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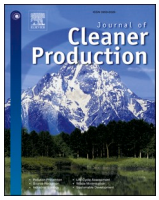

Environmental role of technology, income, globalization, and political stability: Testing the LCC hypothesis for the GCC countries

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ABSTRACT

The importance of non-economic factors for the environment is increasing day by day. ICT, globalization, and political stability (PS) are becoming more and more important in environmental policymaking. However, their impact on the environment has not yet been addressed in the literature for the GCC countries. Therefore, the study focuses on the analysis of the impact of mobile cellular subscriptions and internet usage, two different ICT indicators, as well as income, globalization, and PS on environmental quality (EQ). The study considers a total of six GCC countries from 2000 to 2019, applies the augmented mean group approach at both panel and country levels, and tests the validity of the load capacity curve (LCC) hypothesis. The results show that (i) ICT contributes to the development of EQ; (ii) globalization and PS reduce EQ; (iii) income has no significant impact; (iv) the LCC hypothesis is not valid for the GCC panel, while it is valid in Qatar; (v) the results vary at the country level with regard to the panel level. The study recommends that GCC countries should make more use of the positive aspects of ICT in addressing environmental issues and promoting green digitalization to develop EQ; and work to transform their high-income into an eco-friendly structure so that the progress of EQ can be supported by the income; benefit from globalization to import green products and technologies that can help increase EQ; and use the PS to make eco-friendly decisions.

1. Introduction

Over the years, countries have made efforts to achieve higher economic growth. The desire of countries to offer citizens a better standard of living and to make the economy sustainable is directly related to this trend (Kartal et al., 2023a). Economic issues are therefore at the top of the agenda for political decision-makers.

Since the Industrial Revolution, countries have had an economic focus. However, the exclusive focus on the economic side has a significant flaw, which is the main reason why the world is struggling with climate-related environmental problems (Pata et al., 2023a). Environmental degradation, extreme weather conditions, and climate change are the most well-known and impactful problems that humanity has experienced (Naderipour et al., 2021). In this context, various initiatives and efforts, such as the sustainable development goals, COP meetings, the Paris Agreement, and the Kyoto Protocol have been put into effect. The aim is to reduce the anthropogenic impact on the EQ. Nevertheless, the negative progress in environmental degradation continues and there is still a long way to go.

Climate-related problems can be attributed to various factors. According to Grossman and Krueger (1991), there is a strong nexus between income and environmental degradation, known as the EKC hypothesis. Consequently, the studies have investigated the link between income and environmental degradation. In addition, the studies

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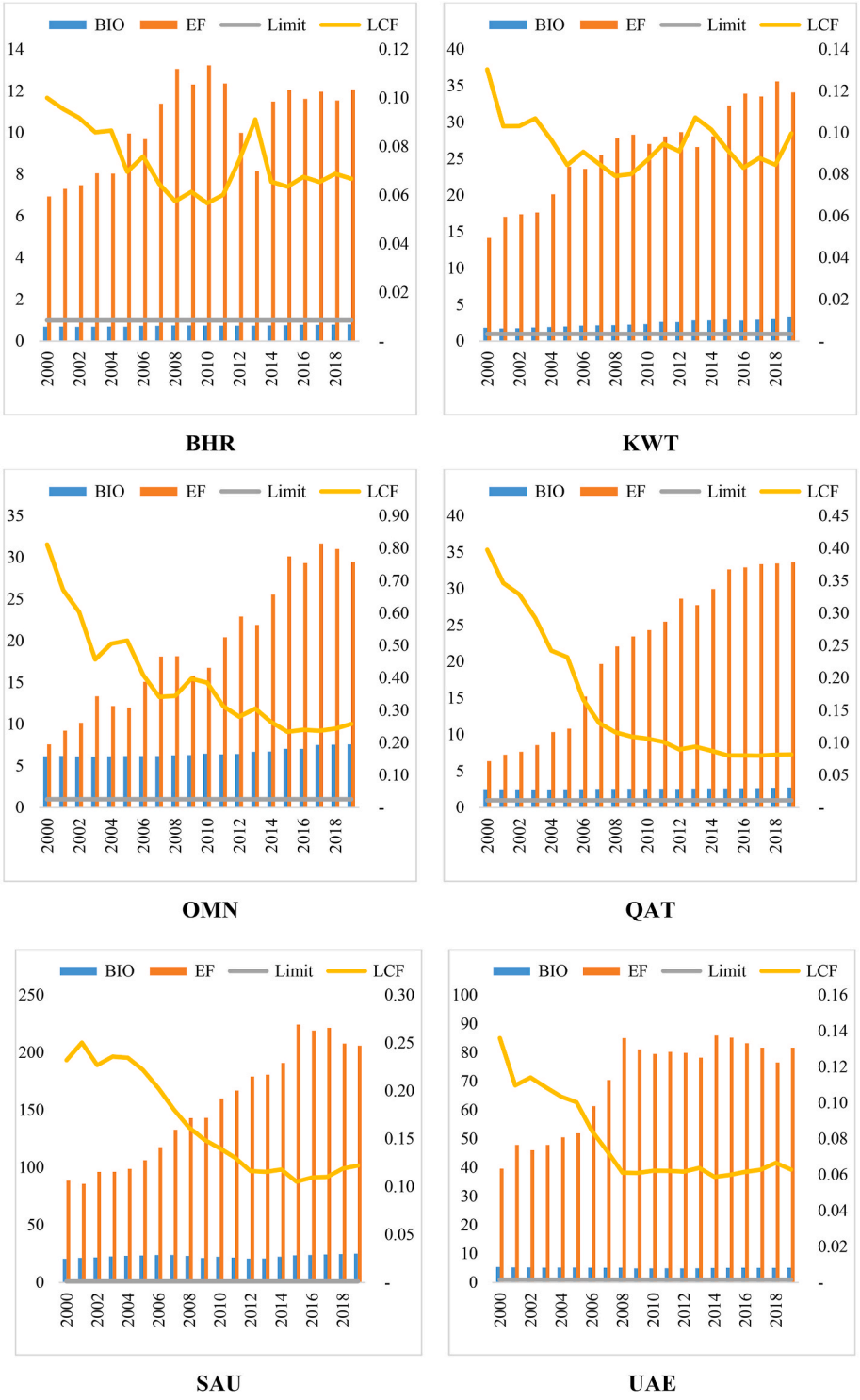
have analyzed the link between energy use and the environment after the energy-led growth hypothesis (Kraft and Kraft, 1978; Apergis and Tang, 2013). Accordingly, income and energy use have been considered as the main drivers in the study of EQ in various countries (e.g., Kartal and Pata, 2023).

Recent studies have taken various factors into account. Among others, the role of globalization, PS, and ICT have evolved. The impact of GLB on EQ has increased as the world has become a global village and countries engage in extensive foreign trade with each other. PS can also have either a positive or negative impact on EQ (Kılıç Depren et al., 2023). Moreover, the recent development in ICT can be highly effective on EQ. Therefore, recent literature has developed based on such factors.



Note: Unit for BIO and EF is million global hectares. LCF values are shown on the right axis of the graphs.

Fig. 1. Progress of EQ in the GCC Countries
Note: Unit for BIO and EF is million global hectares. LCF values are shown on the right axis of the graphs.
Source: GFN (2023)

In the literature, earlier studies mainly considered CO_2 emissions as an environmental indicator (e.g., Magazzino and Mele, 2022; Kartal et al., 2023b; Magazzino et al., 2023). Later studies have used the EF for environmental degradation (e.g., Pata et al., 2023b; Magazzino, 2024). Following the theoretical background of Siche et al. (2010), recent studies have handled the environment from the quality perspective rather than degradation by using LCF as a proxy. In addition, based on the proposed study by Pata and Kartal (2023), recent studies have tested the LCC hypothesis, which investigates the rising influence of income on EQ.

The countries studied can be categorized into different groups based on various criteria, such as level of development, geographical location, economic union, high CO_2 emissions, and use of different types of energy (i.e., renewable energy, nuclear energy, solar energy, wind power). Some of the countries, especially those with high fossil fuel consumption, are in a more critical position to achieve the COP26 targets, which aim to reduce fossil fuel consumption as much as possible. In this context, GCC countries have come to the fore because they have consumed large amounts of fossil energy to sustain economic growth, resulting in high CO_2 emissions and a significant decline in EQ. Therefore, GCC countries deserve a special interest in the study of EQ considering the recent developments in the literature. Fig. 1 presents the progress of EQ in the GCC countries.

In Fig. 1, the sustainable EQ is implied by the critical value of "1″ for LCF. From this perspective, no GCC country has achieved a sustainable EQ since 2000. Of all countries, the UAE has the worst EQ compared to other countries. Moreover, all GCC countries have a fairly high EF (for the demand side) with regard to BIO (for the supply side). Consequently, there is a significant ecological deficit in all GCC countries. This condition requires the GCC countries to take measures to develop EQ.

In the contemporary literature, some studies have analyzed the GCC countries (e.g., Bekhet et al., 2017; Mahmood, 2022; Mahmood et al., 2022; Ulussever et al., 2023). However, these studies have some shortcomings, such as the fact that they mainly rely on traditional factors, do not consider recently emerged factors (i.e., GLB, PS, and ICT), and mainly use environmental degradation indicators (i.e., CO_2 & EF) instead of EQ indicators (i.e., LCF). Thus, there is a gap in the literature and new studies can fill this gap by considering the above points when examining EQ in the GCC countries.

Taking into account the literature gap as well as the leading position in high fossil fuel energy use, which is highly important to ensure EQ is in line with the COP26 targets, the study comprehensively examines the GCC countries. Therefore, the study aims to answer the research question of how both traditional (i.e., income) and emerging (i.e., GLB, PS, and ICT) factors affect the EQ in the GCC countries. In search of answers, the study performs the AMG approach at both panel and country levels for the period 2000–2019, which is the most recent intersect dataset. In this way, the study researches the impact of critical factors on EQ in the GCC countries. In summary, the study presents that ICT helps the development of EQ; GLB, and PS decrease EQ; income has no significant impact. The outcomes also indicate that the LCC hypothesis is not valid, and the results vary at country level. Thus, the results underline the significance of ICT in ensuring EQ in the GCC countries.

By applying a comprehensive conceptual and empirical approach, the study provides the following contributions; (i) The study analyzes the GCC countries by using LCF as an EQ indicator for the first time. Although there are various studies in the literature (e.g., Bekhet et al., 2017; Mahmood, 2022; Mahmood et al., 2022; Ulussever et al., 2023), no study has used the LCF to proxy the EQ based on the best knowledge; (ii) the study is the first to test the validity of the LCC hypothesis for the GCC countries; (iii) the study considers both traditional (i.e., income) and emerging (i.e., GLB, PS, & ICT) factors simultaneously for a comprehensive and meaningful empirical analysis. Thus, the study presents new insights for the GCC countries.

Part 2 presents the conceptual framework and gives an overview of the literature; Part 3 details the methods; Part 4 demonstrates the results; and Section 5 concludes.

2. Conceptual framework and literature review

As a leading study, Grossman and Krueger (1991) propose the EKC hypothesis, which implies the U-shaped nexus between income and environmental degradation. Based on this hypothesis, a large number of studies have investigated the impact of income on the environment. While some of these studies have defined the nexus between income and environment by validating the EKC hypothesis for some countries, some others cannot verify it. Although the EKC hypothesis has been very popular (Magazzino et al., 2020), it has a crucial shortcoming in that it only considers environmental degradation (demand side) and ignores the biocapacity of nature (supply side). Therefore, Siche et al. (2010) propose the LCF that comprehensively represents the progress of the environment by considering two sides simultaneously. In addition, Pata and Kartal (2023) develop the LCC hypothesis based on the LCF, which uncovers the nexus between income and EQ. Accordingly, many recent studies (e.g., Yang et al., 2023; Sun et al., 2024) have used the LCF as an environmental indicator and tested the LCC hypothesis in examining EQ for different scopes.

The literature has evolved to include non-economic factors, such as the digital economy, financial development, clean technologies, foreign direct investment, financial innovation, and green finance (Alshubiri, 2022; Alshubiri et al., 2023; Alshubiri and Al Ani, 2024). Of all of them, GLB, PS, and ICT can be described as the most recent ones.

As the world is becoming more globalized by the day, it is a must to take the impact of GLB on the environment into consideration. Balsalobre-Lorente et al. (2020) investigate OECD countries and conclude that GLB has a curbing impact on tourism-related CO_2 emissions. Aluko et al. (2021) analyze a set of selected 27 industrialized countries and state that GLB has a curbing impact on ecological degradation. Similarly, Thair et al. (2021) determine the controlling impact of GLB on CO_2 emissions in South Asian economies. However, Ghosh (2018) uncovers the selected 29 countries across various income levels and defines the non-causative impact of GLB on ecological degradation. Similarly, Destek (2020) defines the stimulating impact of GLB on CO_2 emissions in European countries. Aydın et al. (2024) examine ten European Union countries and note that GLB reduces LCF for Austria. The impact of GLB on the environment is therefore not certain.

PS is a factor that has recently been considered in the study of ecological progress. Ashraf (2022), for instance, analyzes 75 OBOR countries and concludes that PS reduces EF. Kartal et al. (2024) also define the curbing impact of PS on CO_2 emissions in the Netherlands. Some studies have similarly defined the declining impact of PS on environmental degradation, such as Muhammad and Long (2021) for 65 OBOR countries, Jiang et al. (2022) for G7 countries, Khan et al. (2022) for Morocco, Sohail et al. (2022) for Pakistan, and Yu et al. (2023) for the ten highest emitting nations. However, some studies conclude that PS has an increasing impact on ecological degradation, such as Su et al. (2021) for Brazil and Awosusi et al. (2022) for BRICS. The impact of PS on the environment is therefore not uniform and further research is needed.

ICT can be another factor to consider in environmental management. ICT can curb environmental degradation by enabling faster communication among the parties involved to ensure a better environmental management system. Therefore, it can help to make eco-friendly decisions. N'dri et al. (2021) define ICT as eco-friendly for some countries without affecting high-income developing countries. Appiah-Otoo et al. (2023) specify that ICT has a curbing (increasing) impact on CO_2 emissions when 110 countries have a high (low) level of ICT. Pata et al. (2023c) determine the supporting role of ICT in ensuring the energy transition from fossil to clean energy in Germany. Qayyum et al. (2024) also define the contribution of ICT to the mitigation of EF for the MERCOSUR nations. However, there is also a reverse finding in the literature. Asongu et al. (2018) conclude that ICT does not curb CO_2

emissions in Sub-Saharan Africa. Avom et al. (2020) define that ICT stimulates CO_2 emissions in 21 Sub-Saharan African countries. The influence of ICT on the environment can be seen in a mixed way. Therefore, new research is needed to investigate the impact of ICT on the environment in different countries.

In summary, the above literature review shows that the available studies have used different countries and groups of countries (e.g., OECD, Germany, and Sub-Saharan Africa) for empirical investigations. In the case of the GCC countries, there are also some studies (e.g., Bekhet et al., 2017; Mahmood, 2022; Mahmood et al., 2022; Ulussever et al., 2023). These studies on the GCC countries have mainly relied on traditional factors (e.g., income, energy use, financial development, urbanization, & energy prices) in their empirical analyses. In addition, these studies have generally used CO_2 emissions as an indicator of environmental degradation. In contrast to these studies, this study considers a range of traditional (i.e., income) and newer factors (i.e., GLB, PS, and ICT) when examining EQ in the GCC countries. Moreover, this study uses LCF as an EQ indicator instead of CO_2 emissions and EF, which are degradation-based indicators, allowing researchers to consider the demand and supply sides simultaneously. Therefore, this study provides novel insights into the EQ of GCC countries.

3. Methods

3.1. Data

This study analyzes the environmental role of income, GLB, PS, and ICT on EQ under the LCC hypothesis. In this context, the study uncovers the GCC countries. Since there is a data limitation for the Bahrain case, the period of the study has to be set to 20 years from 2000 to 2019. In line with the aim, the study uses Eq. (1):

$$ln\ LCF_t = \vartheta_0 + \vartheta_1 lnGDP_t + \vartheta_2\ ln\ GDP_t^2 + \vartheta_3 lnGLB_t + \vartheta_4 lnPRI_t + \vartheta_5 lnMOB_t + \vartheta_6 lnINT_t + e_t \quad (1)$$

Pata and Kartal (2023) propose the LCC hypothesis to unveil the U-shaped link between income and EQ. For the LCC hypothesis to be valid, it is expected that ϑ_1, which represents the coefficient of economic growth, is negative, ϑ_2 is positive, and both coefficients are statistically significant. The LCC hypothesis is shown visually in Fig. 2.

Fig. 2 shows that as the economy grows, human pressure on air, water, and land initially increases, causing ecological quality to decline. However, after the turning point, people prefer a greener and healthier life, and in this case, higher income plays a role in increasing the LCF. In such a case, the validity of the LCC hypothesis suggests that civilizational progress ultimately benefits the environment.

GLB can lead to the dirty production process spreading between countries (Pata et al., 2023a), but effective technologies provided by foreign companies under the GLB process can help save energy and thus reduce degradation. Therefore, ϑ_3 can be either positive or negative.

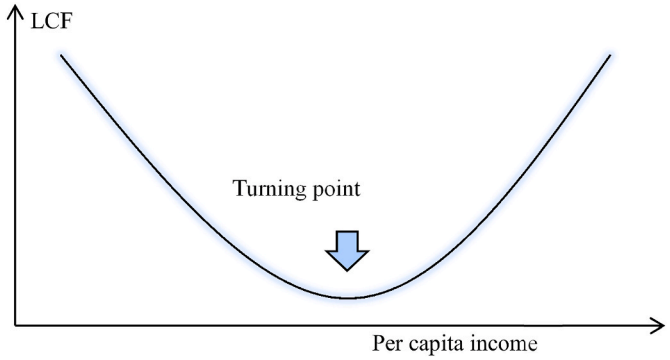


Fig. 2. LCC hypothesis.
Source: Pata et al. (2023d).

The PRI also indicates the political risk index. A higher PRI value denotes a lower political risk, while a lower PRI value implies a higher political risk. ϑ_4 is expected to be negative, as a high political risk can increase CO_2 emissions (Hassan et al., 2022) and EF (Wang et al., 2023).

ϑ_5 and ϑ_6 can take a positive value, as mobile cellular subscriptions and internet usage, which are indicators of digitalization and ICT, can reduce EF (Kahouli et al., 2022; Kartal et al., 2023a, b).

The data on the LCF is gathered from the GFN (2023). The data for GDP, MOB, and INT are collected from WB (2023). The data for PRI is obtained from the Political Risk Services Group (2023), while the data for GLB is taken from Gygli et al. (2019). Table 1 presents the details of all variables used in the study.

Fig. 3 presents the development of the variables over the years.

Fig. 3 shows that the PRI of the GCC countries follows a fluctuating course. The GCC countries are countries that pose a considerable political risk due to their oil reserves, as can be seen from the fluctuating course of the PRI. The GCC countries have experienced significant development in MOB and INT. In terms of GDP, Bahrain and Oman have a stable and slow growth rate compared to the other countries. The fact that the LCF score is below 1 in all GCC countries indicates that the environmental problems in these countries are very severe. Are technological progress and ICT development a solution to the environmental problems of the GCC countries? This study aims to search for answers to these questions. The expected sign of the variables used in the analysis of this study is shown in Fig. 4.

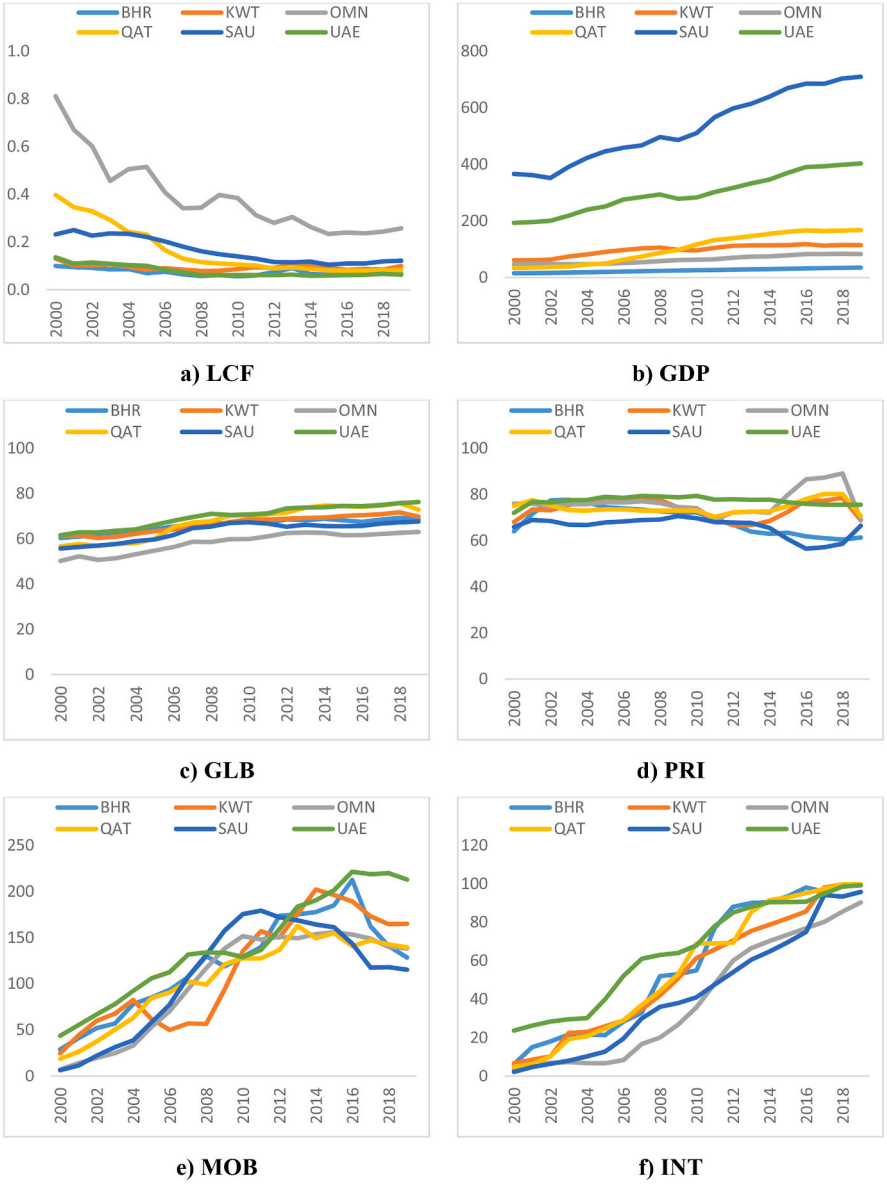
3.2. Empirical approaches

The study applies a four-stage empirical strategy, and these stages are symbolized in Fig. 5.

First, the study analyzes the presence of CSD. The GCC countries have very close economic and political ties. The GCC was founded in 1981 and has set itself goals such as the common market and the common monetary union. The GCC represents a rare institutionalized cooperation among Middle Eastern countries where political unrest prevails (Al-Saidi, 2021). However, the political differences of the GCC countries and the 2008 crisis have complicated the implementation of the monetary union (Ganguli, 2016). The GCC members are major natural gas and oil-producing countries, and it is claimed that they are the main actors hindering climate change negotiations (Reiche, 2010). The environmental problems of the GCC continue to increase and to prevent this, the GCC countries, which are located in the same geography and share common borders, need to take precautions together. CSD should be considered in these measures because the GCC countries are economically, politically, and culturally interconnected. Ignoring this strong interaction may lead to discrepancies in the results of the panel data analysis. For this reason, the study uses Pesaran's (2004) CD test and Pesaran's (2015) weak CD test. The null hypothesis of both tests is that the panel data does not contain CSD.

Table 1
Data definition.

Symbol	Definition (Details)	Source
LCF	Load capacity factor (BIO/EF, global hectares)	GFN (2023)
GDP	Gross domestic product (per capita 2015 constant USD)	WB (2023)
GLB	KOF globalization index (An index with values between 0 and 100 that includes economic, political, and social globalization)	Gygli et al. (2019)
PRI	Political risk index (An index with values between 0 and 100 that includes various sub-indicators)	Political Risk Services Group (2023)
MOB	Mobile cellular subscriptions (per 100 people)	WB (2023)
INT	Individuals using the Internet (% of the population)	WB (2023)



Note: Unit for GDP, GLB, PRI, MOB, and INT is billion USD, index value, basis point, mobile cellular subscriptions per 100 people, and individual using the internet (% of the population), in order.

Fig. 3. Progress of Income, GLB, PS, and ICT in the GCC Countries
Note: Unit for GDP, GLB, PRI, MOB, and INT is billion USD, index value, basis point, mobile cellular subscriptions per 100 people, and individual using the internet (% of the population), in order.
Source: GFN (2023)

In the second phase, the study uses the CIPS unit root test by Pesaran (2007). The CIPS unit root test first calculates the t-statistics using Eq. (2) for each cross-section.

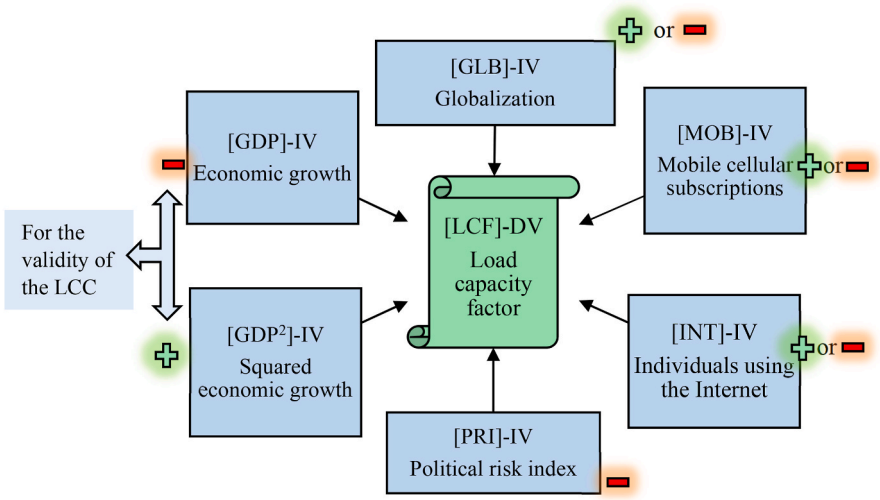
$$\Delta LCF_{it} = \beta_i + \delta_i LCF_{it\text{-}1} + \sigma_i \overline{LCF}_{t\text{-}1} + \sum_{l=0}^{p} \tau_{ij} \Delta \overline{LCF}_{it\text{-}1} + \sum_{l=1}^{p} \varphi_{ij} LCF_{it\text{-}1} + w_{it} \quad (2)$$

where β_i is individual intercepts, l is the lag length. The test statistic can be examined for each cross-section by calculating the t-statistics from β_i. Then, the t-statistics are averaged to measure the CIPS test statistic as in Eq. (3).

$$CIPS = N^{-1} \sum_{l=1}^{p} t_i(N, T) \quad (3)$$

where N denotes the number of observations and CIPS shows the averaged unit root test statistic. If the calculated test statistic is greater in absolute value than the critical value of Pesaran (2007), it is determined that the series is stationary.

In the third phase, the study uses the panel cointegration test according to the error correction model (ECM) by Westerlund (2007). The ECM approach focuses on four different test statistics: Group mean statistics (Ga & Gt) and pooled panel statistics (Pa & Pt). The ECM test offers advantages in practice as it controls endogeneity and has strong statistical properties compared to dynamic cointegration tests (Altıntaş and Kassouri, 2020; Li et al., 2023). The regression model constructed for the ECM panel cointegration approach can be given in Eq. (4).



Note: IV and DV denote the independent and dependent variables, in order.

Fig. 4. The Variables Used in the Empirical Analysis and Their Expected Sign
Note: IV and DV denote the independent and dependent variables, in order.

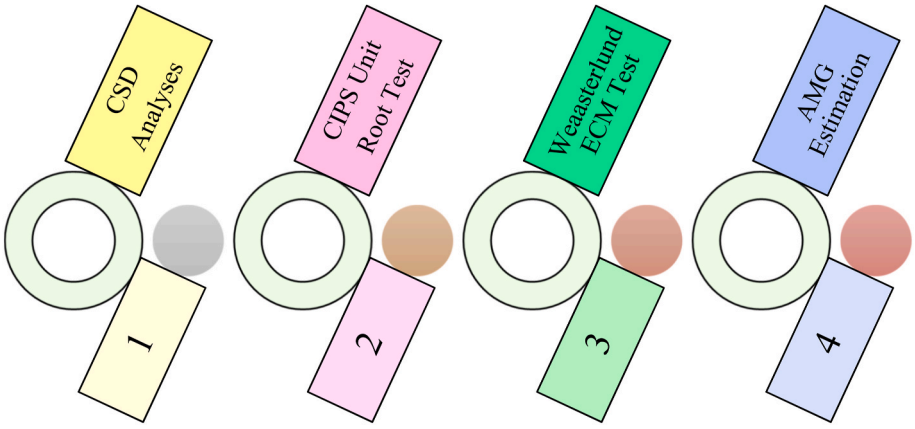


Fig. 5. Empirical process.

$$\Delta Y_{it} = \alpha_i' d_t + \pi_i \left(Y_{it-1} - \beta_i' X_{it-1}\right) + \sum_{j=1}^{p_i} \pi_{ij} \Delta Y_{it-j} + \sum_{j=-p_i}^{p_i} Y_{ij} \Delta X_{it-j} + \varepsilon_{it} \quad (4)$$

where d_t comprises the deterministic factors (i.e., intercept & trend for all cross sections), and $\alpha_i' = (\alpha_{1i}, \alpha_{2i})'$ shows the vector of the parameters. In the application of the ECM test, the null hypothesis H_0: $\alpha_i = 0$ is tested against the alternative hypothesis H_1: $\alpha_i = \alpha < 0$. By rejecting the null hypothesis, it can be determined that the entire panel is cointegrated.

In the final phase, the study performs the AMG estimator. Eberhardt and Teal (2010) proposed the AMG estimator to examine long-run associations between variables in a panel as a whole or a specific country in the sample panel. The AMG estimator improves the regression model with dummies as in Eq. (4):

$$\Delta Y_{it} = \beta' \Delta X_{it} + \sum_{t=2}^{T} v_t \Delta D_t + u_{it}, \widehat{c}_t \equiv \widehat{\mu}_t^{\bullet} \quad (4)$$

where v denotes the coefficient of the dummies. Then, β_{AMG}' estimator is constructed by converting v_t to $\widehat{\mu}_t^{\bullet}$ as in Eq. (5):

$$Y_{it} = \delta_i + \beta_i' X_{it} + \rho_i t + d_i \widehat{\mu}_t^{\bullet} + v_{it}, \beta_{AMG}' = N^{-1} \sum_i \widehat{\beta}_i \quad (5)$$

By adding a unit coefficient to each cross-section and considering the CSD, the AMG strengthens the estimation and provides effective results.

All these approaches used in the study are defined according to the characteristics of the GCC countries. The GCC countries have close economic and cultural ties with each other, so an economic shock in these countries is likely to have an impact on the other countries. Therefore, the study considers CSD and hence the impact of shocks on the analysis. Since the GCC countries belong together geographically and have a similar cultural structure, examining this group of countries with a panel data analysis is more suitable for cross-country collaboration. In this context, the AMG and AMG-I estimators can provide effective outputs for the environmental policies of the GCC countries by taking the CSD into account.

4. Empirical results

Table 2 illustrates that GDP has the highest mean value. INT has the lowest mean value. INT is the variable with the highest standard deviation, which shows that Internet use is highly volatile. The values for skewness and kurtosis show that PRI and MOB do not have a normal distribution.

Table 3 reports the outcomes of the CSD tests. The results of

Table 2
Descriptive statistics.

	Mean	Std. dev.	Min	Max	Skewness	Kurtosis
lnGDP	10.312	0.4636	9.652	11.204	0.472	1.769
lnGLB	4.174	0.0928	3.916	4.333	−0.543	2.967
lnPRI	4.283	0.0826	4.034	4.489	−0.679	3.714
lnMOB	4.559	0.7351	1.854	5.399	−1.508	5.077
lnINT	3.639	0.9463	0.793	4.602	−0.968	2.926

Table 3
CD test results.

	CD Test	*p − value*	*Weak CD Test*	*p − value*
lnLCF	12.878*	0.000	17.010*	0.000
lnGDP	−1.921***	0.055	17.318*	0.000
lnGLB	16.741*	0.000	17.320*	0.000
lnPRI	1.393	0.164	17.317*	0.000
lnMOB	15.978*	0.000	17.248*	0.000
lnINT	16.804*	0.000	17.187*	0.000

Notes: * and *** denote the significance at 1% and 10% levels, respectively.

Pesaran's (2004) test show that other variables, except for PS, include CSD. The results of Pesaran (2015) indicate that all variables include CSD. Therefore, any shocks in the GCC countries can affect other countries.

Table 4 shows the results of the unit root tests. According to the CIPS unit root test, all series contain unit roots at their levels. The first difference values of the series have a stationary structure. Thus, all variables are determined as difference-stationary I(1).

After determining the degree of integration of the variables as I(1), the study uses the panel ECM cointegration test to analyze the long-term relationships and presents the results in Table 5.

The results of the panel ECM test show that there is cointegration at the 5% significance level for three of the four test statistics. In other words, LCF, GDP, GLB, PRI, MOB, and INT are cointegrated. Table 6 reports the results of the AMG approach.

The coefficients for GDP and squared GDP are negative and therefore the LCC hypothesis is not valid. For the GCC countries, GLB and increased political risk play a role as environmental aggravators. A 1% upsurge in GLB and PRI reduces the LCF by 1.75% and 0.60% respectively.

Following Atasoy (2017), the study employs the panel AMG-I estimation in which each cross-section is imposed a unit coefficient to test robustness. The AMG-I results are presented in Table 7.

The results in Table 7 exactly confirm the results of the AMG approach. The invalidity of the LCC hypothesis for the entire panel suggests that income is not an automatic compensating factor for overcoming the environmental problems of the GCC countries. The economic expansion of the GCC countries is not an effective policy instrument for the EF and BIO. This is because the increase in income of the GCC countries is not a statistically significant element that can increase the LCF. This is consistent with the outcomes of Pata et al. (2023d).

GLB increases the pressure on the environment in the GCC countries. In the process of GLB, GCC countries engage in more polluting activities

Table 4
CIPS results.

	Level	First difference
lnLCF	−2.679	−4.380*
lnGDP	−1.693	−2.831***
lnGLB	−2.494	−4.200*
lnPRI	−2.113	−3.723*
lnMOB	−1.520	−3.193*
lnINT	−2.520	−3.659*

Notes: * and *** denote the significance at 1% and 10% levels, respectively.

Table 5
Panel ECM cointegration results.

	Value	z-value	p-value
Gt	−3.423**	−2.394	0.020
Ga	−6.404**	2.189	0.030
Pt	−5.543	−0.282	0.090
Pa	−5.802**	1.176	0.050

Notes: ** shows the rejection of the no-cointegration.

Table 6
Panel AMG estimation results.

	Coefficient	Std. error	p-value
lnGDP	56.092	69.562	0.420
$lnGDP^2$	−2.919	3.540	0.410
lnGLB	−1.753**	0.878	0.046
lnPRI	−0.600***	0.316	0.058
lnMOB	0.147*	0.553	0.008
lnINT	0.145**	0.060	0.016
C	−0.261	340.00	0.442

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

Table 7
Panel AMG-I estimation results.

	Coefficient	Std. error	p-value
lnGDP	33.694	60.410	0.577
$lnGDP^2$	−1.777	3.083	0.564
lnGLB	−1.721**	0.802	0.032
lnPRI	−0.566**	0.280	0.044
lnMOB	0.147**	0.071	0.039
lnINT	0.148**	0.060	0.013
C	−151.690	293.746	0.606

Note: ** denotes the significance at the 5% level.

and increase oil production and use to meet the oil needs of other countries around the world and increase oil exports. As a result, the increase in fossil fuel consumption leads to an increase in the carbon footprint. In addition, GCC countries are polluting land and fishing areas due to the development and industrialization associated with GLB. All these factors lead to a decrease in the LCF. These findings are consistent with Pata et al. (2023a), who confirm that GLB is detrimental to the LCF.

According to the results, increased political risk has a decreasing impact on the LCF. The number of studies investigating the impacts of country-specific political risk on the LCF is limited. Kılıç Depren et al. (2024) find that country-specific PS is a factor that improves LCF, and these results are similar to the current study. If a country is politically stable, it has greater scope to make environmentally friendly investments. As the country moves away from political instability, long-term environmental plans can be made with a team of experts, which can have a positive impact on LCF development.

INT and MOB have advantages for environmental quality according to the results for the GCC countries. Dogan and Pata (2022) conduct the first study to examine the impact of ICT on the LCF and find that the increase in mobile cellular subscriptions upsurges the LCF in the G7 countries. The rise of ICT can increase the LCF by supporting the development of environmentally friendly technologies and practices. ICT can reduce the ecological impact on humanity through features such as the development of smart applications and more effective use of energy. In addition, e-commerce and e-conferencing can increase the LCF thanks to ICT by enabling people to leave a smaller land footprint. In this context, GCC countries should incorporate ICT elements into their environmental policies.

Finally, the study conducts a country-specific panel AMG analysis and reports its results in Table 8. According to the country-specific results, the LCC hypothesis is only valid for Qatar. GLB reduces LCF in

Table 8
Country-specific AMG estimation results.

	BHR	KWT	OMN	QAT	SAU	UAE
lnGDP	126.187	3.225	−74.189	−58.234**	327.521*	−11.225
$lnGDP^2$	−6.263	−0.161	3.797	2.628**	−16.814*	0.536
lnGLB	0.569	0.690	0.179	−2.405*	−4.521*	−2.493***
lnPRI	−0.624**	−1.026*	−0.265	0.526***	−0.728	−1.682*
lnMOB	0.326**	0.004	−0.001	0.139	0.092	0.276***
lnINT	0.325*	0.261**	−0.018	−0.019	0.346*	0.107
C	−639.280	−17.170	362.493	328.55**	−1575.586*	72.633

Notes: * and *** denote the significance at 1% and 10% levels, respectively.

Qatar, Saudi Arabia, and the UAE. The political risk decreases LCF in Bahrain, Kuwait, and the UAE, while it increases it in Qatar. Taken together, the ICT indicators support the development of LCF in Bahrain, Kuwait, Saudi Arabia, and the UAE. The country-specific results show that ICT is a key indicator and policy tool to increase LCF in the GCC countries.

5. Conclusion, policy implications, and future research

5.1. Conclusion

In line with the increasing negative impacts on humankind, countries have been much more interested in climate-related environmental problems. As a result of collaborative efforts around the world, countries have been trying to determine the critical roles of various factors as well as searching for solutions ways to combat climate change. Among all factors, income and energy use have a certain impact on the progress of environmental degradation. However, it is important to develop ecological quality. Hence, focusing on only demand (degradation) side and ignoring the supply (biocapacity) side is a wrong approach. In harmony with the developing literature, many recent studies have used LCF to make a much more comprehensive environmental investigation. Accordingly, the study investigates the environmental role of both traditional (income) as well as relatively new (GLB, PS, & ICT) factors on the LCF. In doing so, the study comprehensively analyzes GCC countries by using a panel dataset between 2000 and 2019 and applying an AMG approach at both panel and country-based levels.

At the panel level, the results demonstrate that ICT helps to develop EQ. Also, GLB and PS decrease EQ. Besides, income does not have a significant impact. Moreover, the LCC hypothesis is not valid for the GCC panel. On the other hand, country-based results vary. For example, increasing income is effective on the LCF in both QAT and SAU. Also, the LCC hypothesis is valid in QAT. Differentiating from the panel level, GLB is insignificant on the LCF in BHR, KWT, and OMN; PS has a stimulating impact on the LCF in QAT; ICT is insignificant on the LCF in OMN and QAT. Furthermore, the results are robust based on alternative econometric approaches.

The results of this study are generally consistent with previous studies. For example, the study does not confirm the LCC hypothesis, which is consistent with Mahmood's (2022) study for the GCC countries, which also concludes that the EKC hypothesis is not confirmed at the panel level. The study also shows the mixed effects of PS on the environment for each GCC country, which is consistent with the study by Ulussever et al. (2023). The environmental impacts of GLB and ICT are also consistent with the studies by Destek (2020) and Balsalobre-Lorente et al. (2023), respectively. The results of this study are consistent with the literature but extend current knowledge by providing new insights into the GCC countries at both the panel and country level.

5.2. Policy implications

The study provides fresh insights into the environmental role of technology, income, globalization, and political stability in the GCC countries by also testing the LCC hypothesis using the AMG approach. Accordingly, various policy implications for both panel and country levels can be discussed based on the collected results.

First, income has no influence on the LCF in the GCC panel. The LCC hypothesis is also not confirmed. This finding implies that although GCC countries have higher income levels, they are unfortunately not able to utilize the higher income to promote EQ progress. Therefore, the GCC countries should consider restructuring their economies to an eco-friendly structure. GCC countries should try to make their economies carbon-neutral by reducing their dependence on fossil fuels through comprehensive energy transition policies. In this context, they can utilize various subsidies to increase the share of clean energy in total energy consumption. GCC governments should also address the consumption behavior of citizens, which is highly related to material use. In this way, GCC countries can transform their economies into friendly structures, and income levels can in turn automatically play a role in the development of EQ.

Second, the results demonstrate the decreasing influence of GLB on EQ in the GCC panel. This finding implies that the GCC countries cannot benefit from GLB to develop their EQ. The GCC countries should therefore comprehensively review and restructure their GLB policies and practices. In this context, they should particularly focus on the import and export side of international trade. For this reason, GCC countries can be importing highly polluting goods and services, which reduces the impact of GLB on EQ. Through these corrective measures, GCC countries can reverse the decreasing impact of GLB into an increasing impact on EQ.

Third, the PS has a decreasing influence on the EQ in the GCC panel. This shows that the GCC countries cannot benefit from PS in securing EQ. Therefore, GCC countries should change their political and economic approach to green PS. If this is the case, the GCC countries can benefit from PS in securing EQ by making long-term environmentally friendly decisions instead of relying on short-term decisions.

Fourth, ICT has an increasing influence on EQ in the GCC panel. Therefore, it can be said that GCC countries can continue to rely on ICT in their efforts to develop EQ. They can also try to make more use of the positive aspects of ICT in addressing environmental problems and promoting green digitalization to develop EQ.

As far as the country-specific results are concerned, it can be seen that the LCC hypothesis is only valid in the case of QAT. This finding implies that QAT differs from the other GCC countries in terms of the level and structure of income and only QAT has an eco-friendly income structure among all GCC countries. Therefore, QAT can rely on income, which can play an automatic role in ensuring EQ.

Globalization has a strongly decreasing effect on EQ in QAT, SAU, and UAE, while it has only an insignificant effect in other countries. Thus, while QAT, SAU, and UAE should ensure that GLB has an increasing impact on EQ, the rest of the countries should revise their GLB approaches to make GLB effective and not just have an insignificant impact on LCF. In this context, all GCC countries should review their GLB policies step by step and make the necessary corrections so that GLB enables every GCC country to import eco-friendly products, services, and technologies.

PS has a decreasing impact on LCF in almost all GCC countries, while there is an insignificant impact in OMN and an increasing impact only in

QAT. This finding implies that only QAT can benefit from PS to secure EQ, while this is not the case for the rest of the GCC countries. Thus, similar to the case of income, PS enables QAT to make eco-friendly decisions. QAT therefore has the opportunity to use PS as an important tool to make long-term decisions that support the progress of EQ by managing the economy in an eco-friendly way.

ICT has a completely increasing effect on the LCF in BHR, while the increasing effect in KWT, SAU, and UAE consists of only one component of ICT. OMN and QAT cannot benefit at all from the increasing impact of ICT on LCF. Accordingly, BHR can further rely on securing EQ by benefiting from ICT (i.e., MOB & INT), while INT is beneficial for KWT and SAU, and MOB is helpful for UAE. Therefore, except for BHR, GCC countries should carefully address ICT issues and think about how to reformulate their nationwide ICT approach so that ICT can make a much more positive contribution to increasing EQ.

Of all the factors used, income has the greatest influence on LCF, followed by GLB, PS, and ICT. Accordingly, GCC policymakers should prioritize these factors in this order when formulating environment-related policies. In this way, they can benefit faster from these factors by moving from highest to lowest impact in the development of EQ. GCC countries should address ensuring EQ by mitigating environmental degradation (i.e., demand side proxied by the EF), and considering biocapacity (i.e., supply side proxied by BIO). In this context, while curbing emissions is highly valuable, another crucial point for GCC countries is to increase their biocapacity through additional steps, such as planting trees, expanding agricultural land, increasing water resources, and avoiding wasting them. In this way, they can not only curb environmental degradation but also increase their ecological capacity. In this way, they can achieve a better EQ level than they currently have.

5.3. Future research

This study examines a total of six GCC countries at both panel and country levels. In this context, the research considers LCF as an environmental quality indicator, includes a set of explanatory variables (i.e., ICT, GDP, GLB, & PS), and applies the AMG approach. Considering these characteristics of the study, new research can consider the various points in designing future research.

First, other non-economic factors, such as energy security risk, environmental policy stringency, and corrupt governance can be included in new research to uncover the impacts of these factors on the environment in line with the developing recent literature.

Second, new studies can examine other countries than GCC countries, which have been using high levels of fossil energy to ensure their economic growth, as in the case of GCC countries (i.e., G20 countries as in Bashir et al., 2024). Hence, a comparative point of view for such countries can be included in new research.

Third, new research can consider the use of much higher-frequency data in empirical modeling because this study uses low-frequency data. Hence, new research can investigate the time-varying impacts of the variables on the environment.

Fourth, new analyses can evaluate employing much more disaggregated level data for empirical investigations (Lin and Ullah, 2024) since this study analyzes at the country level, which implies the use of aggregated level data. However, the impacts of the variables on the environment may differ across economic units, sectors, and geographical areas.

Last, further investigations can apply other novel econometric techniques to make analyses based on various points, such as the recently developed regularized common correlated effect by Juodis (2022). Thus, the LCC hypothesis can be discussed and explored in greater depth.

Disclosure statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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

Data availability

Data will be made available on request.

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Abbreviations

AMG	Augmented Mean Group
AMG-I	AMG-Imposed
BIO	Biocapacity
CO_2	Carbon Dioxide
COP	Conferences of Parties
CSD	Cross-Sectional Dependence
EF	Ecological Footprint
EKC	Environmental Kuznets Curve
EQ	Environmental Quality
GCC	Gulf Cooperation Council
GFN	Global Footprint Network
ICT	Information and Communication Technology
LCC	Load Capacity Curve
OBOR	One Belt One Road
USD	United States Dollar

WB	World Bank

Dependent Variable

LCF	Load Capacity Factor

Explanatory Variables

GDP	Gross Domestic Product
GLB	KOF Globalization Index
PRI	Political Risk Index
MOB	Mobile Cellular Subscriptions
INT	Individuals Using the Internet

Analysis Scope

BHR	Bahrain
KWT	Kuwait
OMN	Oman
QAT	Qatar
SAU	Saudi Arabia
UAE	United Arap Emirates

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