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A Competitive World, Changing Environment: The Environmental Impact of Global Dynamics Between 1990-2022

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This study investigates the long-term and short-term relationships between economic growth, industrial performance, energy consumption, trade openness, and environmental quality by employing the CS-ARDL model for the G-7 countries. The findings indicate that while economic growth and energy consumption negatively impact the environment, industrial performance and trade openness contribute positively to environmental quality. These results underscore the importance of implementing sustainable growth strategies and enhancing energy efficiency measures to effectively address environmental challenges.

I. Introduction

Globalization drives the rapid expansion of national economic activities across borders, promoting industrialization and modernization of economic development paradigms. Historically, industrialization has underpinned economic development but also incurred significant social and environmental costs; presently, addressing these issues constitutes one of humanity's greatest challenges. This situation highlights the urgent need for innovative and collaborative global demand for cleaner energy solutions among industries striving for competitive advantage. These evolving dynamics not only foster economic growth but also support environmental sustainability objectives, creating a mutually beneficial pathway for ecologically sound and enduring economic development.

The Environmental Kuznets Curve (EKC) hypothesis extensively explores the relationship between economic growth and environmental degradation. Grossman and Krueger (1991), in their seminal study, provided evidence that economic growth initially leads to environmental degradation during early stages of development, but as GDP per capita increases, environmental quality improves, thereby supporting the EKC hypothesis. Various studies have confirmed its relevance in diverse geographical contexts, including research by Zafar et al. (2022), Adebayo et al. (2023), and Wang et al. (2024).

The validated mechanisms of the EKC hypothesis emphasize the necessity for developing integrated policy frameworks that balance industrial competitiveness with

environmental objectives. While the competition for industrial supremacy traditionally held an economic focus, it now encompasses adherence to environmental protection principles and sustainability norms. Countries are increasingly integrating environmental considerations into national policies, influencing product production decisions and investments in low-emission energy sources. The alignment between competitiveness and environmental goals underscores the potential for policy frameworks that harmonize economic development with environmental sustainability, especially in advanced economies like the G-7 countries.

Regarding the interplay between industrial competitiveness and environmental quality, Triebswetter & Hitchens (2005) found that strict environmental regulations in German industrial facilities do not significantly impact competitiveness, with compliance costs remaining low. Babool & Reed (2010) noted that stringent environmental policies generally negatively affect the manufacturing sector while benefiting environmentally friendly products. Al-Mulali & Ozturk (2015) highlighted that urban and industrial development in MENA countries adversely affects the environment, although political stability mitigates this impact. Stavropoulos et al. (2018) demonstrated that the relationship between environmental regulations and industrial competitiveness in China is U-shaped, with innovation playing a crucial role. Zhao & Yuan (2021) indicated that local government initiatives and industry-focused policies enhance green competitiveness. While Zafar et al. (2022) argued that industrialization in Asia increases carbon emis-

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sions, Rai & Rawat (2022) contested this negative impact. Rehman et al. (2023) suggested that financial inclusion positively influences environmental quality in high-income countries.

This research focuses on the interactions between industrial competitiveness, trade openness, energy usage, and economic growth in determining environmental quality in the G-7 countries. We propose the Load Capacity Factor (LCF), a novel indicator measuring both biocapacity and ecological footprint beyond traditional environmental parameters. LCF provides a comprehensive understanding of environmental sustainability by quantifying a nation's ability to align resource consumption with its biological boundaries.

II. Data and Methodology

A. Data

This study utilises annual data to examine the dynamic relationships between environmental quality and competitive industrial performance for G-7 countries from 1990 to 2022. The variables in the study are defined as follows: *LCF* (load capacity factor), *RGDP* (economic growth per capita, constant 2015 US dollars), *CIP* (competitive industrial performance index), *ENG* (per capita primary energy consumption, kWh/person), and *TO* (trade openness as a percentage of GDP). Data for these variables were obtained from four distinct sources and log-transformed for analytical purposes. Specifically, the *LCF* variable was sourced from the Global Footprint Network database, the *CIP* variable from the UNIDO database, and the *TO* and *RGDP* variables from the WDI. The *ENG* variable was derived from the OWID database.

B. Methodology

The CS-ARDL model exhibits several key strengths, including the incorporation of both short-run and long-run parameters, error correction terms, and cross-sectional averages for each relevant variable in both time frames. This model permits flexibility regarding the unit root properties of the variables, accommodating both $I(0)$ and $I(1)$ variables. Furthermore, it accounts for heterogeneity across units and yields robust results even in the presence of omitted variables or endogeneity issues (Azam et al., 2022; Chudik & Pesaran, 2015). With these advanced features, the CS-ARDL model, applied in this study, is succinctly presented in Equation (1).

$$\begin{aligned} \Delta \ln LCF_{it} = & \delta_i + \gamma_i \left(\ln LCF_{it-1} - \vartheta_i X_{it-1} - \theta_{1i} \overline{\ln LCF}_{t-1} - \theta_{2i} \overline{X}_{t-1} \right) \\ & + \sum_{j=1}^{p-1} \phi_{ij} \Delta \ln LCF_{it-j} + \sum_{j=1}^{q-1} \zeta_{ij} \Delta X_{it-j} \\ & + a_{1i} \overline{\Delta \ln LCF}_t + a_{2i} \overline{\Delta X}_t + \varepsilon_{it} \end{aligned} \quad (1)$$

In Equation (1), $\Delta \ln LCF_{it}$ represents the dependent variable, which is explained in the long term by a set of independent variables X_{it} (*lnRGDP*, *lnCIP*, *lnENG*, *lnTO*). The symbols $\overline{\ln LCF}_{t-1}$ and $\overline{X}_{t-1}$ represent the long-term averages of the dependent and independent variables, respectively, while $\Delta \ln LCF_{it-j}$ and ΔX_{it-j} reflect the short-term dependent and independent variables. Additionally,

Table 1. CSD and Homogeneity Tests Results

Variable(s)	BP LM	Bias-corrected scaled LM
<i>lnLCF</i>	294.9327 (0.0000)***	42.1593 (0.0000)***
<i>lnRGDP</i>	544.4574 (0.0000)***	80.6618 (0.0000)***
<i>lnCIP</i>	614.2646 (0.0000)***	91.4333 (0.0000)***
<i>lnENG</i>	490.8821 (0.0000)***	72.3950 (0.0000)***
<i>lnTO</i>	391.1525 (0.0000)***	57.0064 (0.0000)***
Slope Homogeneity Test		
$(\tilde{\Delta})$	9.936 (0.0000)***	
$(\tilde{\Delta}_{adj})$	10.985 (0.0000)***	

Note: In the table, *** means statistical significance at a 1% level. The figure in each parenthesis denotes the probability to an accuracy of less than 0.01.

$\Delta \ln \overline{LCF}_t$ and $\Delta \overline{X}_t$ denote the short-term averages of the respective variables. The indices j and t refer to the cross-sectional units and time period, respectively. ϑ_i and ζ_{ij} represent the long-term and short-term estimates of the independent variables, while ϕ_{ij} represents the short-term estimates of the dependent variable. a_{1i} and a_{2i} denote the estimates of the averages of the dependent and independent variables, respectively. Finally, δ_i , γ_i , and ε_{it} represent the constant term, error correction coefficient, and error term, respectively.

III. Empirical Results

Given the significant relevance of this phenomenon, a key issue in macro-level panel data analysis is the potential for spillover effects. When one country experiences a shock, there is a possibility that this impact could be transmitted to other countries. Thus, to avoid spurious results, a fundamental check involves assessing the presence of potential CSD among the panel units by calculating the Breusch-Pagan LM (1980) and the bias-corrected scaled LM (LM_{adj}) tests, which are applicable when $T > N$. In the second stage of the analysis, using the delta ($\tilde{\Delta}$) and adjusted delta ($\tilde{\Delta}_{adj}$) test statistics, it is examined whether the slope coefficients are constant or vary from country to country. The results of these tests are presented in Table 1, while the findings of the panel unit root test are reported in Table 2.

The results of the CADF unit root tests demonstrate that all variables are non-stationary at their level but become stationary after taking their first differences. Consequently, as all variables were determined to be stationary at their first differences, or $I(1)$, the relationships among them were examined using cointegration tests. The study employed the Westerlund ECM (2007) panel cointegration test, which allows for heterogeneity, to assess cointegration among the variables. The results of the cointegration tests for the G-7 countries are presented in Table 3. Consequently, in the last step of the analysis, the dynamic interactions between the variables were estimated by using the CS-ARDL model, and the results are reported in Table 4.

Table 2. The results obtained using CADF test

Variable(s)	CADF	
	Level	First Difference
<i>lnLCF</i>	-2.383	-3.139 ***
<i>lnRGDP</i>	-2.146	-4.007 ***
<i>lnCIP</i>	-2.595	-4.091 ***
<i>lnENG</i>	-1.650	-3.211 ***
<i>lnTO</i>	-2.284	-3.606 ***

Note: The critical values for the CADF test are: 1% = -3.06, 5% = -2.84, 10% = -2.73. Additionally, the *** sign in the table indicates that the series is statistically significant at 1%.

The estimates presented in Table 4 demonstrate that a 1% increase in the competitive industrial performance of G-7 countries enhances environmental quality by 0.15% in the long term and by 0.80% in the short term. Furthermore, a one-period lagged increase of 1% in industrial performance results in a further improvement in environmental quality by 0.17% in the short term. These findings highlight the significance of investments in green technologies in conjunction with industrial policies that align with environmental protection goals in G-7 countries, with these effects becoming more pronounced over time.

The results for the remaining independent variables indicate that economic growth negatively affects environmental quality in both the short and long run, and energy

consumption also has an adverse impact on environmental quality. Specifically, a 1% increase in economic growth reduces environmental quality by 0.59% in the long run and by 1.00% in the short run. Similarly, a 1% increase in energy consumption decreases environmental quality by 0.19% in the long run and by 0.34% in the short run. Conversely, trade openness positively influences environmental quality, with a long-run increase of 0.09% and a short-run increase of 0.15%.

IV. Conclusion

The study examines the relationship between environmental sustainability and economic growth, energy consumption, industrial competitiveness, and trade openness in G-7 countries. It highlights important dimensions of the relationship between development and environmental sustainability. The data analyzed indicates that economic growth and energy usage may contribute to environmental costs, while industry performance and trade liberalization help sustain and maintain the environmental level, acting as stabilizers. This underscores the need for sustainable economic development alongside environmental protection.

The study emphasizes the importance of integrated policy frameworks spanning energy efficiency, green industrial policies, and the role of trade in transferring clean technologies. Policymakers are encouraged to focus on strategies that reduce environmental damage while promoting

Table 3. Westerlund ECM (2007) panel cointegration test results

Test(s)	Statistic	<i>z</i>	<i>p</i>	Robust <i>p</i>
G_t	-2.9440	-2.4840	0.0070 ***	0.0020 ***
G_a	-8.2530	0.6050	0.7270	0.1760
P_t	-6.5520	-1.7960	0.0360 **	0.0160 **
P_a	-6.5020	-1.0140	0.4440	0.2100

Note: The symbols *** and ** in the table denote statistical significance at the 1% and 5% levels, respectively.

Table 4. CS-ARDL short and long-term estimation results

Variable(s)	$lnLCF=f(lnRGDP,lnCIP,lnENG,lnTO)$		
Panel A: Short-Term Results	Coefficient	Std. Err.	<i>p</i> -value
$\Delta lnRGDP$	-1.0072	0.2530	0.0000 ***
$\Delta lnCIP$	0.8005	0.0456	0.0800 *
$\Delta lnCIP (-1)$	0.1720	0.0645	0.0080 ***
$\Delta lnENG$	-0.3435	0.1789	0.0550 *
$\Delta lnTO$	0.1576	0.0499	0.0020 ***
$ECT (-1)$	-1.7513	0.0530	0.0000 ***
Panel B: Long-Term Results	Coefficient	Std. Err.	<i>p</i> -value
<i>lnRGDP</i>	-0.5973	0.1652	0.0000 ***
<i>lnCIP</i>	0.1470	0.0471	0.0020 ***
<i>lnENG</i>	-0.1952	0.1023	0.0570 *
<i>lnTO</i>	0.0909	0.0290	0.0020 ***

Note: Here ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

economic development. This work provides guidance for aligning economic growth with environmental sustainability, supporting broader sustainable development goals.

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