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Economic Development and Environmental Sustainability in the GCC Countries: New Insights Based on the Economic Complexity

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Economic Development and Environmental Sustainability in the GCC Countries: New Insights Based on the Economic Complexity

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Abstract: The economic development and environmental sustainability nexus have long been a fiercely debated issue. Researchers have widely acknowledged the environmental Kuznets curve (EKC) hypothesis when evaluating this relationship. Recently, an emerging strand of research examined the EKC through the lens of the Economic Complexity Index (ECoI) as a broader measure of economic development. However, empirical evidence of the index's environmental impact is still limited. Despite its growing prominence, no prior research has been conducted in the Gulf Cooperation Council (GCC) using the ECoI, particularly in the EKC context. Furthermore, research comparing the ECoI differentiated impacts on Ecological Footprint and Carbon Dioxide (CO_2) emissions is largely lacking. Extending on this line of research, our investigation intends to ascertain the influence of ECoI, income, globalization as well as non-renewable energy consumption on two dominant environmental pressure metrics: CO_2 emissions and ecological footprint per capita (EFpc) within the EKC hypothesis context in six GCC countries during 1995–2018. To this end, Pedroni's cointegration approach was conducted to examine the long-term association between variables; cointegration coefficients were analyzed using Dynamic and Fully modified OLS. Our investigation indicates the emergence of an inverted U-shaped link between ECoI and environmental sustainability in the GCC region for both CO_2 emissions and EFpc. Furthermore, according to the individual country analysis, our findings demonstrate that the EKC hypothesis is sensitive to both the environmental degradation indicator used and the country analyzed; such that the quadratic link incorporating ECoI is confirmed for Saudi Arabia, Bahrain, United Arab Emirates, and Kuwait when EFpc is employed. In comparison, it holds for Kuwait, Oman, and Qatar when CO_2 emissions are used. Moreover, the findings show that income per capita and non-renewables consumption significantly harm environmental sustainability, however, in terms of EFpc only. In contrast, through its three sub-dimensions, globalization contributes to the environmental burden by increasing both EFpc and CO_2 emissions. These conclusions emphasize the economic complexity's dominant role in mitigating environmental pollution in GCC beyond a certain threshold. Finally, the paper reaches a concise set of implications. Among the foremost, the GCC nations could enhance their environmental sustainability by diversifying their energy sources and increasing reliance on renewable sources, encouraging investment in carbon-reduction technologies, converting their economy from energy-intensive to technology-intensive, as well as imposing strict environmental laws to enable globalization to improve environmental quality.

Keywords: economic complexity; environmental kuznets curve; panel data analysis; gulf cooperation council; sustainability

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1. Introduction

Environmental issues have recently gained prominence in political and scholarly circles. The cost of failing to confront environmental hazards is already tremendous and will only worsen. Countries around the globe have concentrated for decades on bolstering economic development at the expense of surrounding natural capital, resulting in severe environmental concerns such as clean water shortages, biodiversity loss, exhaustive use of fossil fuels, soil resource depletion, rising sea level, waste disposal, and climate change, the most destructive threat humanity has ever encountered [1,2]. Moreover, the overexploitation of natural assets erodes the surrounding ecology and increases Carbon Dioxide (CO_2) Emissions [3]. More than 76% of the greenhouse effect is attributed to air pollution induced by CO_2 emissions [4]. Fossil fuels, carbon emissions' primary source, have become overly reliant [5]. In 2019, coal accounted for 39% of global fossil CO_2 emissions, trailed by oil (33%), gas (21%), and cement (4%) [6]. Furthermore, between 1750 and 2019, the global CO_2 emissions concentration grew by more than 48%.

Evidently, the fierce urgency of our age is to rectify the climate crisis while still addressing crucial development requirements. The impact of economic development on environmental sustainability has long been debated [7]. According to the World Bank's latest Climate Change Action Plan 2021–2025, "There is an urgent need to integrate climate and development strategies to deliver green, resilient, and inclusive development" [8]. Researchers have widely acknowledged the environmental Kuznets curve (EKC) approach when evaluating the previous relationship. According to the EKC, pollution increases first as income grows. However, the deterioration deacetylates beyond a certain threshold, creating the so-called inverted U-shaped EKC. The vast majority of EKC research has focused on GDP volume as a proxy for economic development, with minimal attention given to the structure of GDP's environmental impact [9,10]. Real GDP, however, does not fully reflect structural changes, posing an environmental constraint that extends beyond production volume [11]. Ref. [12] developed the Economic Complexity Index (ECoI) to measure and grasp the structure of the economy accurately. As a result of the discussions on economic structure and environmental sustainability, several major considerations for governments and policymakers when pursuing the SDGs have been recognized [13]. Undoubtedly, industrialization could stimulate substantial energy use, with far-reaching implications for environmental sustainability. However, the degree of sophistication and complexity in the industrialization process may influence the extent of such impact. Simple societies that depend on agriculture and raw resources would create limited environmental pollution, whereas developed/industrialized economies generating complex and diverse commodities would pollute the environment excessively [14]. It is generally speculated that societies can reduce pollution by producing highly advanced products using clean manufacturing processes. Therefore, high levels of ECoI would assist in mitigating environmental harm compared to low and moderate levels. Consequently, several emerging investigations incorporating ECoI in the EKC context have been conducted. A substantial corpus of literature focuses on measuring environmental damage through CO_2 emissions. Nonetheless, the indicator overlooks several critical environmental issues, such as water and soil contamination. The Ecological Footprint/capita (EFpc) indicator, developed in the mid-1990s, provides a concise and precise measure of environmental deterioration [15]. The index developers use two metrics to determine a country's ecological deficit/surplus: the EFpc illustrates how much of the earth's natural resources we need to feed ourselves, whereas biocapacity tells how much of our environmental assets we must provide. If demand for environmental assets exceeds supply, there is an ecological shortage, and vice versa [16].

The Gulf Cooperation Council (GCC) was established in 1981 as an economic and political alliance. The alliance comprises six major petroleum exporting countries: the Kingdom of Saudi Arabia (KSA), Qatar, Oman, Kuwait, Bahrain, and the United Arab Emirates (UAE). The GCC member states control over 20% of the proven crude oil reserves and natural gas reserves worldwide [17]. Thanks to natural resource endowments and oil revenues, the GCC countries excelled through the development ladder without any hurdles [18]. However, the immense scale of nonrenewable energy production and consumption leads to severe environmental concerns and jeopardizes the GCC's development and sustainability path.

To summarize, despite its evident importance, there is a paucity of research using ECoI as a gauge of economic advancement in the EKC approach context; the relationship is further neglected for GCC states. Additionally, there have been few attempts to validate the EKC model in GCC countries using GDP and other macroeconomic variables and to use a sole measure of ecological deterioration (see: [19,20]). Moreover, changes in economic structure have consistently emerged as one of the most significant factors influencing environmental sustainability [21]. In this regard, this article intends to ascertain the influence of ECoI, nonrenewable energy consumption, per capita income, and globalization on environmental pollution across a panel of six GCC nations, utilizing both ecological footprint and CO_2 emissions levels. The study assumes that "Beyond a certain development level, the GCC states will concentrate more on enhancing its environmental quality and improving their people's environmental well-being". The research adds to the extant body of research in multiple ways. First, it is among the pioneering attempts to study economic development and environmental degradation nexus using ECoI and thorough environmental efficiency indicators as proxy variables and to apply them to a panel set of countries. Most researchers use CO_2 emissions to evaluate environmental degradation, neglecting the possibility of its invalidity when it comes to resource stocks [22]. Against this drawback, our paper employs both CO_2 emissions and EFpc to fully capture the ECoI differentiated impacts on environmental sustainability, allowing for both comparable and comprehensive conclusions. The paper revisits the EKC theory in the GCC region for economic complexity. In addition to the ECoI, the paper incorporates other environmental efficiency determinants, including non-renewable energy consumption, globalization, and income per capita. Ultimately, this analysis is the first to consider this topic in the GCC. By pioneering this study in the GCC countries, the recommendations from this study serve as a template for other countries with similar conditions (i.e., petroleum exporting) in relation to developing viable policies to improve environmental quality and combat climate change hazards.

We focused on the GCC countries for several reasons: first, they face profound environmental threats as a hub of oil production. For instance, in terms of emissions per person, the Gulf States are among the top 25 global emitters [23]. Furthermore, they all suffer from a biocapacity deficit [16]. Second, they are geographically and economically convergent (e.g., similar economic structure, high reliance on nonrenewable energy sources, and reliance on oil revenues); and third, they are all major petroleum exporters with abundant natural resources, resulting in rapid growth at the expense of series environmental repercussions. In comparison to the rest of the world, Gulf countries have a relatively low complex export basket but a relatively high real GDP per capita [11]. Thus, embracing new factors that help the region better manage its natural capital and grow its economic progress while simultaneously enhancing environmental quality is an inevitable prerequisite for the region's sustainable development.

The article body is divided into the following parts: Section 2 reviews the existing literature, Section 3 exposes the econometrical techniques and data sources, Section 4 highlights the study findings, and Section 5 discusses the main policy recommendations and future research.

1.1. Reviewing the Existing Literature

1.1.1. Prior Research on Globalization, Non-Renewable and Environmental Efficiency

Undoubtedly, the excessive depletion of fossil fuels raises both CO_2 emissions and EFpc levels, stifling long-term growth and exacerbating ecological instabilities [24]. Nonrenewable energy (NREW) consumption, indicating fossil fuel-based energy consumption, has broadly been blamed for degrading the environment [14]. For instance, ref. [25] assessed the EKC theory in the United States from 1980 to 2014. Their results failed to confirm the EKC concept in the USA context. They also reach that expanding renewable energy (REW) consumption reduces environmental destruction while increasing NREW consumption contributes to it. Similarly, Ref. [26] refute the EKC model in European Union countries. They also reach that REW consumption generates 50% less Green House Gases (GHG) per unit of energy than NREW consumption. Furthermore, ref. [27] disclose that switching from NREW to REW resources could reduce CO_2 emissions in Pakistan.

Conversely, ref. [28] prove the existence of an EKC linkage between CO_2 emissions and urbanization. Their experimental investigation verifies the previously indicated linkages between energy types and ecological sustainability in OECD nations. The same conclusions have been corroborated in several countries and regions (e.g., [29–31]).

Similarly, several works review the effect of different energy sources while employing EFpc as an environmental pressure indication. ref. [32] findings indicate the EKC's statistical validity in a sample of five South Asian countries, demonstrating a negative impact of REW on EF. Ref. [33] emphasize the significance of REW consumption in promoting environmental efficiency and the unfavorable impact of NREW consumption in depleting the ecosystem using PMD-ARDL analysis. Ref. [34] discover that raising the demand for NREW and economic growth deteriorates ecological sustainability in G7 countries. Lastly, ref. [35] contend that a 1% rise in NREW consumption produces a 0.5507% rise in EF, while a 1% increase in REW consumption diminishes EFpc by 0.2248% in BRICS-T countries between 1990 and 2018.

The link between globalization and ecological damage has long been a source of contention, with conflicting results. By and large, two distinct strands of research were devoted to examining the environmental consequences of globalization. The first strand states that globalization benefits both society and the environment by enhancing access to new technologies and lowering carbon dioxide emissions. For instance, ref. [36] investigated globalization and emissions nexus in South Asia from 1972 to 2013. They observed that globalization ameliorates environmental sustainability by cutting carbon emissions after a particular threshold. They, moreover, reveal the existence of bidirectional linkage between the variables. Ref. [37] explored the clear linkage between 11 emerging economies and concluded that CO_2 emissions dropped in the early stages of globalization. It does, however, rise as globalization progresses, resulting in a U shape association between the two variables. Similar implications were noted by [38] among Africa's top countries, [39] in the APEC region, and [40] in China. Correspondingly, ref. [41] investigated the same relationship within a panel set of 80 nations from 1980 to 2016 and concluded that globalization improves environmental excellence.

The anti-globalization camp argues that because economic progress is stimulated at the expense of environmental integrity and future generations' well-being, globalization would stymie the path to sustainable development and harm environmental sustainability [42]. Ref. [43] argue that globalization in its early stages results in substantial energy consumption to expedite economic expansion, which raises CO_2 emissions. According to [4], urbanization, as a characteristic of globalization that causes deforestation and climate change, may be detrimental to society. Additionally, ref. [3] found that globalization's economic dimension increases both consumption and production patterns of the EFpc across a sample of 146 countries. According to [44], globalization adversely impacts environmental efficiency despite its favorable impact on economic advancement. Ref. [45] introduce evidence of the harmful impact of several globalization measures (i.e., FDI, the openness of trade, and the KOF index) in stimulating the environmental adversities in South Asia.

1.1.2. EKC Research for Economic Complexity and Environmental Sustainability

The EKC model arose from Kuznets' (1955) work in the early 1990s, demonstrating that the association between income disparity and income exemplifies an inverted U pattern. ref. [46], inspired by Kuznets' work, proposed the EKC notion, which incorporated the environment into the curve context. Their curve postulates an inverted U shape link among numerous environmental contamination indices and income exist. More precisely, increased income brings immense environmental damage and contamination until a tipping point is reached in the early phases of development. Then, this trajectory reverses, and higher income levels lead to improved ecosystems [47].

Economic Complexity Index (ECoI) is a relatively new metric that has garnered traction as a gauge of economic advancement [14,34,48,49]. The index alludes to the economy's industrial structure, which shapes its economy and energy intensity patterns. There is a common perception that in the initial phases of economic development, countries focus primarily on agricultural products and primary minerals, which minimizes environmental damage. However, later development leads to excessive environmental deterioration due to more industrialization. As a result, both low and middle ECoI values contribute to higher pollution [49].

Nevertheless, beyond a specific turning point, high ECoI values would help in averting environmental damage by upgrading technological techniques and human capital [50]. Nations can mitigate environmental damage by generating highly advanced commodities using clean manufacturing techniques at such a phase. Therefore, several nascent types of research have focused on investigating the EKC in the context of ECoI. However, there is scant empirical evidence to substantiate the argument.

Ref. [51] conducted early research that focused on re-examining CO_2 emissions determinants in France; their study proved the hazardous impact of energy utilization on CO_2; highlighted the devastating impact of ECoI on environmental conservation, and provided additional evidence that the EKC theory held true for France. Likewise, the US exhibited an inverted U shape link between ECoI and EFpc from 1980 to 2016, according to [49] US economy analysis. More recently, ref. [52] investigated dynamics between ECoI, FDI, renewable resources, urbanization, and Dioxide emissions in the PIIGS countries from 1990–2019. Their findings authenticate the EKC's inverted U and N shape relationships for ECoI and emissions in the countries' sample. Finally, ref. [53] reached intriguing conclusions in their research focusing on examining ECoI and Emissions of carbon dioxide association in 29 Asia Pacific economies from 2000 to 2018. According to their findings, economic complexity enlarges energy demand and production size, which amplifies the national growth influence on CO_2 emissions. However, improving energy efficiency while escalating economic complexity has a beneficial environmental impact. Ref. [54] also indicate the EKC statistical validity in G7 members between the ECoI and CO_2 emissions over 1995–2015. In contrast, ref. [34] affirm the emergence of a U shape link between EFpc and economic complexity for G7 countries, implying that once a certain tipping point is reached, increasing ECoI eliminates ecological damage in G7 economies.

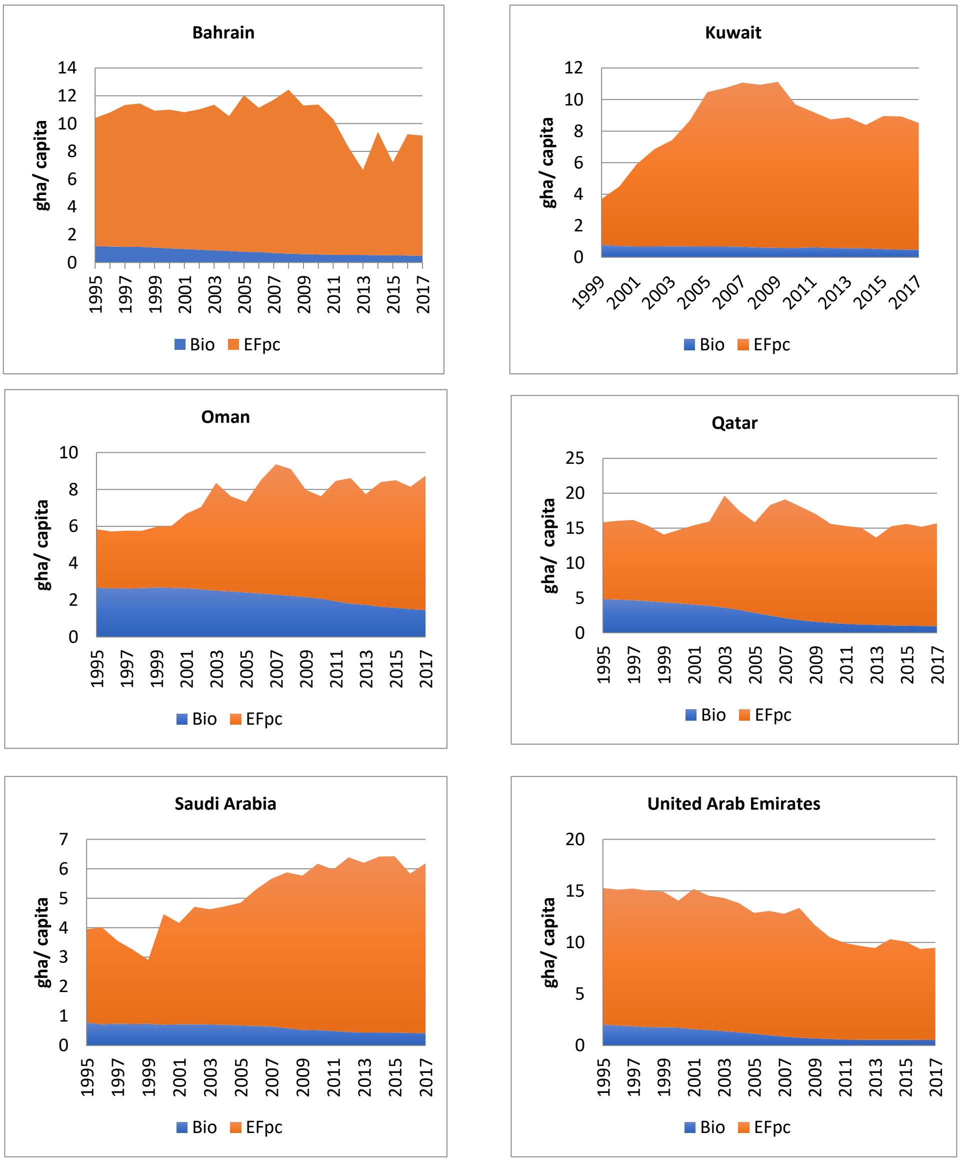
On the other hand, several recent works claim that economic complexity tends to reduce air pollution and improve environmental excellence. As per [55], modernizing and sophistication the production structure can help alleviate reliance on natural resources. Ref. [50] demonstrated that economic complexity lowers ecological damage in Brazil. Furthermore, ref. [56] claim that economic complexity raises certain air pollution indicators, such as CO_2 emissions, while diminishing aggregate environmental pollution. Their findings also show that the EKC holds for 88 developing and developed countries. Ref. [57] suggest augmenting ECoI and renewable sources to improve ecological efficiency and mitigate climate hazards. Finally, ref. [58] show that ECoI increases environmental degradation by aggravating the ecological footprint, whereas a high level of economic complexity reduces it.

1.1.3. The Gulf Member States Economy and Environment at a Glance

The Gulf Cooperation Council (GCC) countries have maintained steady and consistent growth and financial surpluses since its inception in May 1981. In certain instances, their aggregate income per capita has exceeded that of the G10 economies [59]. In terms of consumption, the GCC's energy consumption/per capita is 2.5 times that of the European Union members and more than four times that of the globe [60,61]; UAE is the region's largest energy consumer, followed by Oman [62]. Table A1 in the Appendix A details the economic situation of the six GCC states.

As a hub of petroleum production, the GCC region has overwhelmingly struggled with environmental concerns [63]; they are all among the top 25 Carbon dioxide generators [23]. This can be ascribed to the region's high degree of urbanization, population expansion, economic progress, government subsidies, low energy prices, and copious fossil energy sources [20,60].

Scheme 1 displays the GCC countries' ecological balance. The blue area indicates biocapacity, the red line represents the ecological footprint, and the orange area is the ecological deficit, all in global hectares (gha). Between 1995 and 2018, all GCC members experienced an increasing biocapacity deficit, and the region's biocapacity gap has increased further over the years. Bahrain has the most significant biocapacity deficit, followed by the UAE, Kuwait, Qatar, Oman, and the KSA [16]. Similarly, during 1990–2016, consumption/capita of the ecological footprint increased from 36.7 to 44.9 Giga Hectares, while accessible biocapacity dwindled from 13.3 to 4.0 Giga Hectares, resulting in the region's average EF being more than 20 times greater than the global average.



Scheme 1. Ecological Footprint vs. BioCapacity in GCC states. Source: constructed by the authors based on [16].

The historic CO_2 emissions pattern in the region is depicted in Figure 1. As is evident, between 1990 and 2018, per capita emissions have intensified in the region. Total CO_2 emissions reached 1.3 gigatons (GT) in 2018 [64]. The region's most polluting industry is power generation, accounting for between 27 and 55% of total emissions [63].

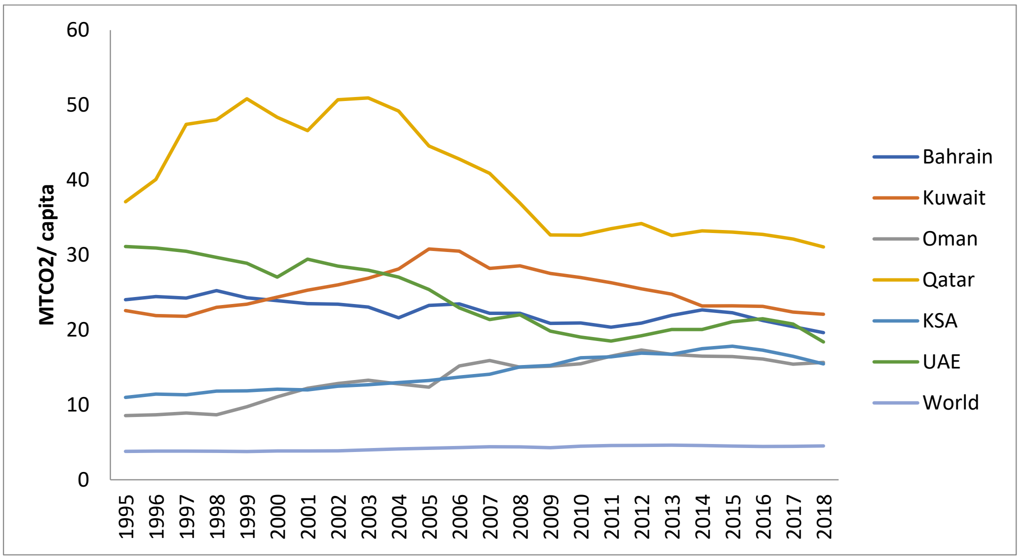


Figure 1. Carbon emission per capita in GCC states vs. global average. Source: [65].

The preceding analysis shows that the EFpc deficit and CO_2 emissions have been mounting for decades, signifying the failure to prevent environmental harm, and highlighting the region's growing environmental burden/per capita. As a result, it is worthwhile to identify the underlying causes driving environmental pressure in the region. Despite growing interest, research on EKC validation in the GCC framework is still modest. This analysis extends prior literature on this topic differently; it considers several predictors that may impede ecological integrity (such as GDP/capita, NREW, and globalization) and employs two dominant environmental pressure metrics (CO_2 emissions and EFpc) rather than relying on a single indicator.

2. Econometrical Techniques and Data Sources

2.1. Study Design and Data

The quadratic form of EKC used in this analysis is based on nonlinear Equation (1), which is as follows

$$f(A, B) = \alpha + \beta A^2 + \gamma B \quad (1)$$

The current research is built on a dataset encompassing six-panel countries: Bahrain, Oman, Kuwait, Qatar, KSA, and the UAE, as well as six different variables spanning between 1995 till 2018. In all, we have gathered 144 pieces of evidence. The Appendix A contains more information on variable definitions and sources (Table A2). This study's design based on the EKC notion is shown in Figure 2.

E-views and R software were used for technical, statistical, and econometrical manipulations. According to Table 1, the average GDP/capita is 27,622, with a minimum of 6216 and a peak of 85,076. Qatar has the largest GDP/per capita (+51,030.4), followed by the UAE, Kuwait, Bahrain, KSA, and Oman, each with an average of 36,174$, 31,533.38$, 17,998.4$, +15,476.92$, and +13,517.55$ USD, respectively. The averages for CO_2, EFpc, NREW, and KOF are 126, 6266, 8.735248, 0.0000487, and 63, 63,945, respectively. Furthermore, the ECoI average varies significantly across countries, with a low of −0.964275 and a maximum of 0.6889987.

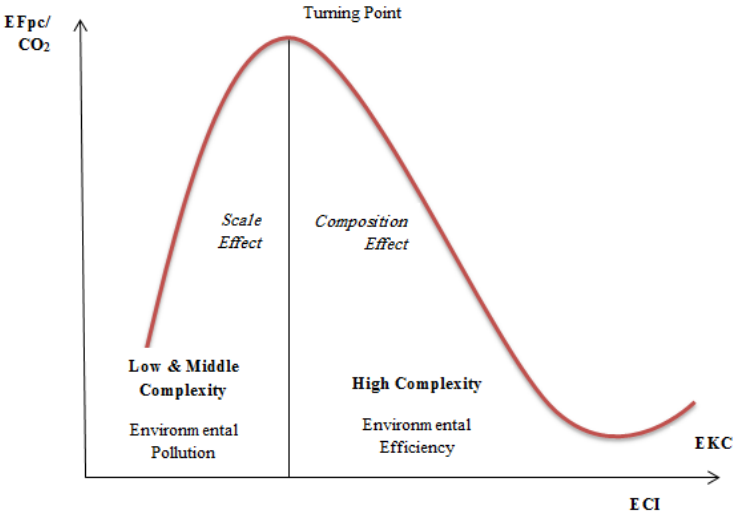


Figure 2. Environmental Kuznets Curve (EKC).

Table 1. Descriptive statistics.

	CO_2	EFpc	ECoI	$ECoI^2$	KOFGI	GDP/Capita	NREW
Min	14.0775	2.165325	−0.964275	0.929826	47.27227	6215.702	0.0000101
Max	645.4086	17.02006	0.6889987	0.474719	75.50694	85,076.14	0.000014
mean	126.6266	8.735248	−0.3197543	0.102242	63.63945	27,621.78	0.0000487
Sd	148.6766	3.640991	0.3197543	0.102242	6.819614	17,970.65	0.00000237
p25	32.2374	5.768481	−0.3659881	0.133947	58.59662	15,409.96	0.00000295
p75	127.5005	11.29355	0.1224329	0.014989	68.88416	36,947.46	0.00000575
cv	1.174134	0.4168159	0.4168159	0.173735	0.1071602	0.650597	0.4863898
skewness	1.944734	0.1064826	0.1064829	0.011338	−0.2204475	1.328424	0.8551407
kurtosis	5.894733	2.105061	2.105061	4.431281	2.326711	4.521928	3.435754
N	144	144	134	134	144	144	144

Figure 3 displays the ECoI historical pattern in the GCC member states between 1995 and 2018. The figure below showcases how the six countries' ECoI rankings evolved considerably throughout the study. Some nations (such as the UAE and KSA) retain an upward rise, particularly in the most recent period. In contrast, others oscillate between the negative and positive sectors, implying that the export policies of the sampled nations vary.

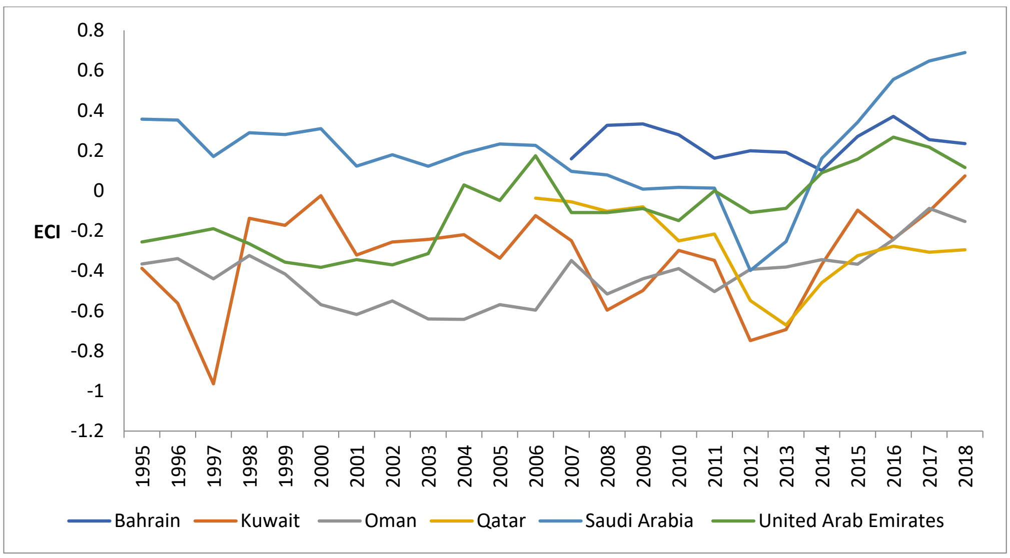


Figure 3. Economic complexity index historical pattern in 6 GCC countries. Source: [66].

The normal distribution test for both the CO_2 and EFpc models is shown in Table 2.

Table 2. Normal distribution test.

	CO_2_EMISSIONS	EFpc
Jarque-Bera	141.0446	4.342362
Probability	0.000000	0.114043
Observations	144	144

2.2. Model Specification

We estimate the following forms adopted from Equation (1):

$$EFpc = f(ECoI,\ ECoI2,\ NREW,\ KOF,\ GDPpc)$$

$$CO_2 = f(ECoI,\ ECoI2,\ NREW,\ KOF,\ GDPpc)$$

$$EFpc_t = \delta_1 + \delta_2 ECoI_t + \delta_3 ECoI_t^2 + \delta_4 NREW_t + \delta_5 KOF_t + \delta_6 GDP_{PC} + u_t \ldots \quad (2)$$

$$LnCO2_t = \beta_1 + \beta_2 ECoI_t + \beta_3 ECI_t^2 + \ \beta_4 NREW_t + \beta_5 KOF_t + \beta_6 GDP_{PC} + \varepsilon_t \ \ldots \quad (3)$$

where *t* indicates time (*t* = 1995, . . . , 2018), δ_1 and β_1 signify the constant terms, δ_2, δ_3, δ_4, δ_5, δ_6 and β_2, β_3, β_4, β_5, β_6 refers to the long run coefficients, whereas u_t and ε_t are the terms of the white noise error. EF_{pc} assigns ecological footprint, CO_2 for carbon dioxide emissions, and *ECoI* and $ECoI^2$ detect the economic complexity index and its square respectively. NREW is the nonrenewable energy consumption, and KOF is an aggregate globalization indicator based on its three sub-dimensions: economic, political, and social. The EKC concept holds if the estimated equations yield a positive δ_2 (β_2) coefficient and a negative δ_3 (β_3) coefficient, and both are statistically significant. More elaboration on the EKC curve cases is given in Table 3.

Table 3. EKC cases.

Coefficients Signs	EKC Shape
δ_2 *and* $\delta_3 = 0$	No association between the ECoI and EFpc
$\delta_2 < 0;\ \delta_3 = 0$	EFpc and ECoI are inversely related; lowering ECoI increases environment quality.
$\delta_2 > 0;\ \delta_3 = 0$	There is a positive relationship between ECoI and EFpc; that is, increasing ECoI improves EFpc.
$\delta_2 < 0;\ \delta_3 > 0$	A U-shaped relationship exists between EFpc and EC0I; such that, negative relationships between the variables exist in early stage and then reverse after a certain threshold.
$\delta_2 > 0;\ \delta_3 < 0\ a$	Inverted U relationship between EFpc and ECoI exists; such that, the variables have a positive relationship at first, but after a specific threshold, the relationship inverts.

NREW consumption is pre-supposed to raise environmental stress. Thus, positive signs for δ_4 (β_4) are anticipated. δ_5 (β_5), on the other hand, is undetermined as globalization impact depends on both the country's development status and whether it is exploited for cleaner production techniques or not. On the contrary, we anticipate a positive influence from income/per capita on environmental stress. The GCC nations have a high income/per capita thanks to oil and gas revenues, which may contribute to environmental deterioration due to the massive income effect of extravagant expenditure.

3. Results

Based on the scatter plot grid, there is a significant correlation between our two dependent variables (EFpc and CO_2 Emissions) and the other independent variables (p, 5%). The absolute value of the correlation is greater than 0.30 for both variables (for more information, see Figure A1 in the Appendix A, which depicts the correlation matrix using the Correlogram.). We computed certain missing values using several techniques, primarily the multiple imputations and mean methods, as we employed a longitudinal data set from 1995 to 2018. These approaches increase data quality and inference validity by offering stable imputations of missing datasets. In what follows, we present the empirical findings from the panel data.

3.1. Examining for Cross-Sectional Dependence

The Breusch–Pagan LM, Pesaran scaled LM, and Pesaran CD tests are employed to investigate cross-sectional correlation. Accordingly, the following hypotheses will be tested:

H0: *There is no association between the disruptions in various cross-sections (countries).*

H1: *Disturbances across several cross-sections (countries) have no association.*

The *p*-Values for most variables are less than the threshold (5%) value, as indicated in Table 4 below. Therefore, we refute (H0), which implies that cross-sectional dependence prevails in the observations. As a result, there is no cross-sectional dependence relationship between variables.

Table 4. Cross-sectional dependence.

Test	$LnCo_2$		EFpc		ECoI		$ECoI^2$		GDPpc		KOFGI		NREC	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Breusch-Pagan LM	58.74	0.00	55.03	0.00	55.971	0.000	35.03	0.002	103.3	0.000	126.4	0.00	98.1	0.000
Pesaran scaled LM	6.889	0.00	6.213	0.00	6.3847	0.000	2.562	0.01	15.02	0.000	19.24	0.00	14.1	0.000
Pesaran CD	−1.01	0.31	2.916	0.00	0.8086	0.419	−0.89	0.371	2.065	0.04	7.603	0.00	0.17	0.866

3.2. Examining the Variables Stationarity

To check the dataset's stationarity, we employ [67] and [68] procedures. Test results shown in Table 5 indicate that the level value variables are not stationary. They are rather first-order integrated for a 1% level of significance.

Table 5. Stationarity tests.

Variables	LLC		Augmented Dickey–Fuller	
	Intercept	Intercept Trend	Intercept	Intercept Trend
LN CO_2	−0.939308	0.64429	3.18671	10.795
EF	4.0014	−2.102	43.142	39.014
ECoI	−2.502 **	−1.214	50.124	55.142 *
$ECoI^2$	−0.215 **	−0.124	141.131	145.167 *
NREC	−2.214 **	−1.254	53.214	62.012
KOFGI	−3.142 **	−2.648	60.415	64.1542
GDP	−4.872 **	−3.514	80.142	89.154
Δ EF	−4.242 **	−3.214 **	102.101 **	180.311 **
Δ ECoI	−5.401 **	−4.215 **	130.142 **	190.884 **
Δ $ECoI^2$	−3.121 **	−3.217	170.134	188.171 *
Δ NREC	−3.512 **	−2.647 **	133.214 **	180.333 **
Δ GDP	−7.302 **	−6.154 **	180.201 **	181.012 **
Δ $LNCO_2$	−7.334 **	72.9987 **	−6.5706 **	57.8833 **

Note: ** indicates that 5% statistical significance. * Indicates that 1% statistical significance.

3.3. Panel Cointegration Tests Results

The following verifies the variable's stationarity. We run the [69] test to determine the long-term link between variables.

- $LnCO_2$

The Pedroni cointegration test for $lnCO_2$ is shown in Table 6. All statistics have Prob. Values smaller than 5% (the critical value), indicate the presence of a co-integration relationship between LnCO2, NREC, KOFGI, ECoI, ECoI2, and GDP.

Table 6. Pedroni cointegration test for $lnCO_2$.

Test	Statistics	Prob.	Statistic	Statistic
Common AR Coefficients (within-dimension)				
Panel v-statistic	−8.1542	0.0000	3.0154	0.0021
Panel rho-statistic	−8.1541	0.0001	3.1547	0.0031
Panel PP-statistic	−7.3976	0.0000	5.5147	0.0041
Panel ADF-statistic	−8.1542	0.0000	5.6154	0.0032
Individual AR Coefficients (between-dimension)				
Panel rho-statistic	−6.1474	0.0014		
Panel PP-statistic	−7.4179	0.0000		
Panel ADF-statistic	−7.4154	0.0000		

- EFpc

Table 7 depicts the test results for (EFpc). There is a genuine co-integration link among EFpc, NREW, KOFGI, ECoI, ECoI2, and GDP/capita since four out of seven statistics match Prob. values that are less than 0.05.

Table 7. Pedroni cointegration test for EFpc.

Alternative Hypothesis: Common AR Coefs. (within-Dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	1.282194	0.0999	0.879764	0.1895
Panel rho-Statistic	0.617808	0.7316	−0.050940	0.4797
Panel PP-Statistic	−2.398809	0.0082	−3.311669	0.0005
Panel ADF-Statistic	−2.165310	0.0152	−2.507321	0.0061
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	0.678546	0.7513		
Group PP-Statistic	−4.304709	0.0000		
Group ADF-Statistic	−2.374712	0.0088		

3.3.1. Estimating the Long-Run Parameters

The co-integration component is confirmed at the 1% significance level for both (FMOLS and DOLS) estimates, as shown in Table 8. It is further demonstrated that EFpc and ECoI have a long-run quadratic relationship, suggesting an inverted U shape connection; such that the ECoI coefficient is positive (0.409; 0.625), and its square is negative (−2.08; −0.402). NREW consumption has a statistically significant positive influence on EFpc; a unit increase in NREW raises EFpc by (9.255%; 7.625%). Identically, globalization increases ecological pressure in terms of EFpc. EFpc increases by 0.0402% and 0.0354% for every unit of globalization increase. Ultimately, GDP's effect on EF is also positive and statistically significant.

Table 8. Equation (2) co-integration coefficients.

Panel DOLS (a)					Panel FMOLS (a)					
GDP	**KOFGI**	**NREC**	**ECoI^2**	**ECoI**	**GDP**	**KOFGI**	**NREC**	**ECoI^2**	**ECoI**	
7.18 ** [3.34]	0.0354 ** [2.95]	7.625 ** [5.29]	−0.402 ** [−4.089]	0.6256 ** [4.319]	6.18 ** [3.85]	0.0402 ** [4.106]	9.255 ** [8.302]	−2.08 ** [−5.1]	0.409 ** [4.476]	Panel
		0.9599					0.774008			R squared
		144					144			Several obs.

** indicates that 5% statistical significance.

The panel co-integration coefficients for Equation (3) of lnCO_2 are included in Table 9. With a 1% significance level, the co-integration coefficients are affirmed for both estimates. Data confirms the statistical validity of the inverted U association between lnCO_2 and ECoI. NREW's impact on lnCO_2 is significantly negative; for every unit increase in NREW, carbon emissions crumble by 13.94% and 8.25%. In contrast, globalization has a positive effect; for every unit increase in KOF, emissions increase by 0.077–0.074%. Meanwhile, the GDP effect on lnCO_2 is statistically negligible.

Table 9. Equation (3) co-integration coefficients.

Panel DOLS (a)					Panel FMOLS (a)					
GDP	**KOFGI**	**NREW**	**ECoI^2**	**ECoI**	**GDP**	**KOFGI**	**NREC**	**ECoI^2**	**ECoI**	
7.01 [0.6809]	0.074 [8.523]	−8.25 ** [−2.264]	−1.893 ** [−4.88]	1.29 ** [4.38]	3.7 [0.4]	0.077 [13.48]	−13.94 ** [−2.158]	−0.69 ** [−4.687]	0.34 ** [4.746]	Panel
		0.89523					0.9843			R squared
		144					144			Several obs.

Note: ** indicates that 5% statistical significance.

3.3.2. Testing for Errors

The test findings in Table 10 reveal that both FMOLS and DOLS residuals in the generated equations have a stationary tendency at a significance level of 5%.

Table 10. Equations residuals stationarity test.

IPS		LLC		
Intercept & Trend	**Intercept &Trend**	**Intercept & Trend**	**Intercept**	
−0.978	−1.3765	−1.252	−1.784	FMOLS resid
−1.23	−1.838	−1.27	−1.33	DMOLS resid

To evaluate the cross-correlation of the errors, we use the Breusch–Pagan, Pesaran scaled LM, and Pesaran CD procedures. The findings in Table 11 show that cross-sectional dependency is present in the residuals from the FMOLS estimate but not in the DOLS estimation (the value of Prob is 0.000).

Table 11. Equations residuals cross-section dependence test.

Test	FMOLS		DOLS	
	Statistic	**Prob.**	**Statistic**	**Prob.**
Breusch–Pagan LM	74.78617	0.0000	25.38463	0.045
Pesaran scaled LM	9.819967	0.0000	0.800521	0.4234
Bias-corrected scaled LM	9.683603	0.0000	0.650521	0.5154
Pesaran CD	1.703136	0.0885	−1.59859	0.1099

In the case of both estimation techniques, Prob is above 5 percent, which supports the null hypothesis of a residual stochastic series (Table 12). As a result, the error series for the DOLS and FMOLS equations is stochastic, with the anticipated future value being the same as the current value.

Table 12. Variance ratio test of equations residuals.

Statistics	FMOLS		DOLS	
	Max |z|	**Prob.**	**Max |z|**	**Prob.**
Normal	8.9758	0.705	6.993	0.8581
Wild Bootstrap	9.147	0.6903	8.2882	0.7622

3.3.3. Country-Based Analysis Results

Finally, after testing the regression coefficients of the EFpc equation for the six countries (Table 13), we can infer that the hypothesized relationship is validated only for four countries: Bahrain, Kuwait, the United Arab Emirates, and the KSA. The FMOLS and DOLS equation coefficients are validated at a 1% significance level.

Table 13. Equation (2) regressors co-integration test.

State	Johansen Test	Variable	FMOLS	DOLS
Bahrain	49.0542 **	ECoI	72.123	39.58
		$ECoI^2$	−126.268	−3.8617
Kuwait	32.1046 **	ECoI	40.27108	48.599
		$ECoI^2$	−37.0308	−52.6339
Oman	23.422	ECoI	−26.1732	−22.6145
		$ECoI^2$	−29.9757	−22.9889
Qatar	15.65032	ECoI	−79.757	−80.0386
		$ECoI^2$	−97.975	−96.8220
KSA	28.50193	ECoI	3.45268	1.9306
		$ECoI^2$	−16.57856	50.185
UAE	19.49543	ECoI	1.9287	6.09413
		$ECoI^2$	−155.03	−166.99

** indicates that 5% statistical significance.

The results of $LnCO_2$ coefficient estimation for the six individual nations are shown in Table 14; the quadratic relationship between CO_2 emissions and ECoI is verified only for three countries: Kuwait, Oman, and Qatar. Both estimation technique equations' coefficients are assessed at a 1% significance level.

Table 14. Equation (2) regressors co-integration test.

State	Johansen Test	Variable	FMOLS	DOLS
Bahrain	57.967 **	ECoI	21.62887	40.0172
		$ECoI^2$	45.502	84.69291
Kuwait	24.53	ECoI	21.3943	24.8451
		$ECoI^2$	−19.7092	−26.1937
Oman	15.42176	ECoI	17.8308	15.8598
		$ECoI^2$	−20.795	−16.9728
Qatar	23.93632	ECoI	22.8711	22.617
		$ECoI^2$	−25.7214	−24.6305
KSA	21.44622	ECoI	9.20866	3.730785
		$ECoI^2$	13.65451	54.31338
UAE	19.72147	ECoI	5.90795	6.053075
		$ECoI^2$	71.51187	71.23752

** indicates that 5% statistical significance.

4. Discussion

The study findings support a quadratic relationship of CO_2 emissions and EFpc on economic complexity in the long term, referring to the existence of an inverted U-shaped link between ECoI and environmental degradation in Gulf countries. In general, our insights are corroborated by [49,53,54]. In regards to the link between CO_2 emissions and ECoI, our findings are consistent with those of [70], who validated the EKC hypothesis between ECoI and CO_2 emissions in OECD countries. Ref. [71] reported similar results in the economies of Brazil, Russia, India, China, and South Africa; as well as [52] in PIIGS countries. As per the EFpc and ECoI association, our results are consistent with [13] who confirmed the EKC hypothesis between EFpc and ECoI in G7 economies; as well as [72] who statically validated the EKC hypothesis between the two variables.

Based on individual country analyses, the EKC hypothesis appears to be sensitive to the environmental indicator used and the country being considered. From the EFpc equation, the quadratic model was verified for only four nations: Bahrain, Kuwait, KSA, and UAE. Bahrain is the hardest-hit state with the highest long-term elasticity (72.123 and −126.268). Kuwait came in second with (40.2710 and −37.030), trailed by Saudi Arabia (3.45268 and −16.5785). Lastly, the UAE has the lowest long-term elasticity (1.9287 and −155.03). Therefore, based on the individual country analysis in the CO_2 emissions equation, the quadratic model is only viable for three countries: Kuwait, Oman, and Qatar. Qatar is the most severely affected country, with the most outstanding long-term elasticity (22.8711 and −25.7214), backed by Kuwait (21.3943 and −19.7097). However, Oman has the lowest elasticity (17.8308 and −20.795). The Appendix A contains a pictorial depiction of the EKC in these nations.

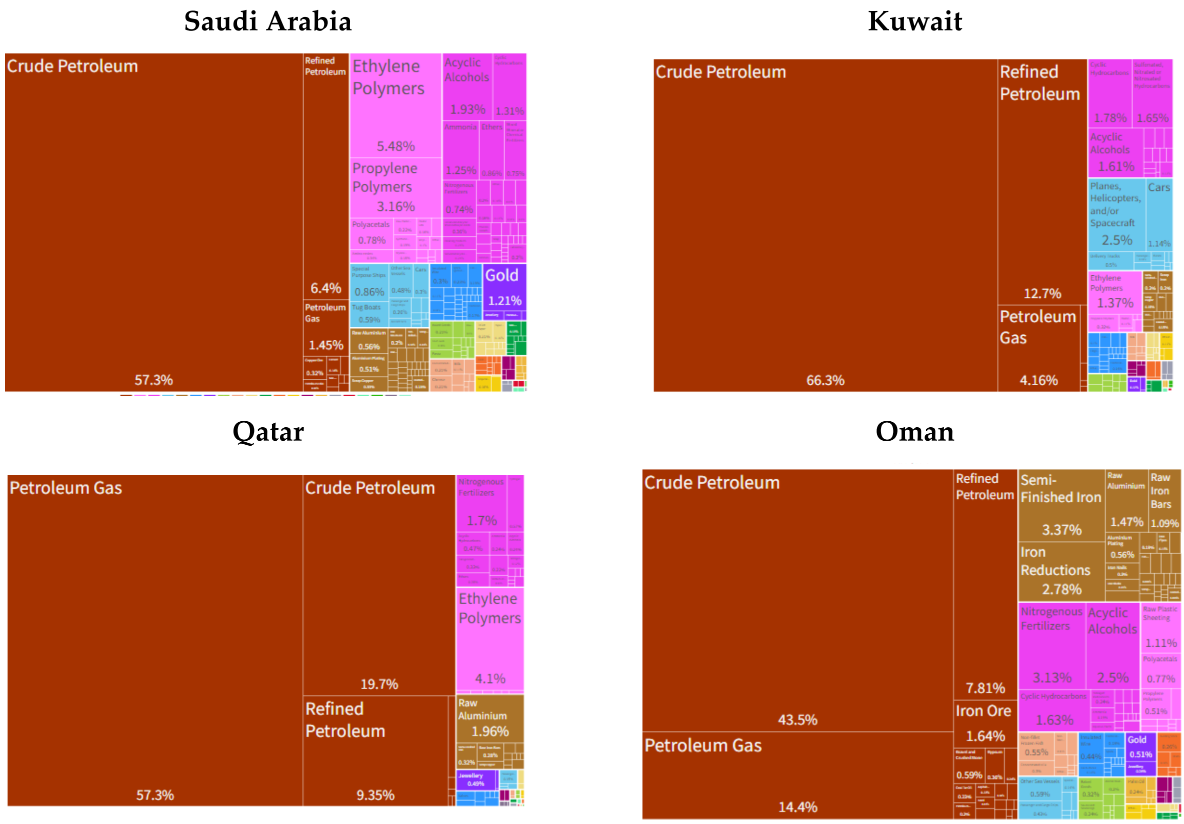
Concerning the impact of NREW consumption, the data showed that NREW simulates environmental degradation in terms of EFpc, with a 1% increase in NREW increasing EFpc by (7.625%; 9.255%), which is congruent with earlier findings of [32,34,35]. This conclusion calls for a greater emphasis on reducing reliance on nonrenewable. Furthermore, it urges policymakers to devise a comprehensive strategy to improve the efficiency of current energy sources while boosting the size of renewables in the whole energy mix.

Conversely, NREW appears to have a statistically significant lowering impact on CO_2. For example, a 1% increase in NREW reduces $lnCO_2$ by (13.94%; 8.25%). Our findings oppose the previous literature that widely affirmed NREW's positive impact on CO_2 emissions [14,34,49] However, this can be attributed to the Gulf governments' efforts to mitigate climate change through several measures, including demand-side management measures, energy efficiency programs, renewable energy generation, and carbon capture and storage. Furthermore, rather than being caused by NREW, excessive carbon emissions in the Gulf region may result from a mix of structural forces such as hot temperatures, energy-intensive companies, low energy prices, and wasteful energy and resource management practices [63].

Furthermore, the empirical analysis demonstrates that GDP/capita has almost no impact on CO_2. Our results agree with [73–75]. This further has crucial policy implications since it indicates that economic growth is insufficient to reduce exhaust emissions; in other words, the region's high income cannot be blamed solely for the region's high level of emissions. In contrast, income has a statistically significant positive impact on EFpc. This conclusion seems quite plausible because, in practice, there is a significant positive association between environmental destruction and development. When energy demand rises, so will economic development and environmental destruction [76]. As a result of the over-exploitation of natural resources, economic development produces constant environmental strains. Our results concur with those of [20,77,78].

Ultimately, our analysis highlights the severe negative influence of globalization on GCC environmental circumstances. For example, a 1% rise in KOF raises EFpc (0.0402%; 0.0354%) and CO_2 emissions (0.077%; 0.074%). Numerous research supports our findings by emphasizing the deleterious consequences of globalization on ecological sustainability [42,44,45]. Globalization, particularly its economic component, has undeniably improved production efficiency and investment prospects [40], resulting in environmentally friendly production technology and lower contamination. However, the excessive resource depletion and a polluting natural environment that accompany globalization aggravate the environmental circumstances in the production process. In this regard, ref. [79] argue that weaker environmental regulations will pollute industries in developing countries.

It is worth mentioning that this inquiry portrays the fact that GCC countries are still far from realizing the benefits of increased levels of complexity. The Gulf economies are hampered in garnering the environmental benefits of higher sophistication levels due to less diverse economic structures, overdependence on oil production, and low levels of complexity among others (see Scheme 2). More precisely, they are heavily reliant on the oil industry, consigning industrial activity associated with high levels of sophistication and complexity to a subordinate status.



Scheme 2. Export Structure of some selected GCC States. Source: [66].

5. Concluding Remarks and Implications

Despite the growing awareness of environmental hazards among scholars, governments, and international entities, pressure on the global ecosystem is still mounting. The ramifications of over-reliance on fossil-fueled consumption patterns in the economy, environment, and human well-being became more evident. The GCC region is not an exception; it has inherently been prone to a slew of environmental hazards due to its reliance on nonrenewable energy supply and unsustainable consumption and production patterns. Thus, grappling with the grave threats imposed by environmental hazards is of utmost importance for the region's sustainability path. To appropriately deal with environmental pressure, it is essential to analyze the underpinning factors/generators that cause this pressure.

This analysis re-evaluates the EKC model linkage between environmental destruction for the first time, utilizing two comprehensive pollution metrics and economic complexity as a holistic gauge of economic advancement in GCC member nations throughout 1995–2018. In doing so, Pedroni's cointegration test was employed to test for the long-term association between variables, and cointegration coefficients were analyzed using Fully Modified and Dynamic OLS. However, broadly speaking, the empirical investigation provided evidence that the EKC theory holds for the GCC area, and it has further led to the following conclusions:

- The EFpc model: overall inverted U-shape association between EFpc and ECoI is statistically verified for the entire country's sample when other independent variables are considered. As per the individual country analysis, however, it holds for only four Gulf economies. Moreover, the long-term coefficients also show that NREW consumption, GDP/capita, and globalization harm ecological efficiency.
- The CO_2 emissions model: similarly, inverted U shape nexus has been detected between CO_2 emissions and ECoI for the entire sample when other independent variables are considered. Individual country analysis, however, indicates that the EKC is statistically valid for only three GCC member states. Furthermore, long-term coefficients demonstrate that globalization increases CO_2 emissions, whereas NREW consumption declines them. Nonetheless, GDP has yet to have any significant impact.

This research draws some policy implications in ECoI, Globalization, and energy areas.

- ECoI policies

The inverted U-link between environmental pollution and economic advancement in the GCC region affirms that the first milestone toward controlling ecological externalities caused by industrialization/modernization is to convert the economy from a hydrocarbon-intensive economy to a technology-based one to realize the benefits of the highest level of complexity attained after a certain threshold, as the EKC states. This is in addition to several measures and incentive schemes that should be offered to industries, such as providing tax exemptions and other forms of subsidies to industries and businesses that export innovative products, establishing an effective industrial law carbon strategy to encourage more low-carbon technology and enterprise innovation, and eventually developing appropriate rewards programs to businesses that use renewables resources. On the other hand, the GCC states must expand engagement in green investment and work to reduce industrialization's reliance on nonrenewable sources. Fortunately, the Gulf Cooperation Council has plenty of room to spur investment in carbon capture and storage and renewable energy projects [80].

- Globalization policies

Owing to the structural changes implemented in numerous globalization-related sectors, GCC countries have accomplished considerable achievements in expanding trade and luring international investment. For instance, three of the top 10 nations globally to strengthen the business environment are from the Gulf alliance (KSA, Bahrain, and Kuwait) [80]. However, further effort is needed to counteract the harmful consequences of globalization on the environment. According to [15], economic globalization reinforced by stringent environmental legislation can improve environmental quality in high-income countries through structural changes and effective technology. In addition to the rigorous environmental regulations enacted in the Gulf nations, foreign investment and businesses regarded as energy-intensive heavy industries must be scrutinized for environmental viability. Thus, governments can provide benefits and incentives to foreign investors participating in green projects and technologies.

- Energy policies

It is an inescapable fact that the Gulf countries rely heavily on nonrenewable as a primary source of energy consumption and a sizable chunk of their income. For instance, the combined oil contribution to the region's GDP amounted to 26% in 2017, climbing by 22.1% yearly. The Gulf subregions' energy consumption/per capita is almost four times that of the global average [61]. Renewable sources have the potential to reduce EFpc while also solving biocapacity shortages and lowering carbon emissions. The good news is that the Arab Gulf states have recently escalated their efforts to promote the use of renewables. As a result, the non-oil sector's contribution to GDP increased from 55% in 2013 to 73.7% in 2017. However, the governments are not investing enough in the renewable energy sector.

Additionally, resource diversification policies implemented by Gulf authorities away from fossil fuel resources have begun to eventuate. However, most regions' economic activity remains tied to the hydrocarbon value chains [80]. Therefore, governments in Gulf nations must better manage their natural resources, increase incentives for low-carbon energy consumption, improve energy efficiency, and reduce energy concentration.

Regarding the reliance on oil and gas as primary sources of income, fossil fuel subsidy reforms and carbon pricing/carbon taxes will shift energy consumption to cleaner sources and enhance energy efficiency and evoke government revenues. Furthermore, encouraging green lifestyles, pro-sustainable consumption behavior, and increasing society's awareness of environmental devastation would mitigate environmental pressures and stimulate the demand for more sophisticated green products.

In a nutshell, besides being particularly vulnerable to climate impacts that imperil its development and citizens' well-being, the GCC must retain its competitiveness as the world economy approaches a net-zero era. Therefore, any reforms that overlook environmental efficiency are no longer viable options. The GCC states have joined the fight against climate change by declaring national pledges to cut carbon emissions and recently joining the global net zero race. Their endeavors, however, are distinguished by the lack of solid domestic maneuvers and insufficient institutional mandates [63]. Moreover, the region's overdependence on nonrenewable resources renders it vulnerable to energy price fluctuations. Hence, the region's policy challenge is determining how to achieve resilient and green economic development. Accordingly, the paper's outcomes propose considering the ECoI as a policy variable when targeting environmental sustainability. Furthermore, improving natural resource management and facilitating population and business access to renewables are required to attain sustainability, generate less waste, and enhance the region's biocapacity.

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Abbreviations

ECoI	Economic Complexity Index
CO_2	Carbon Emissions
EFpc	Per capita Ecological Footprint
RNEW	Renewable Energy
NREW	Nonrenewable Energy
GCC	Gulf Cooperation Council
EKC	Environmental Kuznets Curve

Appendix A

Table A1. GCC Economic Outlook-2019.

Country	Population (Million)	Current GDP (US$ Billion)	Per Capita GDP (Current US$)	Real GDP Growth	Inflation
Bahrain	1.6	38,574.07	23,504.0	1.8%	1
Qatar	2.8	175,837.55	62,088.1	0.8%	−0.7
Oman	4.9	76,331.52	15,343.1	−1.6%	0.1
Kuwait	4.2	134,628.54	32,000.4	0.4%	1.1
KSA	34.3	792,966.84	23,139.8	0.3%	−2.1
UAE	9.7	421,142.27	43,103.3	1.7%	−1.9
Total	57.5	1,639,480.79			

Source: World Bank Open Data. (2021).

Table A2. Study Variables: Definitions and Measurements.

Abbreviation	Definition	Source
EFpc	Per capita Ecological footprint measured by gha	[81]
NREW	Fossil fuel energy consumption (% of total)	[65]
CO_2 Emissions	Carbon dioxide emissions/person measured by Ton of oil equivalent	[82]
ECoI	Economic complexity measured by export diversification and ubiquity	[66]
KOF	Measures globalisation 's impact on the economy, society, and politics	[83]
GDP_{pc}	GDP per capita growth (annual %)	[65]

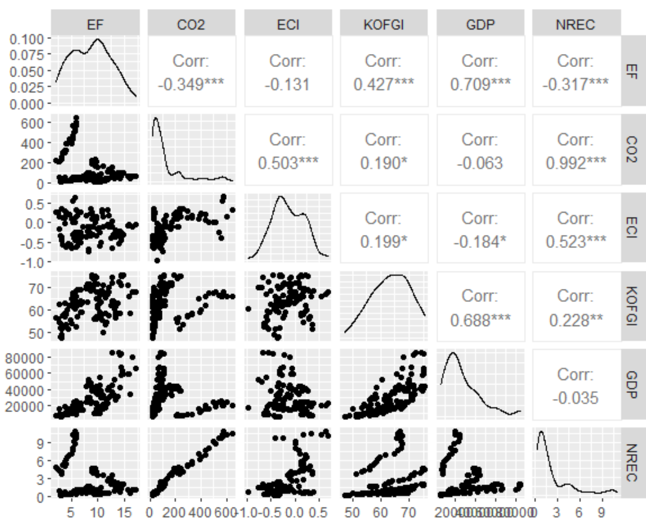

Figure A1. Pairwise correlation results. * Indicates 0.05 significance level; ** indicates 0.01 significance level; and *** indicates 0.001 significance level.

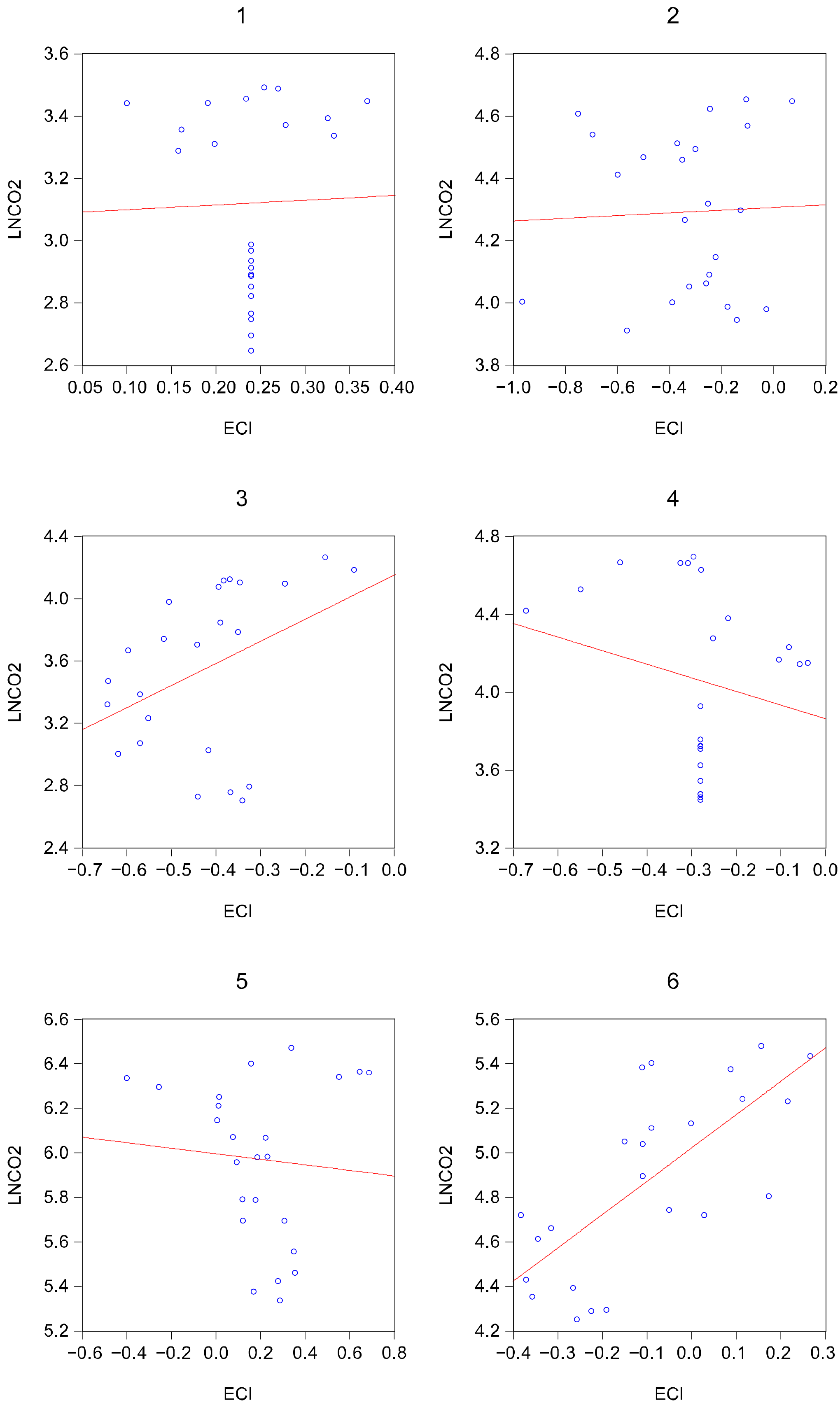

Figure A2. CO_2 and ECoI.

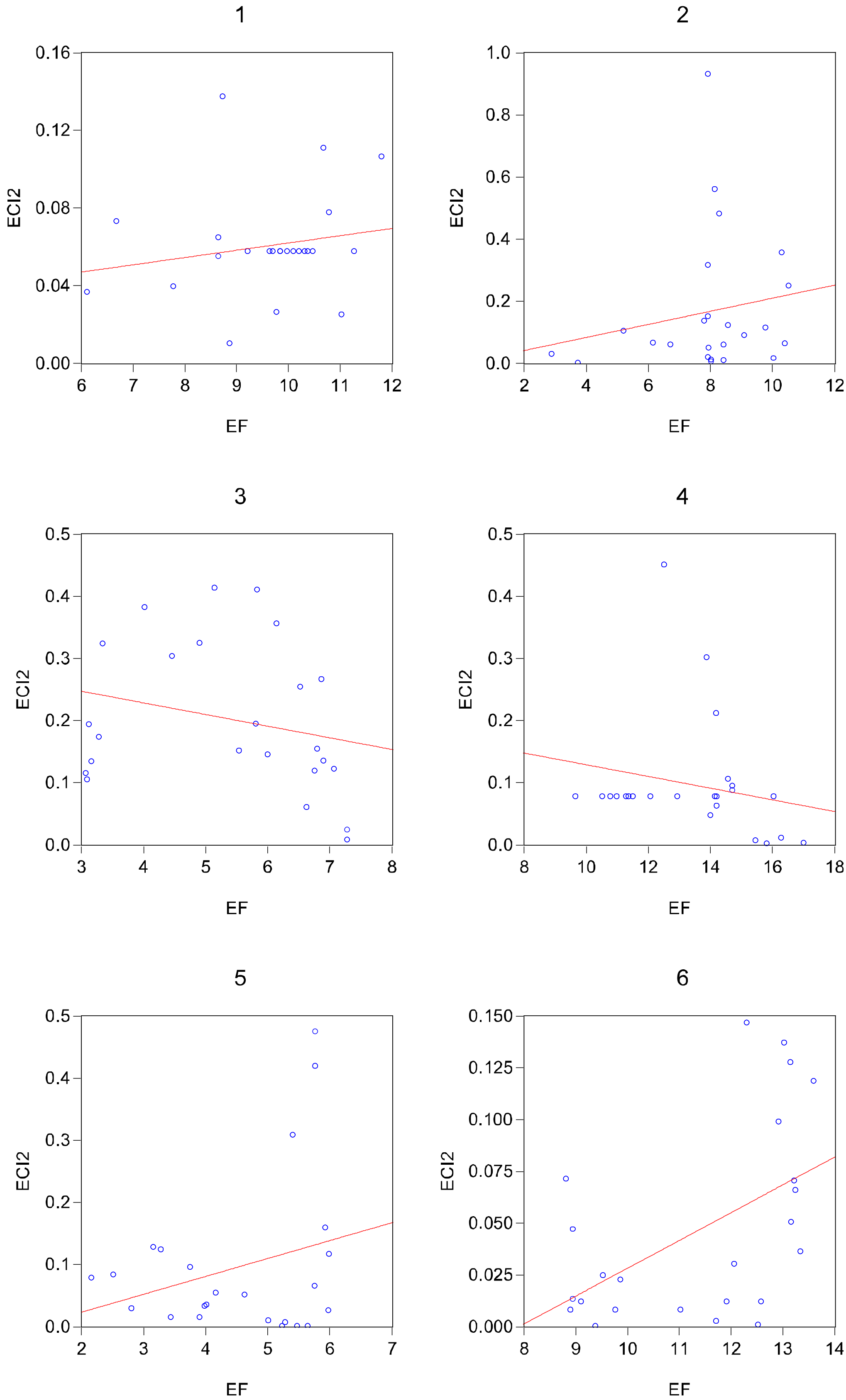

Figure A3. EFpc and ECoI.

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