate policy instruments to direct the technological changes and investment inflows resulting from TOP. However, it's essential to note that TOP may lead to decreased ENQ in less-developed EP countries, necessitating the implementation of strict regulations to ensure ENQ. Hazardous industrial and human activities should be restricted to safeguard the ecological capacity of ENQ. Firms producing more pollution should face fines and charges to discourage pollution and protect ecological indicators like fishing land, grazing land, and cropland. The funds generated from these penalties can be utilized to finance government initiatives aimed at improving ENQ. Furthermore, comprehensive transportation policies should be implemented, incorporating clean energy alternatives like biodiesels, hydrogen, electricity, and renewable energies. Various strategies can be employed to reduce pollution from industries, such as switching to alternative fuels, enhancing energy efficiency, adopting renewable energy sources, and promoting material recycling. Additionally, the ECF and harmful gas emissions can be minimized through sustainable forest management, slowing down deforestation rates, and preserving ecological diversity and forest carbon stocks. In order to enhance ENQ, reforms within the energy sector are crucial. EP countries should prioritize efficient and effective energy usage, foster renewable energy development, and upgrade outdated technology to modern, eco-friendly production techniques. The transition from climate-damaging energy sources to environmentally friendly and green alternatives (excluding hydropower) like biogas, geothermal, solar, wind, ocean/tidal, and other projects is essential.

Lastly, it is essential to acknowledge the limitations of our study, which can offer valuable insights for forthcoming studies in this field. First and foremost, it is essential to acknowledge that specific pollutants, along with perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and sulfur dioxide (SO_2), were not included in our analysis due to data unavailability. Incorporating these emissions in future studies would allow for a more comprehensive examination of their impact on ENQ. Furthermore, it is essential to acknowledge that our study focuses solely on the EP region, so the findings may not be universally applicable. Conducting further research with a broader perspective encompassing developed, developing, and emerging economies would contribute to a better extensive awareness of the interconnection between FD and ENQ.

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Conflict of interests

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.

Appendix

Table. List of EP Sample Economies

Less-developed EP economies		Developed EP economies	
Low-income nations ($1135 or below)	Lower-middle income nations ($1136 to $4465)	Higher-middle income nations ($4466 to $13845)	High-income nations ($13846 or more)
Korea, Dem. People's Rep.	Philippines	Fiji	Macau (SAR, China)
Guam	Myanmar	Indonesia	Australia
Kiribati	Micronesia Fed. Sts.	China	Korea, Rep.
	Samoa	Thailand	New Zealand
	Vietnam	Malaysia	Brunei
	Vanuatu	Tonga	Singapore
	Mongolia		Japan
	Timor-Leste		Hong Kong (SAR, China)
	Lao PDR		French Polynesia
	Papua New Guinea		
	Cambodia		
	Solomon Islands		

Note: The EP economies are divided into different income groups on the basis of World Bank (2023) classification, which relies on GDP per capita levels.

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