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RESEARCH ARTICLE

Linking financial development, economic growth, and ecological footprint: what is the role of technological innovation?

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Abstract

The literature analyzing the ecological impacts of financial development (FD) documents mixed results. In addition, very limited researches consider the role of technological innovation in ecological sustainability even though technological innovation is indispensable to achieve technological advancement, which may help in sustainable development and ecological sustainability. Therefore, this work probes the effects of technological innovation, financial development, and economic growth (GDP) on the ecological footprint (EF) controlling urbanization and employing a STIRPAT framework. The analysis of data from West Asia and Middle East nations from 1990 to 2017 revealed cointegration in the model. The long-run coefficients produced by the continuously updated fully modified technique revealed that a 1% upsurge in technological innovation decreases EF by 0.010%. Interestingly, technological innovation is helpful to decrease EF and enhance economic growth in the West Asia and Middle East (WAME) countries. However, a 1% rise in FD boosts the level of EF by 0.0016% inferring that FD stimulates ecological degradation. Likewise, urbanization in the WAME countries raises EF levels and contributes adversely to ecological quality. In addition to this, the study revealed the environmental Kuznets curve hypothesis in the selected countries accounting for technological innovation, FD, and urbanization in the model. The causal analysis provided evidence of unidirectional causality from FD to EF and bidirectional causality between technological innovation and EF. The study recommends more investment in research and development and strong collaboration between the universities and industries to promote the level of technological innovation for both sustainable development and ecological sustainability. In addition, urban sustainability policies are necessary without decreasing the urbanization level.

Keywords Technological innovation · Ecological footprint · Financial development · Economic growth · Urbanization

Introduction

The steady increase in the environmental footprints of countries around the world has made it highly difficult to accomplish the goal of sustainable development. Ecological footprint (EF) which gauges the repercussions of anthropogenic activities in terms of waste generation and resource consumption is continuously growing against the productive

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capacity of this planet (Ahmed et al. 2020b). Consequently, economies around the world have been dealing with the ecological deficit, which can lead to climate change, food shortage, resource depletion, and environmental degradation (Ahmed et al. 2020a).

The world is experiencing different issues that lead to ecological degradation, such as rising energy demand, increasing waste generation, water scarcity, and rising EF (Ulucak and Lin 2017; He et al. 2018; Agyekum et al. 2021; Wang et al. 2019; Zhao et al. 2020; Quan et al. 2021; Yuan et al. 2021). To mitigate growing EF, scholars are linking different factors with the EF to divulge some mitigation options that could help to attain sustainable development. Grossman and Krueger (1995) suggested the linkage between environment and income in an environmental Kuznets curve (EKC) framework. After his influencing work, scholars are generally linking the income level of nations with different measures of environmental degradation. In initial studies, the focus was on using CO_2 emissions and energy consumption to measure environmental impact. However, in recent years, scholars are employing EF as a measure to capture environmental impact since EF measures the overall impact of human actions on the environment in terms of water, soil, and air and, undoubtedly, it is more comprehensive compared to emissions that merely capture repercussions of energy usage (Awosusi et al. 2021; Al-Mulali et al. 2015). The notion of the EKC proposes that the high-income level is favorable to the environmental quality due to the increasing level of innovation, knowledge, technological advancement, environmental regulations, and countries' preferences to the environment over income (Nathaniel and Bekun 2020).

In the light of the EKC hypothesis, raising the level of technological innovation (TIN) is a key to achieving the reducing effect of income on environmental degradation at the high-income level, which shapes an inverted U-shaped pattern between environment and income as low-income level hastens environmental degradation. Besides, innovation drives productivity and economic development, and technological advancement associated with innovation can help in decreasing environmental degradation (He et al. 2021; Mensah et al. 2018). Technological advancement associated with innovation can pave the way towards a low-carbon economy as it enables energy transition through the development of renewable energy technologies.

In addition, financial development (FD) is an important factor that can influence EF and technological innovation levels. FD can affect EF in different ways, for example, financial institutions' lending leads to the expansion of businesses, which can intensify energy use, land usage, and waste generation. Financial institutions also support the financial needs of individuals, and an increase in the purchasing power of people can intensify resource consumption leading to higher EF. On the flipside, financial institutions can promote technological advancement that can decrease the consumption of energy and other resources, which in turn will decrease EF (Ahmed et al. 2021). Besides, the financial institution can play a positive role in funding the projects that could lead to technological innovation since innovation is impossible without reasonable investment in research and development.

When it comes to the empirical evidence on the association between FD and EF, some studies report that FD boosts EF, for instance, Baloch et al. (2019) and Saud et al. (2020) in BRI nations. However, some empirical works also support the claim that FD contributes to mitigating EF levels, for example, Baloch et al. (2020) for OECD nations, Uddin et al. (2017) for a panel of 27 nations, and Ahmed et al. (2019) for Malaysia. Likewise, controversies exist regarding the impact of TIN on environmental degradation. For example, the studies of Sinha et al. (2020) in the Next 11 nations and Adebayo et al. (2021) in Chile claim that TIN boosts emissions as countries direct their TIN for achieving economic motives rather than improving the environment. On the flipside, the work of Ahmad et al. (2020) in emerging economies concludes that TIN reduces EF. The studies of Khan et al. (2020a) for BRICS and Mensah et al. (2018) for OECD countries also unveil that TIN reduces emissions. In addition to these mixed results, there are very limited empirical studies on TIN and EF linkage. Hence, it is important to study the effects of TIN and FD on EF since these regressors can play a crucial role in reducing EF and also in the EKC.

Based on this discussion, this work examines the influence of financial development, technological innovation (TIN), and economic growth (GDP) on EF in West Asia and Middle East (WAME) nations located along the belt and road. The use of pollutant energy sources for economic development has raised energy use, pollution level, and environmental degradation in WAME economies (Magazzino and Cerulli 2019). The severity of the environmental degradation can be understood from the high ecological deficit of some of these nations, for example, Turkey (150% deficit), Jorden (1095% deficit), Qatar (1422% deficit), Iran (333% deficit), Oman (400% deficit), United Arab Emirates (1574% deficit), and Israel (2445% deficit) (GFN 2021a). These high ecological deficits portray that the footprints of these nations are way more than the available resources. Hence, in order to accomplish sustainable development, it is vital to analyze possible mitigation options. The role of innovation in these nations is increasingly important because most of these countries are not industrialized nations. Thus, they still have to achieve industrial development which depends a lot on technological advancement and financial resources. Thus, increasing the level of innovation is the way forward for these nations but the ecological impacts of innovation are still unknown in the context of these economies. In addition to this, the level of FD is also expected to increase in the selected nations (Kihombo et al. 2021), and keeping in view the relaxed environmental regulations in the

WAME economies, it is important to understand the role of FD in EF. Hence, the role of FD and TIN in environmental sustainability is important in the context of WAME economies.

This paper contributes to present literature in different ways. Firstly, it determines the role of financial development in EF in the WAME economies, which previous studies have not determined in the context of sample countries. Ecological footprint, the proxy for environmental deterioration, adopted in the study is acknowledged as the most trustworthy and comprehensive proxy to gauge the environmental impacts in the recent literature (Saint et al. 2019; Nathaniel et al. 2019, 2021; Ahmad et al. 2020; Saud et al. 2020). Secondly, this paper includes technological innovation in the model, which may play a critical role in ecological sustainability. It is noteworthy that the existing literature on TIN and EF is scant, and the studies on the role of TIN in CO_2 emissions present mixed results. Thirdly, the investigation of the EKC is conducted by omitting energy consumption from the model since the study of Jaforullah and King (2017) proved that considering energy in economic growth and environment relationship leads to biased outcomes. Thus, the results of this work are expected to be more reliable. Lastly, the econometric methodology used in the study, the continuously updated fully modified (CUP-FM) method, produces trustworthy long-run results for panel data robust against heteroscedasticity, endogeneity, fractional integration, and cross-sectional dependency. For robustness of long-run panel outcomes, the study adopted the continuously updated bias-corrected (CUP-BC) technique which also offers similar advantages (Danish et al. 2019).

Literature review

In recent years, studies analyzing the factors behind ecological degradation are growing (Bekun et al. 2019; Adams et al. 2020; Joshua and Bekun 2020; Deng et al. 2021; He et al. 2021; Li et al. 2021). Environmental pressure is indeed linked with the development level of nations, and most scholars follow the concept of the EKC while assessing the association between development and the environment. Interestingly, the empirical outcomes are mixed with different conclusions in different nations and panels, therefore leading to different policies for different country groups. Some studies that evaluate this nexus using EF as the proxy to gauge environmental deterioration are as follows.

The influential study of Al-Mulali et al. (2015) set the trend for using EF to track ecological pressure rather than relying on emissions. Their findings for a panel of 93 nations disclosed that the EKC only holds in nations that are categorized into middle and high income. In support of this argument, Ozturk et al. (2016) used data from 141 nations and proved that in the context of upper-middle- and high-income nations, the EKC is valid. Conversely, the study of Charfeddine (2017) reported a U-shaped link rather than the EKC in the context of Qatar, which is categorized among high-income nations. Based on his empirical research in African countries, Sarkodie (2018) provided similar findings. However, Alola et al. (2019) found that EF is greatly increased by income level and energy consumption in 15 EU nations, while green energy, trade, and fertility rate are negatively connected with the EF. In contrast, Ahmad et al. (2021) disclosed that economic expansion reduces EF, and the EKC holds in emerging nations. In addition, economic complexity is an important element in ecological sustainability, and institutional quality expands the beneficial ecological effects of economic complexity.

In contrast, Mrabet and Alsamara (2017) illustrated the EKC in Qatar. However, the empirical work of Charfeddine and Mrabet et al. (2017) confirmed the EKC only in oil exporting and the overall panel of MENA countries, and findings for the other panels demonstrated a U-shaped link. After analyzing the EKC in 11 nations, Destek and Sarkodie (2019) indicated that the EKC is valid only for some nations, while the U-shaped nexus also exists in some countries. Ahmed et al. (2020c) documented a U-shaped link rather than the EKC in Pakistan. Similarly, Mrabet et al. (2017) for Qatar, Ozcan et al. (2018) for Turkey, and Wang et al. (2013) for a worldwide panel could not unfold the EKC.

However, Katircioglu et al. (2018), Hassan et al. (2019), and Bello et al. (2018) documented the EKC in top tourist nations, Pakistan and Malaysia, respectively. In contrast, in the context of EU nations, Destek et al. (2018) documented a U-shaped nexus. Conversely, in the EU nations, Adedoyin et al. (2020) used DOLS and FMOLS and unfolded that research and development and renewable energy subsidize the level of EF and the EKC exists in the sample nations. They also revealed that energy usage boosts EF. Likewise, Ahmed and Wang et al. (2019) report the EKC in India. In a recent study, Joshua and Bekun (2020) used annual data from South Africa and indicated that environmental degradation is stimulated by economic expansion and energy consumption, whereas natural resources alleviate environmental problems. The above studies documented different findings by adopting different methodologies and considering many variables, such as energy, renewable energy, GDP, electricity consumption, human capital, and globalization, and research and development, etc.

Some empirical studies have also considered FD when checking the EKC and also when exploring the linear association between income and EF. For instance, Al-Mulali et al. (2015) disclosed that FD is negatively liked with EF in a panel of 93 nations, and therefore, an increase in FD improves ecological quality. Likewise, Uddin et al. (2017) documented a similar negative association between FD and EF in a panel study of 27 countries. Supporting this view, Destek and Sarkodie (2019) documented the mitigating effect of FD on EF in China and Malaysia. Most of these studies that document the favorable ecological impact of FD believe that FD supports innovation, R&D, and green energy projects and, therefore, promotes ecological quality.

On the flipside, Baloch et al. (2019) illustrated that FD raises EF in Belt and Road nations and the study of Saud et al. (2019a) supported this finding by expanding the sample size of Belt and Road nations. Likewise, Mrabet and Alsamara (2017) noted that FD mounts the EF level in Qatar. Charfeddine (2017) also supported this outcome and illustrated that FD raises EF in Qatar, while decreases emissions. Ahmed et al. (2021) proved that FD upsurges EF in Japan using both non-linear and linear methods. Summing up, most of the studies that documented ecological degradation associated with FD believe that lending of financial sector considers profit motives rather than environment and easy availability of financial resources mount resource consumption.

Technological innovation (TIN) is relatively ignored in the previous literature, and scholars have indicted unfavorable as well as favorable effects of TIN. Khan et al. (2020b) suggested that innovation decreases consumption-based emissions in G7 nations. Likewise, Santra (2017) illustrated that technological innovation helped to curb energy absorption and emission in BRICS. Similarly, Rafique et al. (2020) documented that technological innovation mitigates emissions in BRICS. In contrast, Sinha et al. (2020) unfolded that technological innovation actually boosts emissions in the Next 11 nations; however, the EKC is valid. Using the non-linear method, Adebayo et al. (2021) also noted that technological innovation boosts consumption-based emissions in Chile. They suggested that innovation is targeted towards achieving economic motives rather than ecological sustainability. Conversely, Khan et al. (2020a) illustrated that technological innovation alleviates emissions in BRICS because it supports energy-efficient technology. Mensah et al. (2018) also documented that TIN reduces emissions; however, EKC is invalid in most OECD nations. Baloch et al. (2020) used the research and development from the energy sector as a proxy of innovation, and their empirical estimation revealed that FD boosts innovation in the energy sector, innovation stimulates environmental sustainability, and the EKC exists in the context of OECD nations. In addition, globalization also boosts the level of innovation and environmental quality. They recommended to enhance energy innovation and FD to attain ecological targets.

The literature regarding the impact of technological innovation (TIN) on EF is scant. In this regard, the study of Ahmad et al. (2020) found that TIN alleviates EF in emerging nations. There are some studies available on the TIN and CO2 emissions relationship; however, most of their findings are inconsistent with positive and negative effects of TIN on emissions. Therefore, it is not agreed in the previous literature whether TIN boost or alleviates ecological degradation. Also, EF is a comprehensive measure and the ecological impacts of regressors on ecological footprint can be more useful for policymaking because CO_2 emissions only depict the impact of energy usage (Ahmed et al. 2019; Nathaniel et al. 2021). Apart from this, the above literature unfolds significant differences regarding the presence of the EKC and the impact of FD on EF. Keeping in view these disparities in results and the insufficiently investigated nexus between TIN and EF, this paper investigates the ecological impacts of FD and TIN to direct appropriate policy suggestions for WAME economies.

Data and methodology

Model and data

This work studies the impact of FD, TIN, and GDP on EF in WAME economies. FD can either drive or subsidize EF, for example, according to Saud et al. (2020) FD intensifies ecological degradation, while Ahmed et al. (2019) documents that FD supports environmental quality. Technological innovation is an essential tool to achieve technological advancement that may decrease EF (Ahmad et al. 2020). EF is greatly influenced by the consumption and production of goods and services; hence, EF is connected with the economic progress of countries (Ahmed and Wang 2019). According to Pata and Caglar (2020), EF and income have an inverted U-shaped association, while Ahmed et al. (2020c) documents a U-shaped link between them. Urbanization intensifies EF by stimulating travel time, traffic congestion, and resource consumption (Nathaniel 2020). Conversely, urbanization moves in tandem with economic progress and, after reaching a high level, urbanization can increase efficiency in production by availing economies of scale. Also, better transportation and other services at the collective level through sustainable urbanization policies can reduce energy and EF (Ahmed and Wang 2019). This discussion motivated us to achieve the objective of this paper by using a STIRPAT model proposed by Dietz and Rosa (1997). The basic equation for the "Stochastic Impacts by Regression on Population, Affluence, and Technology" model is as follows:

$$I_t = aP_t^b A_t^c T_t^d \mu_t \tag{1}$$

where EF measures I (environmental impact), GDP and GDP2 measure A (affluence), technological innovation measures T (technology), and urbanization measures P (population effect). Financial development (FD) will be an additional factor in the STIRPAT model. The model for long-run estimation is as follows:

$$LOGEF_{it} = \delta_0 + \delta_{1it}LOGGDP + \delta_{2it}(LOGGDP)^2 + +\delta_{3it}LOGFD + \delta_{4it}LOGTIN + \delta_{5it}LOGUR + \omega_1 \tag{2}$$

This study is conducted on selected WAME economies (Turkey, Iran, Qatar, Bahrain, Georgia, Jordan, Oman, United Arab Emirates, and Israel) from 1990 to 2017, and this period is stipulated to data availability on technological innovation and EF. The study could not include some nations due to data unavailability. EF in per capital global hectares is collected from GFN (2021b). The data on FD (addition of financial institution as well as financial market index) came from IMF (2020), and the data on economic growth (per capita GDP) and urbanization (% of the total urban population) are obtained from World Bank. Technological innovation (all patents related to technologies) is based on the OECD database[1]. Variable log transformation is an important step to improve the reliability of analysis and smoothen the data (Zafar et al. 2019); hence, variables are converted into logarithm form.

Methodology

This paper used cointegration-based techniques to ascertain the effects of FD, TIN, and GDP on EF since GMM as well as random and fixed-effect techniques are unsuitable for data with larger T dimension and fewer N. In the era of globalization, countries are often interlinked and certain events in any selected economy can indeed affect other economies (Tufail et al. 2021; Khan et al. 2020b). Therefore, cross-sectional dependence (CD) must be analyzed before initiating the analysis.

Thus, employing three different techniques, this study inspected CD before starting proper empirical estimations. As suspected, the findings portray CD in the dataset. The presence of CD leads us to use Pesaran (2007) CIPS and CADF tests to probe the integration level. This step is also crucial to overcome misleading regression results. These two tests are robust against the underlying CD issue.

After this step, this paper utilized Westerlund (2007) test which can unfold the cointegration relationship in panel data amidst CD. This ECM-based method is composed of two group and two panel tests and uses bootstrapping process to generate probability values. This bootstrapping process enables this method to offer reliable properties for small sample sizes. Next, this paper adopted the Pedroni (1999) cointegration technique which is composed of within-dimension and between-dimension tests. To aid decision-making, the Kao Residual method is also employed to inspect cointegration.

Tracing the evidence of cointegration, this research employed the CUP-FM method of Bai et al. (2009) that allows fractionally integrated regressors in the model and performs well even during heteroscedasticity, endogeneity, CD, and autocorrelation (Ozcan et al. 2018; Ahmed et al. 2020b). For robustness analysis, the other similar estimator (CUP-BC) proposed by Bai et al. (2009) is adopted since this estimator also offers similar advantages. Finally, the flexible DH causality method of Dumitrescu and Hurlin (2012) is utilized to inspect causal linkage. This methodology is applicable for data with large T dimensions and less N and vice versa, and produces trustworthy outcomes amidst CD (Saud et al. 2019b).

Results and discussion

Proceeding to the interpretation and discussion of empirical findings, the CD test estimates (Table 1) depict that in both Breush-Pagan and Pesaran scaled LM methods test statistics are significant suggesting CD in the dataset; however, CD test tabulated below these two methods shows some differences. However, this test is more suitable for datasets with large N, which is not the case in this research.

In Table 2, the estimates from unit root approaches robust against CD portray that EF and UR are stationary at 1(1), while GDP is stationary at 1(0). The other regressors show some differences in the stationary properties in both methods.

After analyzing stationary features of series, cointegration is examined using various estimators. The outcomes in Table 3 from the Westerlund (2007) method showed robust p values for Pt (0.063), Gt (0.030), and Pt (0.077) statistics below 0.10; therefore, cointegration is present in our model.

To provide strong and robust evidence of cointegration, this research utilized two more methods to ascertain cointegration. The Pedroni (1999) residual test in Table 4 elucidates that two-group and four-panel statistics out of eleven statistics are significant; therefore, the majority of within- and between-dimensions tests are significant denoting cointegration in our model. A similar finding is unfolded by the Kao residual test where ADF statistics is significant.

These tests signal that in the long run our data series move together; therefore, it is reasonable to inspect elasticities of regressors in the long run. To do so, this paper employed the CUP-FM method, and the findings are revealed in Table 5. The estimates divulge that a 1% rise in GDP escalates EF by 0.015%, while a similar upsurge in the quadratic term abates EF by 0.014%. This finding validates the EKC in the context of WAME nations, and it opposes the conclusions of Ahmed et al. (2020c) for Pakistan, Bekun et al. (2021) for Indonesia and Dogan et al. (2020) for BRICST. However, these estimates are supported by Charfeddine and Mrabet et al. (2017) for MENA countries, Baloch et al. (2020) for OECD nations, Soylu et al. (2021) for China, Ahmed and Wang et al. (2019) for India, Destek and Sarkodie (2019) for industrialized nations, Ahmed et al. (2021) for Japan, Hassan et al. (2019) for Pakistan, and Adedoyin et al. (2020) for EU nations. Our conclusion is more appropriate because it aligns with the theory. The scale effect intensifies pollution at early development levels; however, technique and composition effects at higher development

[1] https://stats.oecd.org/# (accessed January 2021)

Table 1 Test for cross-sectional dependence

	LOGEF	LOGGDP	LOGGDP^2	LOGFD	LOGTIN	LOGUR
Breusch-Pagan LM	456.2096*	527.7591*	508.6206*	379.0918*	480.4873*	407.2268*
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Pesaran scaled LM	49.52218*	57.95437*	55.69887*	40.43375*	52.38333*	43.74949*
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Pesaran CD	−2.38941**	−1.27716	−1.04774	−1.94057***	10.77922*	3.33404*
	[0.0169]	[0.2015]	[0.2947]	[0.0523]	[0.0000]	[0.0009]

*, **, and *** show 1%, 5%, and 10% significance

levels abate pollution levels by expanding innovation, advanced technology, and environment-friendly laws (Ulucak and Bilgili 2018). Hence, EF mitigation at a high level supports the concept of the EKC and this study presents a shred of new evidence accounting for TIN and FD in the model.

Proceeding to FD, financial development in our analysis escalates EF in WAME countries. This is against the conclusions of Uddin et al. (2017), Baloch et al. (2020), and Ahmed et al. (2019) for 27 nations, OECD, and Malaysia, respectively. However, the studies of Saud et al. (2020) and Baloch et al. (2019) for BRI countries support these conclusions. In addition, the study of Kihombo et al. (2021) illustrates a similar effect of FD on emissions in the context of WAME countries. This estimate in the context of WAME economies is not surprising since these nations are not highly developed and their environmental laws are weak. In these countries, FD escalates EF since financial institutions are a great source of financing to individuals and businesses, and there are no environmental laws to check the ecological impacts of their financing. Expansion in business projects increases the utilization of resources, such as energy, land, and water. The magnitude of this effect is likely to increase particularly due to the lending for infrastructure development projects such as, railway tracks, buildings, seaports, and roads that occupy a vast area of land and consume a huge chunk of resources. Even in the case of consumer loans, an increase in purchasing power can lead to a luxurious lifestyle (Ahmed et al. 2021). The environmentally friendly effects of FD are hard to witness in the selected sample; therefore, profit seeking financial institutions are degrading the environment in the WAME economies.

In Table 5, the effect of technological innovation (TIN) is statistically significant, i.e., a 1% upsurge in TIN alleviates EF by 0.010% revealing a significant reduction in EF caused by an increase in TIN. This fresh finding contradicts the studies of Sinha et al. (2020) in the Next 11 nations and Adebayo et al. (2021) in Chile. Both these studies illustrate that TIN boosts emissions as countries direct their TIN for achieving financial motives rather than improving the environment. However, this favorable impact matches our expectations since technological innovation is indispensable for building better technology that not only helps to achieve sustainable development but also decreases resource consumption leading to a decrease in EF. This fresh outcome corroborates with the work of Ahmad et al. (2020) for emerging economies. Also, this effect somewhat matches the conclusion of Baloch et al. (2020) who document an improvement in environmental quality linked with energy innovation. Although there is less evidence of TIN and EF nexus in the previous literature, this finding is also supported by some studies that analyzed the TIN effect on emissions levels, for example, Khan et al. (2020a) and Mensah et al. (2018) for BRICS and OECD countries, respectively. Additionally, the rising level of TIN in the selected sample indicates that technological efficiency linked with

Table 2 Unit root tests

Variables	CIPS		CADF	
	Level	Difference	Level	Difference
LOGEF	−1.536	−5.741*	−2.400 [0.389]	−4.049* [0.000]
LOGGDP	−3.008*	−4.936*	−3.212* [0.002]	−3.322* [0.001]
LOGFD	−2.716	−5.182*	−2.819*** [0.050]	−3.703* [0.000]
LOGTIN	−3.448*	5.818*	−2.353 [0.444]	−3.587* [0.000]
LOGUR	−1.167	−3.375*	2.348 [0.451]	−2.814*** [0.052]

* and *** denote significance at 1% and 10% level, respectively

Table 3 Westerlund cointegration test results

Statistics	Value	Z value	P value	Robust P value
Gt	−3.593**	−1.885	0.030	0.030
Ga	−8.356	3.550	1.000	0.630
Pt	−9.683***	−1.331	0.092	0.063
Pa	−11.402***	1.423	0.923	0.077

** and *** refer to 5% and 10% significance level, respectively. Bootstrap 400 option is employed to compute results

Table 4 Pedroni and Kao cointegration tests

Pedroni residual cointegration test				
Within-dimension tests				
	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	−0.83448	0.7980	−0.86311	0.8060
Panel rho-statistic	0.58057	0.7192	0.77278	0.7802
Panel PP-statistic	−4.22224*	0.0000	−3.32099*	0.0004
Panel ADF-statistic	−4.08920*	0.0000	−2.97858*	0.0014
Between-dimension tests				
	Statistic	Prob.		
Group rho-statistic	1.76796	0.9615		
Group PP-statistic	−3.52264*	0.0002		
Group ADF-statistic	−3.19243*	0.0007		
Kao residual test				
	T-statistics	Prob.		
Kao ADF	−2.3497*	0.0094		

*means 1% significance level

growing innovation helps to decrease EF in our sample countries. This makes sense because the rise in innovation leads to the development of better technology that uses fewer resources. The reduction in resource consumption can surely decrease EF levels. In addition, technological innovation is necessary for the development of green technologies that can discourage the use of dirty energy sources.

Finally, a 1% surge in UR adds to the EF by 0.008% implying that urbanization in WAME countries is harmful to environmental quality. This conclusion opposes some previous studies, for instance, Martínez-Zarzoso and Maruotti (2011), Charfeddine and Mrabet et al. (2017), and Ahmed and Wang et al. (2019) who suggest that upsurge in urbanization supports sustainability. These outcomes are aligned with Charfeddine (2017), Al-Mulali and Ozturk (2015), and Ahmed et al. (2020b) for Qatar, MENA countries, and G7 nations, respectively. This fresh finding supports the traditional view that an increase in urbanization causes resource consumption in housing, transportation, and other sectors. The countries selected for the analysis are experiencing high urbanization levels, and in the absence of sustainable urbanization policies, this high urbanization level is adding to EF since urban residents require housing, energy, transportation, heating, and refrigeration, which increase EF levels. The long-run conclusions are also given in Fig. 1.

Table 5 Result of CUP-FM and CUP-BC

Dependent variable: LOGEF				
	CUP-FM		CUP-BC (robustness)	
Variable	Coefficient	T-Stat	Coefficient	T-Stat
LOGGDP	0.01551	36.49070*	0.01707	37.79876*
$LOGGDP^2$	−0.01394	−29.21893*	−0.01343	−25.63248*
LOGFD	0.00165	4.57965*	0.00658	16.98793*
LOGTIN	−0.01045	−16.96359*	−0.00684	−10.92271*
LOGUR	0.00899	19.08064*	0.00640	12.89724*

*denote 1% significance

After conducting the analysis using CUP-FM, the study adopted the CUP-BC method in Table 5. The obtained coefficients are highly consistent with the coefficients generated by CUP-FM; therefore, the conclusions made in this study are robust.

The causal directions explored in the study in Table 6 show bidirectional causality between EF and GDP, between TIN and GDP, and between UR and GDP, while FD Granger causes EF without any reverse causality. TIN causes GDP indicating that technological innovation is important for economic development. Bidirectional causality between FD and GDP is also found implying that reducing FD can discourage GDP and vice versa. Likewise, the feedback effect between UR and GDP indicates the importance of sustainable urbanization policies without decreasing the urbanization level.

Conclusion and policy implications

Recent literature highlights the need to raise the level of technological innovation to reduce ecological degradation. However, empirical studies on technological innovation and CO_2 emissions linkage report mixed findings. Also, there is less empirical evidence on EF and technological innovation nexus; thus, the role of technological innovation (TIN) in EF reduction is ambiguous. Against this backdrop, using data from 1990 to 2017, this research analyzed the effects of FD, TIN, and GDP on EF. To do so, the study adopted the STIRPAT model based on the EKC framework and employed second-generation methodologies for inspecting integration level and cointegration. Evidence from the Westerlund and other techniques revealed cointegration in the model. After this, the reliable CUP-FM methodology is employed, and generated coefficients indicated that technological innovation (TIN) can help to realize the dream of a sustainable environment since it subsidizes EF levels in WAME countries. Conversely, FD and urbanization contribute to raising EF levels in the selected countries. The study captured the EKC hypothesis adding TIN, FD, and UR to the model. The findings of the DH causality test depicted causality from FD to EF and from TIN to GDP, while feedback effect is revealed between TIN and EF, between EF and GDP, and between UR and GDP.

The findings denote unfavorable effects of FD on ecological quality; however, this issue should be handled with

Fig. 1 Long-run findings of CUP-FM

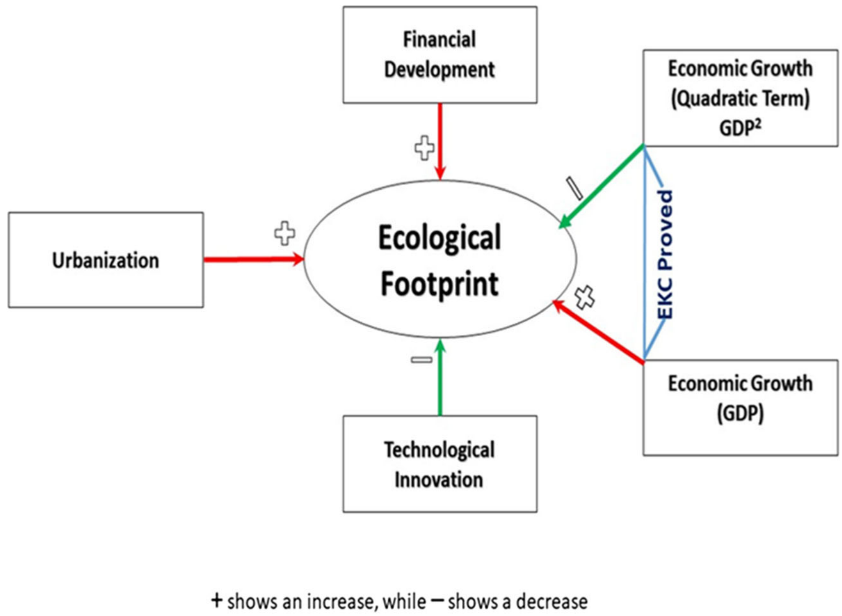

Table 6 Dumitrescu Hurlin causality tests

Causal directions	W-Stat.	Zbar-Stat.	P value
LOGGDP to LOGEF	3.62992***	1.73318	0.0831
LOGEF to LOGGDP	3.72230***	1.84598	0.0649
LOGGDP^2 to LOGEF	3.49225	1.56507	0.1176
LOGEF to LOGGDP^2	3.65064***	1.75848	0.0787
LOGFD to LOGEF	3.71885***	1.84177	0.0655
LOGEF to LOGFD	3.49461	1.56796	0.1169
LOGTIN to LOGEF	2.65783*	2.84130	0.0045
LOGEF to LOGTIN	3.70994*	4.74908	0.0000
LOGUR to LOGEF	5.57706*	4.11077	0.0000
LOGEF to LOGUR	6.34930*	5.05373	0.0000
LOGGDP2 to LOGGDP	3.45375	1.51806	0.1290
LOGGDP to LOGGDP2	3.53091	1.61228	0.1069
LOGFD to LOGGDP	5.45375*	3.96020	0.0000
LOGGDP to LOGFD	4.70283	3.04328	0.0023
LOGTIN to LOGGDP	5.09047*	3.51661	0.0004
LOGGDP to LOGTIN	3.10805	1.09594	0.2731
LOGUR to LOGGDP	7.87664*	6.91871	0.0000
LOGGDP to LOGUR	12.3948*	12.4356	0.0000
LOGFD to LOGGDP^2	5.41803*	3.91658	0.0000
LOGGDP^2 to LOGFD	4.63627*	2.96200	0.0031
LOGTIN to LOGGDP^2	4.94196*	3.33527	0.0009
LOGGDP^2 to LOGTIN	3.01563	0.98309	0.3256
LOGUR to LOGGDP^2	7.43862*	6.38387	0.0000
LOGGDP2 to LOGUR	12.4333*	12.4827	0.0000
LOGTIN to LOGFD	4.15202**	2.37070	0.0178
LOGFD to LOGTIN	2.97111	0.92873	0.3530
LOGUR to LOGFD	6.59401*	5.35254	0.0000
LOGFD to LOGUR	10.4795*	10.0970	0.0000
LOGUR to LOGTIN	3.70487***	1.82470	0.0680
LOGTIN to LOGUR	9.59899*	9.02183	0.0000

*** and * refer to 10% and 1% significance, respectively

caution since the reduction in FD can negatively affect GDP. Although urbanization (UR) is detrimental to ecological quality, reduction in UR can hurt economic progress due to feedback effects between these regressors and GDP. Technological innovation is not only closely associated with the EF but also affects GDP.

Hence, considering the weak environmental laws of the sample countries, policies should be implemented for strengthening environmental regulations in the financial sector. The financial sector must inspect the ecological viability of projects before lending. This will help to get desired benefits of FD because the prevalent profit motive makes the lending of the financial sector unsustainable. Alongside, steps need to be taken to make borrowing relatively easy for green energy projects. Government should develop necessary policies to encourage low-interest loans for efficient technology. This will help to boost technological capacity in the sample countries that can lead to a reduction in resource consumption. Technological innovation is sustainable in WAME economies, and its level should be boosted by enhancing investment in research and development. Investment in technology should be supported by offering tax benefits and subsidies. A close collaboration between universities and industries and offering research grants may also boost TIN level.

Urban sustainability can be achieved by establishing special institutions for urban planning. The focus on centralized cities and launching energy-efficient products in the residential sector may play a vital role in minimizing the adverse effects of urbanization. At the same time, transportation policies focusing on enhancing rail and bus-based shared transport will be vital to mitigate the negative effects of UR. In the sample nations, the cities are rapidly expanding due to urban sprawls. If the current situation continues, there would be a serious threat to the availability of resources and EF will further increase. Therefore, urban housing policies are also essential to minimize the negative impacts of UR. The existence of the EKC is a vital finding in the context of WAME nations, which intend to accomplish high development. The path of development in the sample nations can be continued with a focus on increasing renewables to fuel the development and developing the necessary technology to switch towards alternative fuels. Innovation should also be increased in this context since TIN Granger causes GDP in the sample nations. Hence, increasing innovation is indispensable for sustainable development and EF mitigation.

This study probed the impacts of FD and TIN on EF in the WAME economies, and the analysis is limited to the long-run and causal estimation. Future studies can analyze the role of GDP, FD, urbanization, and other regressors on technological innovations. This will be helpful to enhance the level of technological innovation in the sample nations. In addition, future studies can use quantile regression methodology to apprehend the impact of regressors on EF at different quantiles.

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Data and material availability Links are provided in the paper to access the data used in the paper free of cost.

Declarations

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