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Research article

The dynamic nexus between economic factors, socioeconomic factors, green growth factors, and ecological footprint: evidence from GCC economies

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Abstract: Industrialization, financial activities, and intensive human activities have reduced continuous habitats to smaller patches, threatening the safety of the ecosystem. However, as technological innovation and digitization increase, this negative impact will be somewhat neutralized. To address this issue, the current study examined the role of economic, socioeconomic, and green indicators on the ecological footprint in the Gulf Cooperation Council (GCC). By using data from 1990–2019, we have applied multiple panel tests to determine the long-run and short-run relationships among the variables. The findings show that economic growth increases the long-term ecological footprint in the GCC. The human development index and financial inclusion coefficients are also positively and significantly linked with the ecological footprint. The socioeconomic index, however, reveals a negative relationship between ecological footprint and GCC. Similarly, digitalization and environmental technologies have a negative and major impact on the ecological footprint. It indicates that green growth factors contribute to long-term improvements in environmental quality. So, GCC nations should emphasize investing in green growth factors and enact strict environmental regulations to safeguard their country from environmental problems.

Keywords: economic growth; socioeconomic indicators; ecological footprint; GCC countries; panel analysis

1. Introduction

One of the biggest problems the world is currently experiencing is environmental degradation. In particular, greenhouse gas emissions, global warming, and ozone layer loss pose severe dangers to human survival. Consequently, the quality of the air is constantly getting worse. Academics and decision-makers agree that both developed and developing countries should take environmental protection very seriously [1]. In a similar line, effects of environmental degradation are also investigated previously. Now, researchers are working to devise methods to lessen the effects of environmental deterioration on the ecosystem [2–4]. In this sense, this problem has become critical for the coming generation. As a result, if it does not resolve as soon as feasible, it might continue to endanger both the present and the succeeding generations [5].

The global community, especially Gulf Cooperation Council (GCC) countries, is currently in a fix regarding dilemmas connected to their ecological footprint. The GCC nations have experienced a higher rate of industrialization and urbanization, which have caused high levels of greenhouse emissions, excessive use of resources, and loss of biological diversity. These environmental effects intensify these problems since high dependency on fossil fuels results in air and water pollution. The other important challenge is water deficiency: the freshwater deficit in GCC countries is satisfied by desalination, which is energy-consuming [6]. This is, of course, on the backdrop of the leaders in ecological footprints, which are developed nations that have high levels of consumption and waste output. For example, Qatar and Kuwait are among the highest international per capita waste generators; these countries face enormous waste management and pollution issues. However, reports have also shown that due to population growth and development, natural resources have been stretched to the limit, thereby compromising on the habitats and the services offered by an ecosystem [7]. Effects of climate change are also felt in the GCC region, whereby increases in the average temperatures and rising sea levels present a risk to the coastal structures and human settlements. Solving these issues calls for extensive policies aimed at the achievement of sustainable development, the rise of investment in renewable energy resources, and stringent environmental legislation to minimize the impact of the social entity's action on the environment and make it more resistant to change.

In countries with access to large oil reserves, there is considerable research conducted on the connections between economic expansion and environmental deterioration, as well as the relationship between energy use and economic expansion [8]. Even though they own plenty of renewable energy sources, these countries' economies, nonetheless, rely heavily on the export of products made using fossil fuels [2]. The Gulf Corporation Council (GCC) countries rank eighth concerning the greenhouse gas effect and have the most oil and natural gas resources globally [9]. The GDP and per-person energy demand of GCC member states are much greater compared to similarly rising nations, which are indicators of these states' economic expansion at the moment [10]. The significantly proportion of these economies' primary energy requirements is met by fossil fuels, which ultimately results in significant greenhouse gas emissions per person in these countries [11].

The term "ecological footprints" was first introduced in the study by Wackernagel M, et al. [12], where it was described as "the use of soil and water to supply all human-consumed products and the eradication of environmental pollution produced by human beings [13]. According to the

Global Footprint Network, the ecological footprint is a measurement based on the number of natural resources we possess and the quantity we have already taken [14]. It creates a framework for evaluating how ecological systems' innate capacities to meet basic human needs for natural assets and remove waste caused by those requirements compare to those systems' inherent capacities to support life [15]. In order to measure how heavily reliant human economies seem to be on natural resources, the ecological footprint provides a unique indicator of environmental sustainability. In addition, it assesses the impact of social and technological developments on the environment [16]. Also, in prior studies, carbon emissions were used to evaluate pollution levels. However, it was necessary to utilize a broader proxy in environmental quality modeling that simulates the limits inherent in carbon emissions and offers meaningful information to decision-makers concerning the sustainability of the environment [2]. In this perspective, the ecological footprint is widely acknowledged as a more specific indication of environmental pollution, especially environmental sustainability [17–20].

It took almost 40 years to develop the present idea of sustainable development and growth [21,22]. As a concept, sustainable development has evolved to emphasize how economic growth, ecological sustainability, and socioeconomic evolution are interconnected and contribute to future prosperity for humanity and the environment [23,24]. In the past, development meant attaining and maintaining growth in per-capita income, with the expectation that this progress would either "trickle down" to the nation through the development of economic possibilities or result in a more fair allocation of economic and social well-being [25]. On the one hand, economic development provides the resources required to promote improvements in human development. Nevertheless, improvements in human development (excellent health, wealth, education, and standard of living) can boost productivity and consequently support economic growth [26,27]. Economic advancement continues to be the main driving force in industrialized nations, and the steep increase in energy consumption will significantly worsen the already crippling environmental problems [28]. Several countries have begun the shift from economic growth to green economic initiatives, including digitalization and environmental technology, which signify collaboration among economic growth, resources, and ecological advancement to achieve sustainable development goals (SDGs) [1].

The study's importance comes from preserving sustainable development while pursuing environmental sustainability in GCC countries. However, it does not address the potential for human well-being, which encompasses life expectancy, education, and level of wealth [29]. To evaluate national socioeconomic progress, the United Nations Progress Program created the Human Development Index (HDI) [30]. However, economic expansion and human development have a natural symbiotic relationship. On the one hand, economic expansion provides the resources required to sustain improvements in human development. However, improvements in human development (such as health, income, and education) can increase productivity and, hence, support economic growth [31]. Therefore, this paper contributes to the existing literature by evaluating the indicators of development: 1) economic growth, and 2) the human development index. According to our limited knowledge, this study is the first to evaluate the human development index and the socioeconomic circumstances index by examining the effectiveness of economic institutions to analyze the social aspects in GCC nations. This study also considers the significance of financial inclusion and whether it might lessen the harmful effects of human activity on the environment. According to earlier research [32], there is a dynamic interaction between environmental technology and the environment. This study adds to the body of knowledge by examining a comprehensive model of technological development that consists of two variables, using digitization and environmental technologies to create a detailed and accurate picture. So, exploring the connection and causality between the ecological footprint, economic growth, financial inclusion, human development index, socioeconomic conditions index, environmental technology, and digitalization within a single framework is appropriate. More concisely, this research helps us better grasp the advantages and challenges of applying environmental technology and digitalization in GCC countries.

The goals of this study are to investigate the impact of economic, socioeconomic, and green growth indicators on the ecological footprint in Gulf Cooperation Council (GCC) countries. Utilizing data from 1990 to 2019, the study aims to analyze both long-term and short-term relationships among these variables through multiple panel tests. Specifically, the research seeks to understand how economic growth, human development, and financial inclusion affect environmental sustainability, while also assessing the mitigating effects of digitalization and environmental technologies. Ultimately, the study aims to provide insights that can guide policy decisions to promote green growth and environmental preservation in the GCC region.

In light of the contributions, the study's three main objectives are as follows. The first objective of this study is to investigate the impact of economic factors (economic growth and financial inclusion) on the ecological footprint in GCC countries. The second objective is to examine the role of socioeconomic factors (the human development index and socioeconomic conditions index) on the ecological footprint. The study's third goal is to examine how green growth factors, such as environmental technologies and digitalization, affect the ecological footprint.

The most contentious topic in the literature on the connection between finance and the environment is whether financial inclusion advances ecological sustainability, degrades it, or has no impact [33]. Increasing financial inclusion might have both favorable and adverse environmental effects. Financial inclusion attracts additional research and development, reducing ecological damage by funding green initiatives and accelerating the economic development cycle [34,35]. On the other hand, the traditional financial system provides people with access to low-cost consumer credit to buy more traditional cars and household equipment, which eventually increases traditional energy use and, in turn, increases environmental damage [36].

The United Nations Development Program (UNDP) started the Human Development Index (HDI) in 1990 to evaluate national socioeconomic development, and then in 2010, it established a new methodology [30]. Since then, the HDI has become a substitute for economic growth in gauging the nation's development [37]. However, economic progress and human development have a genuine bidirectional relationship. The HDI is a comprehensive indicator that takes into account a variety of aspects, including: (1) a healthy life expectancy, (2) availability of knowledge, and (3) a reasonable level of living [38]. Most crucially, the HDI allows a nation to plan their route to the 2030 Agenda for Sustainable Development’s goals [39]. Even though environmentalists and stakeholders have traditionally prioritized environmental protection and human well-being, the environmental literature must thoroughly describe and explain the mechanisms linking these two goals [40].

Economic, sociological, and environmental concerns are all part of the green environment's guiding principles. Social and economic structures influence how social effects on health incorporate into the global environment and how energy distributes [41]. It is now more apparent than ever that recent occurrences around the world have irrefutably demonstrated that the impacts of our ecological footprint on the planet's climate are manifesting even more quickly than scientists had anticipated [5]. Humanity faces global crises due to unsustainable growth, consumption, and production: pollution, global warming, and biodiversity loss [42]. Many techniques have been employed to determine how human activity affects environmental performance, but the ecological footprint (EF) model has proven to be a practical resource [43].

There is a unanimous consensus that technology contributes to economic growth. However, it is not apparent how certain technologies, such as financial and environmental technology, contribute to the green environment [44]. The GCC's industry, economy, and other factors are all expanding quickly, increasing resource consumption and the ecological footprint [45]. Innovation in environmental technology has been among the most significant contributors to productivity growth and a green environment [46]. Environmental technologies are production tools, processes, procedures, new product development, and delivery methods that limit or reduce the unfavorable environmental effects of goods and services. The fusion of labor-intensive industries and environmental technology in the digital economy is hastening the fast development of the global economy in the direction of more innovation, intelligence, and green initiatives [47].

The unfavorable effects of the intermittent industrial expansion have also become a significant limiting factor influencing citizens' health and standard of living [48,49]. For the achievement of the perfect cohabitation between humanity and the environment and the advancement of environmentally friendly development, the rapid expansion of the digitalization sector has significantly affected the economic and social development trend [50]. The financial industry's connectivity with information technology has gotten stronger in recent years [51]. Using emerging technologies like artificial intelligence [52] and cloud computing in digital finance is crucial for advancing the green environment [53].

The causal connection between natural conservation and social evolution hypothesizes that environmental pollution and the earth's fragile ecosystems harm people's health and happiness, worsening the ecological environment's disaster [54]. Economic growth and ecology have an essential link, and studies related to this relationship are concerned with the environmental Kuznets curve [55]. Initial economic growth has typically been seen by massive industry development and the unrestricted use of ecologically damaging forms of energy [56], and that deterioration continues [16,57]. In recent decades, environmental instability and ecological footprints have created concerns about long-term economic expansion worldwide because of the limited natural resources availability [41].

Researchers worldwide have examined the connection between environmental pollution and financial inclusion and have identified various pieces of evidence [58]. Through channeling funding into clean and green energy facilities, financial inclusion in several studies is considered a significant contributor to reducing the ecological footprint [59] through providing funding to businesses for environmentally friendly technical innovation [60] and technology transfer from developed economies [61]. The research in Destek MA, et al. [62] affirmed the link between financial inclusion and ecological footprint. Their investigation showed that the BRICS countries' strong financial growth had accelerated ecological footprints. Although the transition to a greener economy has had good effects on the environment, the data that supports these generalizations remains confusing and vague [63].

It has commonly known that environmental functions are essential to human health and well-being [40]. Researchers have linked ecological footprint measurement with indicators of human development to assess whether a country has progressed toward ecological sustainability [41]. At the expense of public and environmental health, energy consumption boosts the economic growth of global markets [64]. The ecological footprint and adverse environmental and human health impacts rose along with using non-renewable energy [65]. Environmental deterioration harms human well-being and can potentially destroy ecosystems [66].

Researchers have recognized the importance of ecological services to human health and welfare [67]. According to the study by Panayotou T [68], the significant development of human societies' financial well-being typically came at the expense of a pronounced increase in their ecological footprint. Social systems and economics have a big impact on how society affects health [69]. These frameworks and channels have affected the distribution of authority, wealth, and resources locally and internationally [70]. This socioeconomic dispersion formed societies to meet their basic needs. Polluted air, tension, injury, and sickness were more likely to occur in minority populations or those with lower incomes [41]. The detrimental effects of environmental degradation have increased and continue to undermine many facets of socioeconomic growth [71], endangering human sustainability [72]. As ecological and environmental awareness has grown in the economy and society, environmental protection efforts have stepped up, and the share of green energy consumption has risen [73].

The relationship among environmental technologies and the ecological footprint has been the subject of various studies in the past [44]. They have demonstrated that technological improvements have turned into a successful method of decreasing the environmental impact [74]. According to the study by Hussain M [75], to lessen environmental hazards, the BRICS countries elevated the standard of their institutions' ecological footprints. They also suggested that people spend money on environmental technology, which might lessen their ecological footprint. Environmental technology advancements reduced non-renewable energy usage and increased the demand for carbon-emissions-reduction technologies in renewable energy sources [76]. Economic and social advancement frequently exacerbates the "butterfly effect" of ecological footprint growth under low technology conditions by making the environment more brittle and vulnerable [77].

Following the industrial and agricultural economies, digitalization acts as a new socioeconomic platform [78]. In the period of economic and technology transition, the strategic importance of digitalization has grown. Most past research has been qualitative and focuses mostly on ideas like the conceptualization of the digital economy [79]. The researchers also develop a rating mechanism to determine the degree of digitization and the digital economy [80]. By constructing that eco-friendly platform, the digitization framework has encouraged the green revolution of industry and directed green consumption [81]. Also, while digital finance aided businesses in overcoming financing challenges, digitization enhanced organizations' manufacturing capacity and efficiency [82].

In short, we have determined that while the research focuses on economic development's impact on environmental pollution, these investigations did not consider the influence of financial inclusion, the human development index, the socioeconomic factors index, environmental technology, or digitalization on the environment in the framework of the GCC countries. Nonetheless, it is a reality that a lack of these elements could deteriorate environmental conditions by escalating the consumption of unfriendly resources.

2. Materials and methods

2.1. Data and models

We employ data from the GCC nations between 1990 and 2019 for our empirical research. Kuwait, Bahrain, Qatar, Oman, Saudi Arabia, and the United Arab Emirates comprise the sample's six nations. The ecological footprint is the most accurate metric for measuring sustainable development for the environment [83]. The extent to which human activity impacts the environment's capacity to regenerate is made possible by understanding the ecological footprint [84]. Therefore, the dependent variable for the current research is the ecological footprint (EFP). We have divided independent variables into three subsets: the first is a set of economic factors that include economic growth (GDP) and financial inclusion (FINC). The second one is socioeconomic factors, which include the human development index (HDI) and socioeconomic conditions index (SEI). The last subset contains green growth factors, which include environmental technology (ET) and digitalization (DIGIT). We collected the data from different sources; details are given below in Table 1.

Table 1. Definitions and sources.

Indication	Variable	Measure	Source
EFP	Ecological Footprints	The per capita ecological footprint (in global hectares)	Global footprint network
GDP	Economic Growth	Gross domestic product	WDI
FINC	Financial Inclusion	Cubic meters (in millions)	WDI
HDI	Human Development Index	Human well-being	https://hdr.undp.org/data-center/human-development-index#/indicies/HDI
SEI	Socioeconomic Conditions Index	The quality of economic institution	International Country Risk Guide (ICRG)
ET	Environmental Technology	Percentage	OECD
DIGIT	Digitalization	Industry revenue of "computer programming, consultancy and related activities" (in millions of U.S. dollars)	https://www.footprintnetwork.org/our-work/cities/

The following are the empirical equations that were employed to analyze the association between the variables individually:

Model 1 provides the economic factors that affect the ecological footprint in GCC countries, which are reported in Eq (1):

$$EFP = f\ (GDP, FINC) \tag{1}$$

Model 2 provides the socioeconomic factors that affect the ecological footprint in GCC countries, which are mentioned in Eq (2):

$$EFP = f\ (HDI, SEI) \quad (2)$$

Model 3 provides the green growth factors that affect the ecological footprint in GCC countries, which are given in Eq (3):

$$EFP = f\ (ET, DIGIT) \quad (3)$$

Model 4 combines all of the factors and examines the impact on the ecological footprint in GCC countries, which are presented in Eq (4):

$$EFP = f\ (EGDP, FINC, T, DIGIT, HDI, SEI) \quad (4)$$

The natural logarithm of each variable is used to stabilize the variance and linearize the nexus between them. The following are the empirical equations that come after the log (in Eqs (5–8)):

$$lnEFP = \alpha_0 + \beta_1 lnGDP_{it} + \beta_2 lnFINC_{it} + \varepsilon_t \quad (5)$$

$$lnEFP = \alpha_0 + \beta_1 lnHDI_{it} + \beta_2 lnSEI_{it} + \varepsilon_t \quad (6)$$

$$lnEFP = \alpha_0 + \beta_1 lnET_{it} + \beta_2 lnDIGIT_{it} + \varepsilon_t \quad (7)$$

$$lnEFP = \alpha_0 + \beta_1 lnGDP_{it} + \beta_2 lnFINC_{it} + \beta_3 lnHDI_{it} + \beta_4 lnSEI_{it} + \beta_5 lnET_{it} + \beta_6 lnDIGIT_{it} + \varepsilon_t \quad (8)$$

where $lnEFP$, $lnGDP$, $lnFINC$, $lnHDI$, $lnSEI$, $lnET$, and $lnDIGIT$ stand for the natural logarithm of the ecological footprint, economic growth, financial inclusion, the human development index, the socioeconomic conditions index, environmental technology, and digitalization, respectively. The intercept α_0 indicates that the ecological footprint is identical to this autonomous number when other factors remain the same. The parameters β_i, i = 1 and 2, are the estimation factors that reveals the link among dependent and independent variables, and i and t portray the country and time in panel data estimation. Moreover, ε_t is an error term.

We follow several academics and employ the important variables connected to the ecological footprint in the literature to evaluate the environmental issues that are consistently important. According to earlier research [85], we anticipate that economic growth will impact the environment because it causes environmental damage, and economic growth and the ecological footprint are correlated in both directions. According to some experts, financial growth improves the ecosystem by supporting environmentally friendly projects [86]. In contrast, due to industrialization and wealth effect channels, financial development might harm the ecosystems [87]. These highlights allow one to speculate on potential positive or negative trends for the coefficients associated with financial inclusion. Based on prior research, financial inclusion will favorably affect the environment. The results of [88] support this prediction. Along with economic activity, it is essential to include the society's level of education, health, income, and quality of economic institutions when characterizing the effects of environmental degradation [40], so we use the human development index and socioeconomic conditions index for this purpose. As a result of technological improvements across many industries, production processes now use less energy without sacrificing quality. In light of this, we would speculate that environmental technology and digitization may have improved environmental quality.

2.2. Methodology

The current study uses mean group (MG) and pooled mean group (PMG) methods for estimation. The MG and PMG methods are very relevant for analyzing dynamic heterogeneous panel data. One approach for degrees of cross-sectional dependence is the MG estimator introduced by [89]; this estimator averages the results of regression estimates for each cross-sectional unit. The approach is useful when there is a cross-section heterogeneity but can be rather inefficient should there be homogeneity. The PMG estimator originates by Pesaran MH, et al. [90], which incorporates short-run dynamics as well as error variances across groups but restricts long-run coefficients' homogeneity. This makes it more efficient than MG when the homogeneity assumption is met, which is particularly beneficial when analyzing countries/regions' macroeconomic data. Due to the favorable properties of the MG and PMG estimators, it is possible to build the econometric model taking into account the presence of long-run relationships in panel data with heterogeneous slopes for carrying out reliable inference.

A relatively extensive literature list of empirical analyses of cross-section heterogeneous panels includes using the mean group (MG) and pooled mean group (PMG) techniques. For example, Osman M, et al [91] employed the PMG technique to analyze the long-run cointegration of energy consumption and economic growth across countries and pointed out that the method allows short-run difference across them, thereby enforcing long-run parameter homogeneity. In another application, Benhabib J, et al. [92] used the MG estimator to analyze the effect of financial development on economic growth. They, thus, ended their paradigm flexibility to accommodate heterogeneity in the short-run dynamics and obtained the country-fixed effects, which indicated the existence of a vast inter-country variability in the growth effects of the financial development. Likewise, in the analysis of the long-run relationship between financial development and economic growth in the Middle Eastern and North African countries, Samargandi N, et al [93] applied the PMG technique that indicated a long-run equilibrium relationship and heterogeneous short-run dynamics.

2.2.1. Cross-sectional dependency and slope homogeneity test

The cross-sectional dependence (CSD) test estimates support the empirical findings. CSD is an essential test to move the panel estimation forward. The CSD test calculates the cross-sectional correlations. Most nations are related to one another due to economic globalization and liberalization. Any financial shock in one country could substantially impact other countries. The CSD will produce useful estimators when an approximation involved in the panel data.

The slope homogeneity test (SHT) is also examined in this study because ignoring it could lead to estimates of erroneous and distorted forecasts [94]. Thus, we use the SHT [95] in this study. The mathematical expressions of SHT and adjusted SHT are as follows in Eq (9) and Eq (10):

$$\tilde{\Delta}SHT = (N)^{\frac{1}{2}} 2K^{\frac{-1}{2}} \left(\frac{1}{N}\tilde{S} - K\right) \tag{9}$$

$$\tilde{\Delta}ASHT = (N)^{\frac{1}{2}} \left(\frac{2K(t-K-1)}{T+1}\right)^{\frac{-1}{2}} \left(\frac{1}{N}\tilde{S} - K\right) \tag{10}$$

Accordingly, $\tilde{\Delta}SHT$ stands for the delta SHT and $\tilde{\Delta}ASHT$ for the adjusted SHT. Moreover, cross-sectional dependency (CSD) could render the tested parameters unreliable and unproductive. These problems may consequently result in a number of things, including occasional disturbances, area effects, and unanticipated country-specific aspects. It is crucial to test the CSD concerning the variables since it contributes to overcoming bias and inconsistent results [94]. Therefore, the CSD test described below is applied in this study by Chudik A, et al [96]. The mathematical representation of Chudik A, et al [96] is as follows in Eq (11):

$$\sqrt[CSD]{\frac{2T}{N(N-1)} \sum_{i=1}^{N} \varphi_i \sum_{m=i+1}^{N} \partial_{im}} \tag{11}$$

Here, time is denoted by T, the CSD in the panel is signify by *N*, the correlation coefficient of i is indicated by ∂_{im} with *m* units.

2.2.2. Panel unit root tests

In order to determine if the variables are stationary, we use the cross-sectional augmented Dickey-Fuller (CADF) and cross-sectional Im-Pesaran-Shin (CIPS) variants of the second-generation panel root test. When analyzing regression results, the CADF and CIPS tests assist with CSD challenges and handle inaccurate information. Additionally, the investigators could evaluate the reliability and correctness of the series heterogeneity using both stationarity tests. The following equation, Eq (12), describes the formula used in mathematics for the CADF test.

$$\Delta x_{it} = \alpha_{it} + \beta_{it-1} + \delta_I T + \sum_{j=1}^{N} \gamma_{ij} \Delta x_{it-j} + \mu_{it} \tag{12}$$

where x_{it} denotes the variables included in the analysis, Δ symbolizes the variance between the variables, and μ_{it} signifies the white error term. The mathematical representation of the CIPS test is presented in Eq (13):

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} \varphi_i(N,T) \tag{13}$$

with the CADF regression test statistic indicated by the parameter $\varphi_i(N, T)$.

2.2.3. Wasterlund (2008) panel cointegration

The Westerlund test makes sense because it permits for cross-sectional dependence, heteroscedasticity, and serial correlation while controlling the nuisance caused by the endogeneity of the regressors. Therefore, the cointegration test in the study by Westerlund J [97] can be used to examine cointegration in our panel dataset more effectively. In accordance with the Durbin-Hausman criterion, Westerlund J [97] develops two test statistics for the null hypothesis of no cointegration. These two statistics are the tests for group mean and panel data (DH-group and DH-panel, respectively). The DH-panel can support the null and alternative hypotheses, allowing every nation's autoregressive parameter to remain identical. The alternative theory supported by the DH-group predicts that it varies among nations. If the DH-group and DH-panel reject the null hypothesis, cointegration exists. The Westerlund panel cointegration test has another benefit over conventional panel cointegration testing: it has fewer size distortion issues and more test power.

2.2.4. Parameter estimations

Throughout this period of modernization, every country has been profoundly impacted by the global advancements in specific countries' trade openness [98]. According to several studies, economic downturns and unanticipated dynamics induce CD between countries. Once the variables have long-term cointegration, the following stage examines the magnitude of the variables. The mean group (MG) and pooled mean group (PMG) are two models we used to determine the models' short- and long-term performance. We conducted Hausman tests to identify the efficiency estimator between the PMG and MG models.

PMG is preferred to MG most efficiently if both PMG and MG can accept the null outcome. We can use MG over PMG if the null hypothesis is less than 0.05 percent. A short-term approximation of the PMG estimator that considers heterogeneous interception, modification speed, and error variance is possible. This approach has the benefit of being steadier and more effective due to long-term cooperation. However, the error correction term coefficient needs to be negative and below 2. We use the augmented mean group (AMG) and common correlated effect mean group (CCEMG) estimators to test the robustness of the prolonged connection between the variables.

3. Results

3.1. Descriptive statistics

For the panel group under consideration, Table 2 gives descriptive statistics of the variables in terms of mean, median, maximum, minimum, standard deviation, and Jarque-Bera statistics.

Table 2 shows the highest mean value for the ecological footprint and the lowest mean value for the socioeconomic index. The standard deviation for environmental technology is the largest at 2.763, while the standard deviation for financial inclusion is the lowest at 0.018. The study uses the variance inflation factor (VIF) test to eliminate any uncertainty regarding collinearity, as reported in Table 3. The VIF values are not greater than 5, suggesting that there are no issues with multicollinearity.

Table 2. Summary of statistics.

	EFP	GDP	FINC	HDI	SEI	ET	DIGIT
No. of Obs.	180	180	180	180	180	180	180
mean	3.711	0.733	0.562	0.664	0.436	1.451	3.232
max	6.432	0.945	0.843	0.955	0.746	3.772	5.812
min	1.452	0.485	0.271	0.376	0.267	1.032	2.431
Std	2.97	0.018	0.324	0.114	0.231	2.763	1.872
Jarque-Bera	8.832	6.062	11.766	7.085	4.743	17.654	9.566

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors.

Table 3. Test of multicollinearity.

	VIF
GDP	3.164
FINC	2.712
HDI	3.021
SEI	1.674
ET	2.973
DIGIT	3.112

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors.

3.2. Cross-sectional dependence

Three CSD tests were performed in the present investigation to determine the cross-sectional dependence within the chosen sequence. Table 4 shows the outcome of the CSD test. At 1% and 5% significance levels, the test results provide evidence against the null hypothesis that CSD exists in the variable's cross-section. The following stage in the study's approach investigates the degree of stationarity among the series. Table 5 illustrates the results of the slope homogeneity test and reveals the rejection of the null hypothesis for the GCC nations, proving the existence of heterogeneity.

Table 4. Cross-sectional dependence tests.

Series	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM
EFP	148.764***	43.564***	43.007***
GDP	153.432**	32.176***	30.761***
FINC	41.536***	6.642**	6.661**
HDI	261.542***	58.423***	58.112***
SEI	96.772***	19.301***	19.101***
ET	58.853**	12.078**	12.006***
DIGIT	231.414***	48.562***	48.311***
H0: slop coefficient in homogenous			
Δ	P-Stats	Δ Adjusted	P-Stats
11.428	0.000***	8.215	0.000***

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors. *** and ** represent the level of significance at 1% and 5%, respectively.

3.3. Unit root test

It is essential to evaluate the stationarity level and the integration order among the series after addressing the issue of cross-sectional dependency among the study series. Examining the stationarity of the variables while analyzing panel data is crucial. Existing literature shows that non-stationarity in the research data can result in unreliable and erroneous conclusions [2,99]. This study used the CADF and CIPS tests, two novel second-generation unit root tests, to look at the stationarity of the series. Table 6 demonstrates that while GDP and ET are stationary at the level in the CADF, only GDP is stationary at the level in the CIPS. However, after the first difference, all variables are stationary in both tests. If the series employed in this study have long-term cointegration, it can be determined using this approach.

Table 5. Unit root test.

Series	CADF		CIPS	
	Level	1st difference	Level	1st difference
EFP	1.736	−3.922***	0.761	−6.139***
GDP	−0.592*	−5.439***	−1.243**	−5.443***
FINC	−7.592	−5.524***	−0.661	−6.021***
HDI	−1.511	−4.130***	−0.468	−4.389***
SEI	−0.741	−3.531***	1.531	−6.174***
ET	−1.371**	−4.113***	−1.687	−3.712***
DIGIT	−0.563	−7.433***	−0.782	−2.575***

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors. ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

3.4. Cointegration test

The outcomes for the DH-group and DH-panel are provided in Table 6. The DH-group and DH-panel test results indicate that the GCC economies are excluded from the null hypothesis because there is no cointegration at the 1% significance level. The output supports the cointegration evidence for the sample under investigation. Overall, our results show that, for the GCC countries between 1990 and 2019, the ecological footprint, economic growth, financial inclusion, human development index, socioeconomic condition index, environmental technology, and digitalization are in solid long-run equilibrium.

Table 6. Panel cointegration test.

Model 1		Test Stats.	Prob.
	DH-panel	3.415***	0.000
	DH-group	4.321***	0.000
Model 2			
	DH-panel	−2.867**	0.020
	DH-group	1.632***	0.000
Model 3			
	DH-panel	2.162**	0.015
	DH-group	4.231***	0.000

*** and ** represent the level of significance at 1% and 5%, respectively.

3.5. Estimation

Upon having a better knowledge of the cointegration of each variable, the next step is to estimate the long-term elasticity of the three research models. We used mean group (MG) and pooled mean group (PMG) to evaluate the long-term and short-term relationships involving the dependent and independent variables. We used the suitability of the MG and PMG methodologies using the Hausman test. The findings in Table 7 show that in this research, PMG is a more effective estimator when compared to MG.

3.5.1. Long-run estimation

The long-term findings in Table 7 indicate that the GCC countries' ecological footprint grows as their economies develop. According to this, an increase in economic growth of 1% causes an increase in the ecological footprint of 1.383 %. It shows that in GCC nations, environmental deterioration is growing faster than economic growth. As a result of the GCC economies falling from the top to the bottom in terms of structural transformation, it demonstrates how the ecological condition decreases as real income rises (from oil-based countries to economically established and industrialized nations), which causes the environmental quality to decline. Our results are consistent with Khalid K, et al [100,101]. Also, the findings show that financial inclusion and ecological footprint pose a significant and positive relationship. This study concludes that financial inclusion promotes employment prospects through strong investment incentives, raising the need for energy use because of strong economic growth while neglecting the environment [102]. The outcomes support the finding of Amin A, et al [103]. The findings of this article imply that governments should consider two crucial, interrelated issues: economic growth and environmental sustainability.

Table 7. MG and PMG tests.

	PMG				MG			
Long-run	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
GDP	1.383***			0.914***	2.105***			1.652***
FINC	0.832***			0.750**	1.651***			1.270**
HDI		0.516***		0.125**		0.712***		0.193**
SEI		−1.265***		−0.973*		0.665		−0.895**
ET			−0.015***	−0.102**			−0.005***	−0.016**
DIGIT			−0.471**	−0.138**			0.415	−0.204**
Short-run	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
ECT	−0.391	−0.046	−0.013	−0.158	−0.415	−0.162	−0.173	−0.011
GDP	0.562***			0.277*	0.241***			0.298*
FINC	−0.458***			−0.183	−0.325			−0.183
HDI		0.351***		0.175		0.213**		0.579
SEI		−0.436		−2.169		1.412		1.954
ET			−0.043***	−0.160*			−0.283***	−0.103*
DIGIT			−1.631	3.018			1.653	1.382
C	56.321	43.898	41.032	39.065	34.116	26.047	19.518	35.160

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors. ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

The findings indicate that the ecological footprint and human development are positively correlated. These findings conflict with those made by results suggesting that improving human well-being has a considerable impact on preventing environmental deterioration. In other words, social welfare programs will result in a detrimental influence on the environment by increasing the environmental pollution of humans [40]. Nevertheless, a negative link exists between the socioeconomic conditions index and ecological footprint. In order to combat environmental deterioration, established economic institutions provide appropriate incentives. This result is supported by Bhattacharya M, et al [104].

The findings, however, demonstrate that environmental technology enhances environmental quality by lowering the ecological footprint. It indicates that a 1% increase in technological innovation results in a −0.015% decrease in the ecological footprint. Although environmental technology has a very small impact compared to the other factors considered in this study, it still helps these nations' environments [105,106]. Also, the level of emissions in the GCC countries has greatly decreased due to digitalization. More specifically, a 1% influence on digitization will help the GCC countries reduce their ecological footprint by 0.471%. Understanding the beneficial influence of the replacing outcome, which is closely related to the decarbonization and dematerialization efforts, can help defend this result.

The GCC countries' significant increase in digitalization has led to an increase in implicitly digital products and services like electronic banking, email, mutually beneficial gatherings, and e-books. This lowers environmental pollution and, as a result, minimizes energy use by Kihombo S, et al. [107].

3.5.2. Short-run estimation

The short-term outcomes demonstrate that, at a 1% significance level, the statistical importance of the error correction factor is negative. It provides even more evidence favoring the long-term link among the variables. According to the ECT value, the short-term disruption should be reduced by 0.391 percent to reach equilibrium in the long term. The outcomes demonstrate a positive connection between the ecological footprint, economic growth, and human development index. However, the financial inclusion, socioeconomic conditions index, environmental technology, and digitalization show negative coefficients, but financial inclusion and environmental technology are for bettering the environment through lowering ecological footprints in the short term.

Table 8. Robustness test.

	AMG		CCEMG	
	Coef.	*P* > *z*	Coef.	*P* > *z*
GDP	2.183	0.000.	1.105	0.007
FINC	0.416	0.017	0.446	0.002
HDI	0.942	0.001	−0.712	0.000.
SEI	−0.435	0.003	0.465	0.037
ET	−0.013	0.000.	−0.105	0.006
DIGIT	−0.371	0.003	0.715	0.004

Notes: EFP shows the ecological footprint, GDP is the economic growth, and FINC is the financial inclusion. HDI and SEI are the human development index and socioeconomic conditions index, respectively. ET and DIGIT represent the environmental technology and digitalization described as the green growth factors. ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

Table 8 discusses the robustness of long-run results. Augmented mean group (AMG) and common correlated effects MG (CCEMG) are the two ways we estimate. These two techniques can also be applied when CD is present in the model. The outcomes exhibit a common pattern to those from the PMG study. It suggests that economic expansion positively and significantly impacts the GCC countries' ecological footprint. Similar to how economic development and human development indexes raise the per-capita footprint in the sample countries, they lower environmental quality—nevertheless, environmental technology and digitization aid in boosting the environmental quality.

3.6. Driscol-Kraay regression

Our results, as presented in Table 9 and based on the Driscoll-Kraay regression, confirm several factors that significantly influence the ecological footprint in GCC countries. In Model 1, the positive and significant coefficient of GDP at 1.264 (a 1% level of significance) supports the hypothesis that economic growth contributes to the ecological footprint. This finding is consistent with the work of Acaravci A, et al. [108], which also noted that industrialization and consumption linked to economic development lead to environmental deterioration.

In Model 2, financial inclusion is shown as 1.329, which has a positive coefficient, $t = 2.338$, and $P < 0.05$, which indicates that greater financial inclusion increases the level of environmental pressure. The human development index is also positive and equals 1.215, which is significant at the 5% level, meaning that the indices of human development are positively related to the ecological footprints. However, the coefficient for the given socioeconomic conditions index is negative, −1.417, which is highly significant at a 1% level, meaning that improved socioeconomic status lowers the level of environmental degradation. This differs from the suggestion made by Yu Y, et al. [109] that socioeconomic enhancement might result in greater environmental pressure arising from increased consumption.

Model 3 incorporates environmental technology, which is always given a coefficient of −1.548, $P < 0.01$, which means that technological progress in the environmental field leads to a decrease in EFP. This result is in line with Wu Y, et al. [110], where the authors stressed the importance of technology in managing environmental effects. In Model 4, the coefficient for DIGIT is negative, equal to −1.920, which is significant at the 1% level to support the assertion that digital advances aid in reducing the ecological impact. This is in line with Ulucak R, et al [111,112], which pointed to the fact that the digitalization process has a positive impact on the reduction of pollution and the improvement of energy performance. Conclusively, it can be argued that economic development, financial liberalization, human capital development, socioeconomic factors, environmental innovation, and digitalization are antecedents of the ecological footprint in the GCC countries. The results call for the notion of co-optimized policies targeting for both economic and human development and the use of technology and digitalization to minimize environment effects.

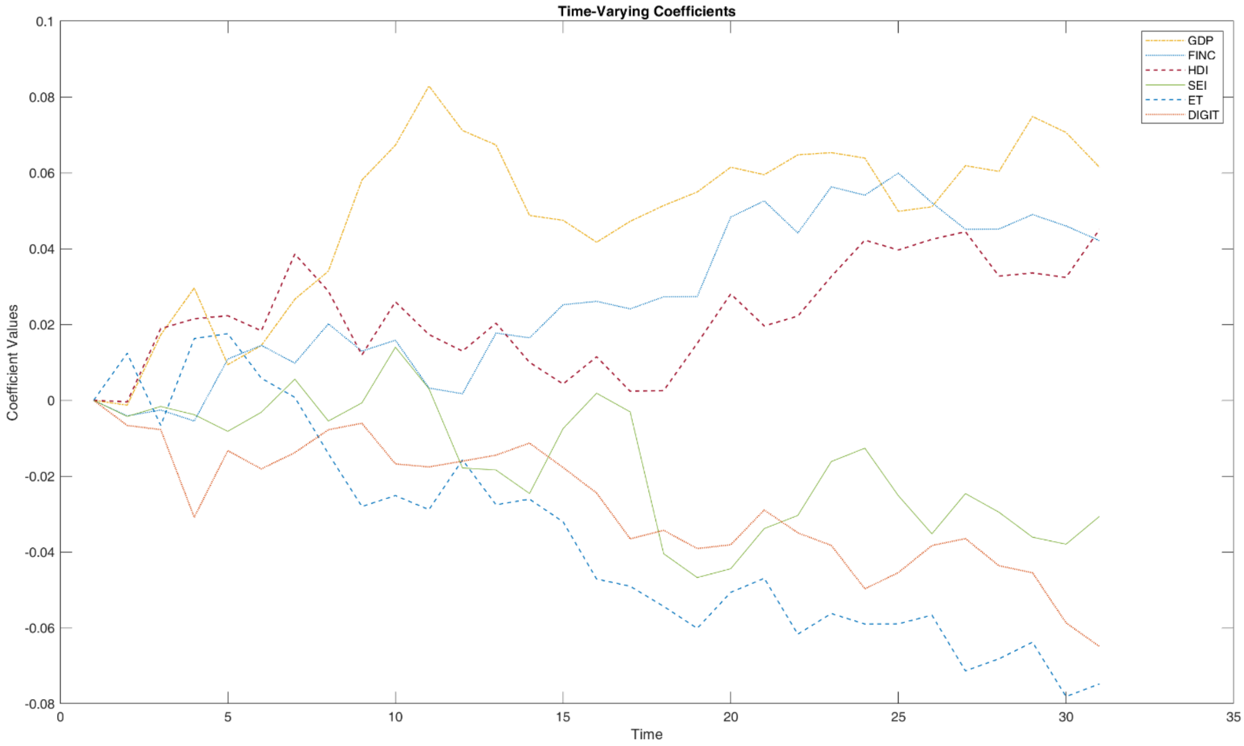
Table 9. Driscol-Kraay regression results.

Variables	Model 1	Model 2	Model 3	Model 4
GDP	1.264***			1.320***
FINC	1.688**	1.329**	1.991***	1.628***
HDI		1.215**		1.012***
SEI		−1.417***		−1.099***
ET			−1.548***	−1.273**
DIGIT			−1.437***	−1.920***
Constant	30.517***	29.427***	34.619***	40.537

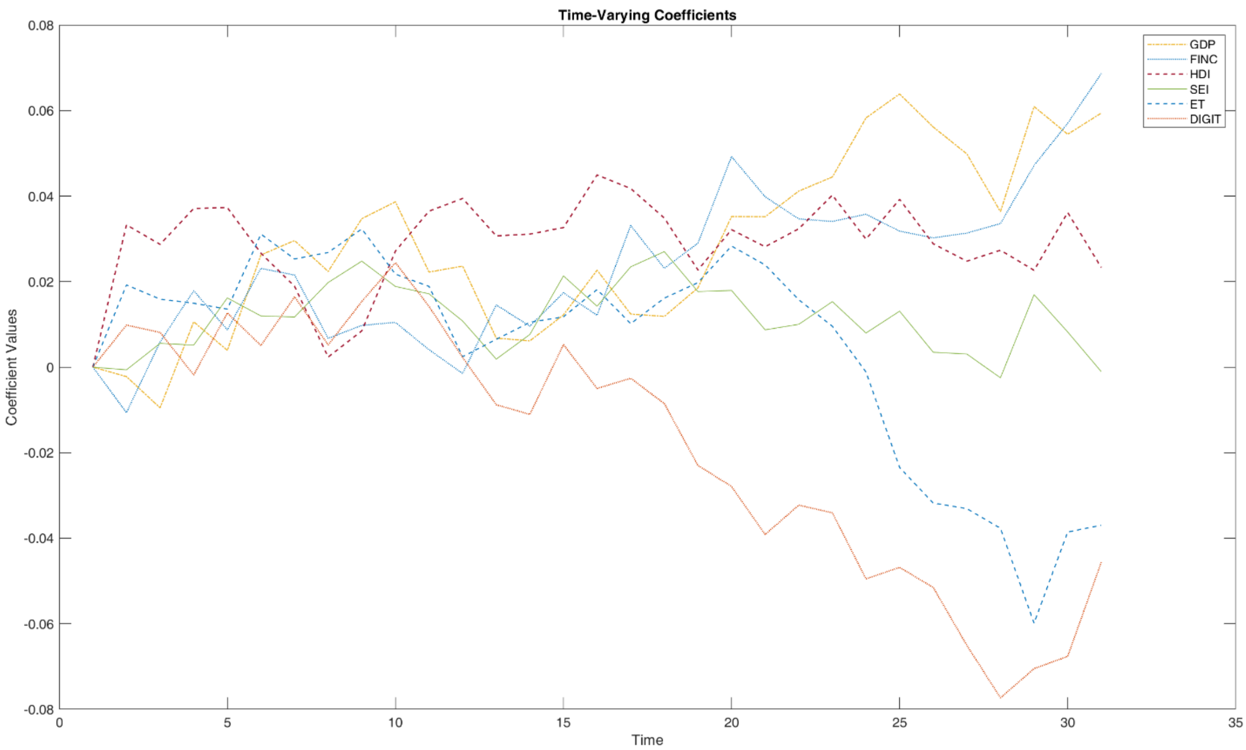
Notes: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

3.7. Time-varying analysis

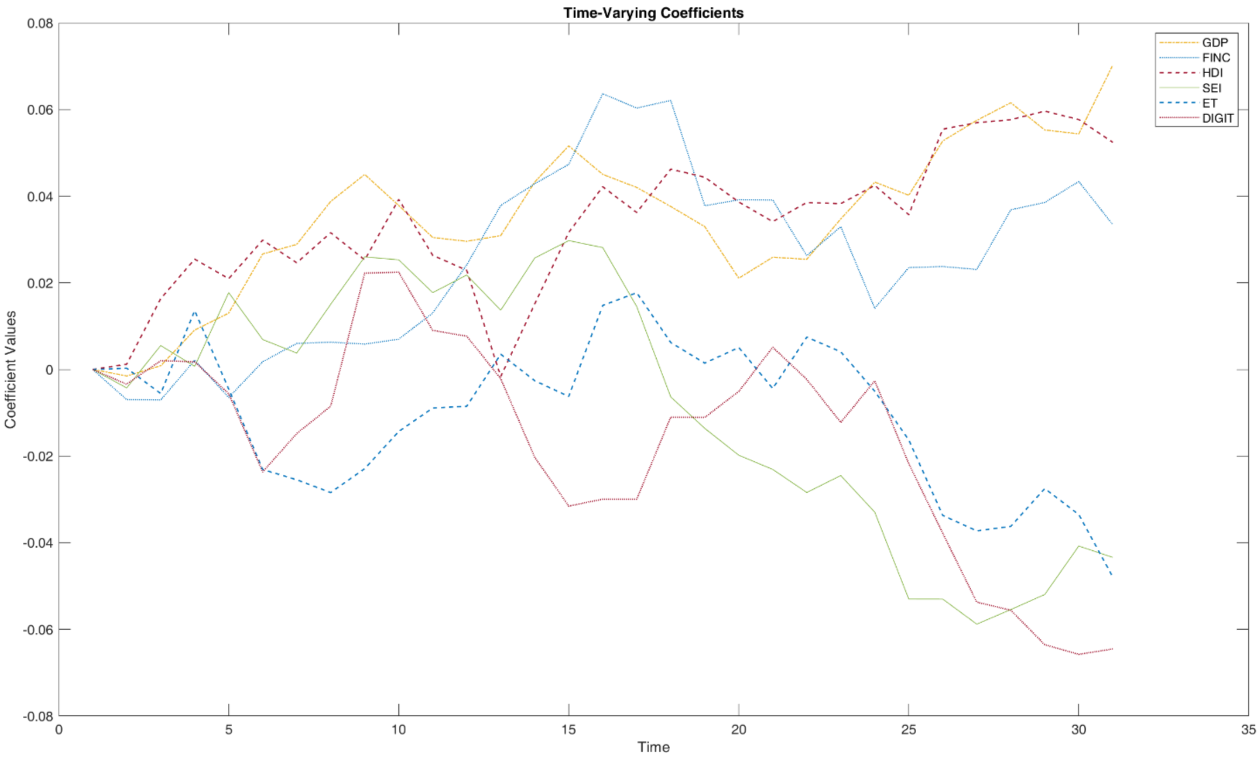
After the regression analysis for multiple models, we have to analyze the time-varying impact of independent variables on the EFP, see Figure 1. The findings vary from country to country, whereas, the coefficients of GDP are higher than 0.00. The findings of GDP confirm that GDP is one of the main causes to increase the environmental externalities in all of the GCC countries. FINC and HDI are confirming similar results for all of the GCC countries, confirming the positive relationship with EFP, across the selected time period. For SEI, the findings vary across the time period. In an earlier time period, the coefficient of SEI is higher than 0.00, whereas, in later years, the coefficients move down and turn to be negative. The coefficients of ET and DIGIT are lower than 0.00, indicating the negative relationship with EFP.



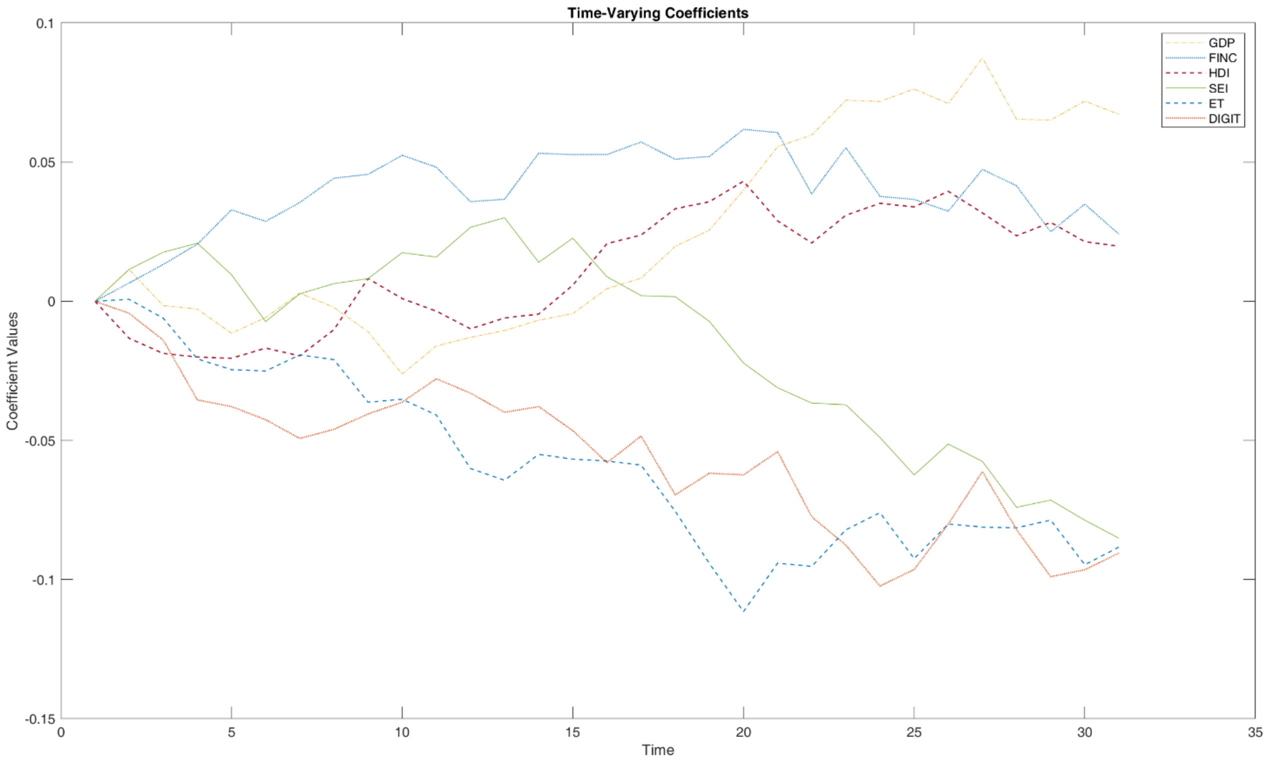
(a) Time-varying analysis of UAE



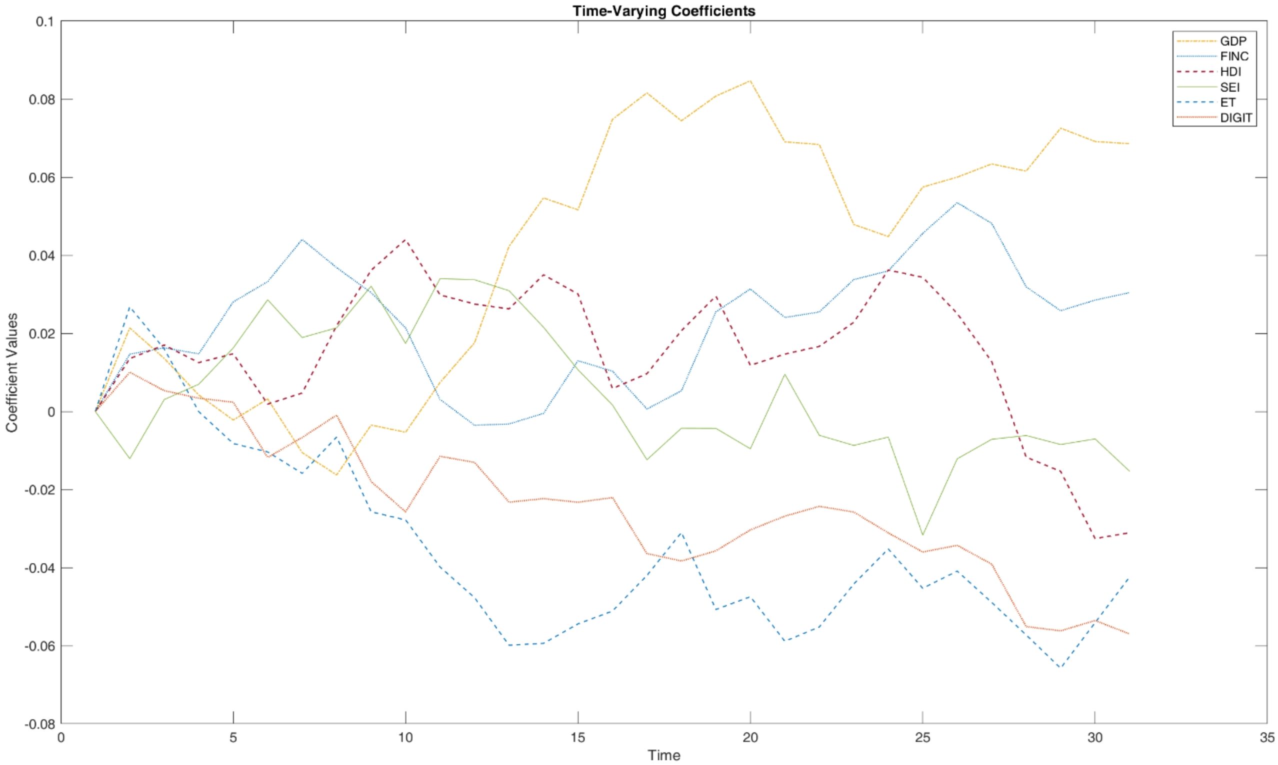
(b) Time-varying analysis of Qatar



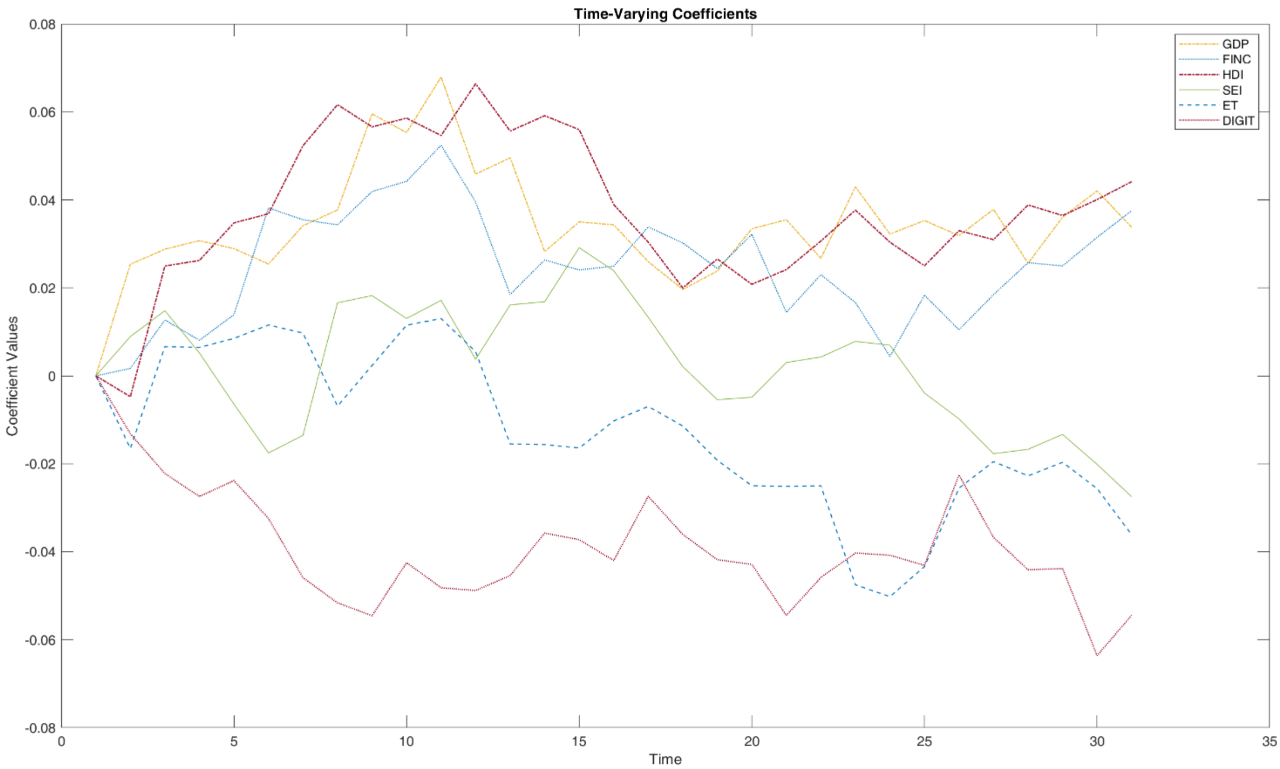
(c) Time-varying analysis of Oman



(d) Time-varying analysis of Kuwait



(e) Time-varying analysis of KSA



(f) Time-varying analysis of Bahrain

Figure 1. Time-varying analysis for GCC countries.

3.8. Analysis based on crisis

Moreover, we have used crisis-based analysis to confirm the findings, as reported in Table 10. For this reason, we have used the monthly data to enhance the data with the cut point 2014. We selected 2014 due to the oil crisis, which hit the economic indicators. During the pre-crisis period, we have witnessed the positive and significant impact of GDP and financial inclusion, whereas the other variables are insignificant. For post-crisis analysis, the coefficients of the GDP, financial inclusion, and human development index are positive and significant. On the contrary, socioeconomic and digitalization have significant coefficients, which mention that higher socioeconomic and digitalization refer to reduced environmental quality.

Table 10. Driscol-Kraay regression results for pre-crisis and post-crisis periods.

Variables	Pre-crisis (2014)	Post-crisis (2014)
GDP	1.638**	1.975***
FINC	0.941*	1.184**
HDI	0.670	1.580**
SEI	1.342	−1.227*
ET	0.117	0.928
DIGIT	0.384	−1.152**
Constant	23.748***	19.467***

Notes: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

3.9. Granger non-causality test

Table 11. Juodis, Karavias, and Sarafidis' (2021) Granger non-causality test [113].

Null Hypothesis	HPJ Wald Test	Coeff.
GDP to EFP	98.376	2.437***
EFP to GDP	125.537	1.647***
FINC to EFP	2439.436	1.437***
EFP to FINC	131.537	1.836***
HDI to EFP	153.637	2.648***
EFP to HDI	154.649	2.313***
SEI to EFP	175.439	−0.538***
EFP to SEI	189.574	0.341***
ET to EFP	111.547	−1.287***
EFP to ET	164.547	1.326***
DIGIT to EFP	193.437	−0.428***
EFP to DIGIT	238.637	0.839***

Notes: ***, **, and * represent the level of significance at 1%, 5%, and 10%, respectively.

The Granger non-causality test results in Table 11 demonstrate bidirectional causality between GDP and EFP, with significant coefficients (2.437*** and 1.647***). Financial inclusion and EFP also show bidirectional causality, with coefficients of 1.437*** and 1.836***. The human development index and EFP exhibit mutual causality, indicated by significant coefficients (2.648*** and 2.313***). The socioeconomic conditions index negatively impacts EFP (−0.538***), while EFP positively affects SEI (0.341***). Environmental technology reduces EFP (−1.287***) but is positively influenced by EFP (1.326***). Digitalization decreases EFP (−0.428***) and is positively impacted by EFP (0.839***). These results underscore the complex interdependencies between economic, social, and environmental factors in GCC countries. Figure 2 also presents the findings.

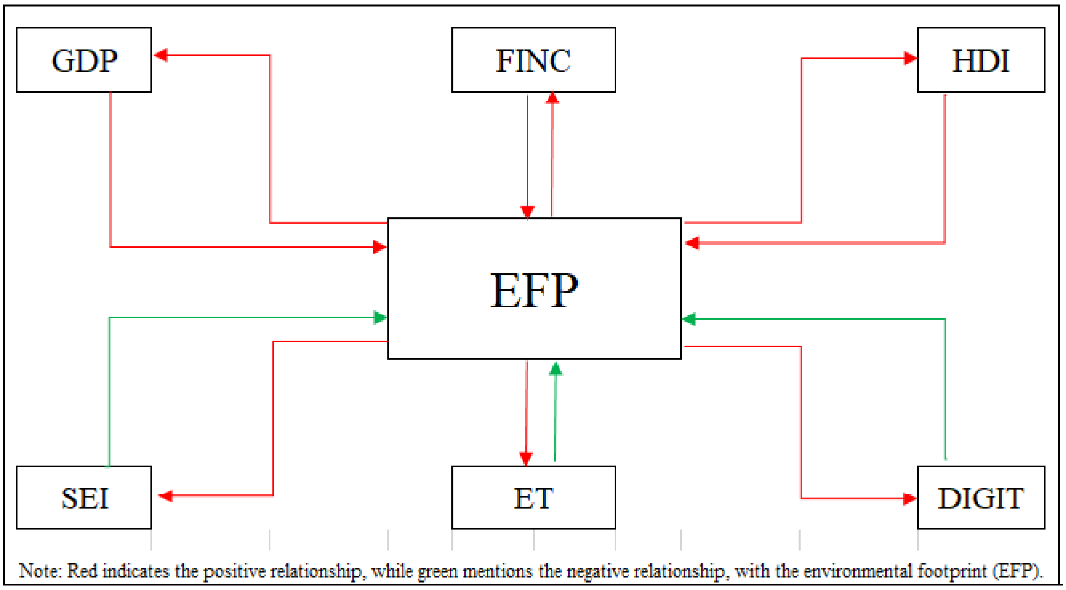


Figure 2. Graphical presentation of Juodis, Karavias, and Sarafidis' (2021) Granger non-causality test [113].

3.10. Discussion

This paper focuses on the impacts of economic, socioeconomic, and green growth on the ecological footprints of the GCC economies. The first model can be composed of economic growth and financial inclusion. Industrialization, which is a measure of economic growth, leads to the large consumption of industrial products, which pollutes the environment. For economic growth to be realized in a country, the country has to adhere to environmental standards. Therefore, it is clear that a country that is enjoying a high rate of economic growth has to pay a certain price, which in this case is the degradation of the environment. In addition, Hassan ST, et al [13,108] established that economic growth causes environmental pollution. The GCC countries are a perfect example of this relationship due to their high economic growth rate attributed to industrialization and high consumption levels. Industrial processes, especially in oil and gas companies, have negative impacts on the environment. Therefore, only the policies that promote economic development and, at the same time, reduce the negative influence on the environment should be adopted. Based on the evaluation of the results, financial development exerts a negative impact on the pressure for ecological sustainability, while economic institutions have a positive impact. These findings are in agreement with those of Sinha A, et al [114,115]. While enhancing economic activities, financial development results in the exploitation of resources and pollutes the environment; therefore, there is a need to integrate green financial instruments. The availability of green finance instruments, including green bonds, is a helpful strategy for advancing green growth, which means the synchronization of the financial industry's growth with ecological responsibility.

The human development index and ecological footprint have a positive and relatively large interaction coefficient. According to the Millennium Assessment of Ecosystems and Human Well-Being [116], when ecosystem changes increase human well-being, environmental quality is negatively affected. Human health and the environment are complexly connected since they are based on the effects of human actions on the environment. The GCC region has relatively high human development indices; however, the region's environment is under pressure due to urbanization and changes in people's lifestyles. The leading debate in the sustainability discussion has been to what extent ecological concerns can be traded for economic development and improvement of human well-being [117]. It is, therefore, important to prioritize goals in GCC nations for the implementation of a green environment. This result shows that the ecological footprint decreases as the socioeconomic condition index increases, implying that improved socioeconomic conditions, which are linked with sound institutions and governance, can help reduce the effects on the environment. It is recommended that the authorities should introduce significant changes in the structural and economic development to improve the quality of economic entities in the region. Further, the governments in the region need to apply sound socioeconomic measures to encourage organizations to spend money on the prevention of pollution or on the conservation of the environment [118]. It can also be observed that the betterment of the socioeconomic status can help to increase public consciousness and, therefore, the level of environmental responsibility of companies and citizens.

The green growth model reflected in the study's conclusion is positive and highly significant with the ecological footprint. Technological advancements in the environment allow industries to use the same resources and materials to produce more, thus improving the ecological impact. Energy efficiency in the energy industry is reduced through environmental technology, as indicated by [99]. The positive replacement effect over time has been higher than the negative cost and consumption effects, resulting in a small EFP. Digitalization and advancement in technology in the GCC, especially in renewable energy and resource-efficient technologies, are instrumental in this process. Many scholars agree with this statement and recommend that digitalization-based substitution significantly decreases pollution concentrations by improving energy efficiency, advancing technology, and developing resource expertise in their relevant industries [105,111]. This trend is especially significant in the GC, as technological advancement is vital in shifting to the right development model. The use of digital technologies in fields like production and services could greatly enhance the decrease of environmental pressures as well as continuing economic development.

4. Conclusion and policy implications

Our investigations look at the connections between economic factors, socioeconomic factors, and green growth factors as predictors of environmental quality in GCC economies for the period of 1990–2019. The current research uses different econometric tests including panel unit root, cointegration, and regression analysis to conclude that financial inclusion and economic expansion worsen the sustainability of the environment in GCC economies, increasing the ecological footprint intensity. In a similar direction, the human development index's long-term coefficient is unfavorable and highly correlated with ecological impact. Nevertheless, the socioeconomic conditions index in GCC economies negatively affects the ecological footprint. This means that socioeconomic institutions are improving the environmental quality in the long run. This research draws another conclusion that green growth factors, which include environmental technology and digitalization, contribute toward a sustainable environment.

The current study suggests several crucial recommendations to green planners and other regulators. We suggest macroeconomic, institutional, and financial measures to advance human progress and safeguard the environment. Importantly, decision-makers need to create certain plans to lessen the adverse effects of economic expansion on society. To maintain a healthy environment and economic growth simultaneously, they should additionally set precise environmental standards for local industrialists. The financial sector should be encouraged by policymakers to provide funding for green industrial growth. They should ensure that the other economic zones work together with the private financial sector as much as possible. Financial institutions should impose regulations on businesses for investing in ecologically sound activities to stop investments in obsolete technology from leaving a bigger ecological footprint.

The association of human development and ecological footprint underscores the difficulties present in the simultaneous goal of environmental sustainability and human development. Overall, we contend that the per-capita ecological footprint has a negative relationship with the economic institutions measured by the socioeconomic condition index. As a result, economic institutions may be useful tools for striking a balance between social welfare and environmental sustainability. According to this perspective, GCC nations must raise public awareness of grave ecological issues.

Industrial framework efficiency and the development of green technologies should play two key functions. The first role quickens the adoption of environmental technology in conventional sectors, investigates new avenues for green growth, and builds a digital mode on the needs and development traits of various industries. Industrial digitalization also directs the flow of production elements toward newly developing industries with features that optimize the environment and conserve resources. The second role quickly integrates digital technologies with clean technology, green manufacturing, and new energy development.

The study offers valuable insights into the intricate relationships between economic, socioeconomic, and green growth factors as determinants of environmental quality in GCC economies. However, like all empirical research, it is not without its limitations, which subsequently pave the way for future research directions. First, the study's temporal scope, from 1990 to 2019, may not capture the most recent shifts in environmental dynamics, especially given the rapid technological and policy changes in the last few years. While this period provides a comprehensive overview, it might miss out on the nuances of the post-2019 era, especially in light of global events such as the COVID-19 pandemic, which has had profound implications for economic and environmental paradigms.

Second, the reliance on specific econometric tests, while rigorous, might only encapsulate some of the spectrum of relationships between the variables. Econometric models are based on assumptions that might not always hold in real-world scenarios. For instance, the assumption of linearity in regression analysis might need to be more accurate in explaining complex, non-linear relationships between economic expansion and environmental sustainability. Furthermore, the study's focus on GCC economies, while providing depth, might limit the generalizability of the findings. The unique socio-political and economic structures of GCC countries might mean that the results are not directly applicable to other regions with different institutional and economic frameworks. The negative correlation observed between the human development index and ecological impact, while intriguing, raises questions about the specific components of the index that drive this relationship. The human development index is a composite measure, and disentangling its components might provide a clearer picture of the underlying dynamics.

4.1. Limitations

The study has the following limitations that need to be admitted. First, we understand that the application of a large number of factors can hide the differences within particular countries and local peculiarities that can remain a great influence on the ecological footprint. Some of the countries of the GCC might have a different pattern of distribution; this can influence the heterogeneity of the environment not considered in this study. Second, the analysis is limited to the available historical data, meaning that trends and conditions that might be developing in the future and can greatly influence the economic and environmental policies or even their very existence are not considered in the process. Further, the generalizability of the study findings could be restricted since the research has targeted only the GCC countries, which have relatively distinct economic characteristics and environmental problems compared to other nations. The high relative measures in these indicators in the GCC could, however, not accurately depict the position in other more diverse economies, given the region’s rather unique economic reliance on oil and gas. Further, the models applied might be rather insensitive to the potential endogeneity problem or the existence of the omitted variables affecting the analyzed relationships between economic growth, financial development, and ecology. One of the issues follows from the third assumption, which assumes homogeneity in the long-run relationship across countries within the GCC, while, in actuality, the development and policies are implemented differently in different countries. Finally, the paper does not uncover the ‘‘black box’’ revealing dynamic causal relationships between the investigated economic, socioeconomic, and green growth indicators and ecological footprints, and further research will be needed to map out how these variables interplay with each other.

4.2. Future research directions

Future research could expand the temporal and spatial scope of the study. Incorporating data from the post-2019 era and comparing GCC economies with other regions might offer a more holistic understanding of the determinants of environmental quality. Additionally, employing alternative econometric models or machine learning techniques could unearth non-linear relationships or interactions between variables that traditional models might overlook. Another promising avenue is a deeper dive into the role of socioeconomic institutions. Given their observed positive impact on environmental quality, a sectoral analysis could elucidate which institutions or policies are the most effective in promoting sustainability. Lastly, while the study highlights the positive role of green growth factors, a more granular analysis of environmental technology and digitalization's specific aspects could be beneficial. Understanding which technologies or digital initiatives have the most significant impact can guide policymakers and stakeholders in their sustainability endeavors. In conclusion, while the study sheds light on crucial aspects of environmental sustainability in GCC economies, there remain many avenues for future research to explore, refine, and expand upon these findings.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors have declared that no competing interest exists.

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