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Research article

A simultaneous impact of digital economy, environment technology, business activity on environment and economic growth in G7: Moderating role of institutions

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A R T I C L E   I N F O

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A B S T R A C T

This study investigates the simultaneous influence of the digital economy, environmental technologies, business activity, and institutional quality on both the environment and economic growth in G7 economies from 1996 to 2020. The study provides an in-depth analysis to investigate the influence of institutional quality, particularly the regulatory environment, on business activity. Employing a rigorous methodology encompassing correlation analysis, long-term examination using Driscoll and regression estimators, and the utilization of various digital economy indicators such as internet usage and cell subscriptions, we uncover significant insights. The findings underscore the substantial impact of digital economies in mitigating carbon emissions and driving economic growth at an accelerated rate. Moreover, the study reveals that certain regulatory constraints on corporate operations can paradoxically facilitate carbon emission management while also fostering economic expansion. The study validates the presence of an inverted U-shaped Environmental Kuznets Curve (EKC) in G7 economies. This suggests that there is a specific point at which economic activities start to contribute more to carbon emissions. Moreover, the study highlights the importance of achieving a balance between economic growth driven by foreign direct investment and the goals of environmental sustainability. Environmental technology is becoming increasingly important in the regulation of emissions. Significantly, the study highlights the need to enhance the quality of implementing institutional regulations. It suggests that G7 economies can improve both environmental quality and economic growth by adopting superior regulatory methods. These findings are relevant for governments seeking economic growth and environmental protection. They suggest the need for specific policy actions to accomplish sustainable development goals.

1. Introduction

Carbon emissions are a significant driver of climate change as they effectively retain heat within the atmosphere, thereby intensifying global warming [1,2]. The warming phenomenon causes disturbances in ecological systems, modifies meteorological patterns, and intensifies extreme weather phenomena, contributing to the escalation of sea levels [3]. In light of the most severe consequences of

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climate change, the members of the Group of Seven (G7) have committed to decrease emissions and shift towards economies with lower carbon footprints [4]. The G7 economies, comprising the United States, Canada, United Kingdom, Germany, France, Italy, and Japan, represent a coalition of advanced industrialized nations that convene regularly to address economic policies and global challenges. The implications of G7 carbon emissions are essential for global climate change initiatives and a sustainable future [5,6].

The G7 economies consist of several of the largest economies in the world and represent a substantial portion of global carbon emissions [7]. Industrialization and economic progress in these nations often entail heavy fossil fuel usage, resulting in substantial CO2 emissions from various sectors including energy generation, transportation, and industry [8,9]. G7 nations have pledged to reduce carbon emissions and move to low-carbon economies [10]. The goal is to keep global warming well below 2 °C above pre-industrial levels, which is in line with global accords like the Paris Agreement. G7 members establish domestic objectives for reducing emissions, provide resources for renewable energy, advocate for energy efficiency, and endorse actions to enhance climate resilience. The achievement of a sustainable environment necessitates substantial expenditures, technological advancements, and legislative backing from the G7 nations.

The G7 can achieve carbon reduction through two primary paths: the energy revolution and the digital revolution [11]. These two approaches have the potential to foster the advancement of production technology and governance models collaboratively, thus instigating significant transformations inside industries within the G7 economies. Wang et al. [12] suggest using the digital economy to reach a carbon emission peak and carbon neutrality. The "dual carbon" goal requires digital economy growth. The 2016 G20 Leaders' Summit in Hangzhou defined "digital economy" as a collection of interconnected economic activities that use data resources as a factor of production, modern information networks as a medium, and effective ICT use to optimize economic structure and efficiency. Digital technologies and their integration into various sectors, have revolutionized traditional business models, communication channels, and consumer behaviors [13]. This transformation has not only accelerated economic activities but has also introduced new challenges and opportunities for environmental sustainability. Simultaneously, the rapid advancement of ecological technologies has offered innovative solutions to mitigate environmental degradation and address climate change concerns. However, the extent to which these technologies contribute to sustainable development and economic growth varies depending on institutional frameworks and policy interventions within each G7 nation.

Moreover, business activities can directly and indirectly affect environmental sustainability and economic growth [14]. Businesses drive innovation, generate employment, and foster economic growth. However, business activity leads to the consumption of natural resources, produces emissions, and contributes to environmental degradation [15]. Consequently, there exists a pressing need to explore how business activities can be aligned with ecological sustainability objectives to achieve inclusive and sustainable economic growth in the G7 nations.

At the heart of this discussion lies the modirating function of institutions, which encompasses regulatory frameworks, governance structures, and policy mechanisms that influence both economic and environmental outcomes. Regulatory institutions are tasked with enforcing environmental laws and regulations, including emissions standards, pollution controls, and conservation measures [16,17]. Institutions of high quality ensure stringent enforcement, monitoring, and mitigation of environmental degradation [18]. Regulatory certainty and stability provided by quality institutions encourage investment in environmental infrastructure, such as wastewater treatment plants, renewable energy facilities, and pollution control technologies. Regulations and permitting processes facilitate private sector participation and innovation in sustainable development projects, leading to improved environmental outcomes [19]. High-quality regulatory institutions provide a stable and predictable regulatory environment conducive to business investment and economic growth. Transparent and consistent regulations reduce uncertainty and transaction costs for businesses, fostering investor confidence and attracting domestic and foreign investment [20].

Institutions play a pivotal role in mitigating the effects of the digital economy, environmental technology, and business activities on both the environment and economic growth. Therefore, this study investigates the dynamic impact of the digital economy, environmental technology, and business activity on environmental quality and economic growth within the G7 nations from 1996 to 2020. Additionally, the study underscores the moderating role of institutions in stabilizing environmental quality and fostering economic growth. The study contributes to the existing literature in several ways: Firstly, it employs two core digital economy indicators, namely internet usage and mobile subscriptions, concurrently to analyze their effects on both the environment and economic growth. Secondly, the study utilizes environmental technology to evaluate its implications for both the environment and economic growth. Thirdly, it assesses the impact of business activity by considering the days required to start a business. Lastly, the study examines the moderating role of institutions, specifically regulatory quality, to offer valuable insights for policymakers, businesses, and governments in formulating evidence-based strategies to promote sustainable environmental management and development within the G7 economies. This paper presents a comprehensive analysis of these interconnections to contribute to the 21st-century discourse on balancing economic growth and environmental conservation. The subsequent sections of the study are structured as follows: Section 2 delineates the Literature Review and Hypothesis Development, while Section 3 elucidates the Theoretical Framework and Methodology. The Data and Methodology are expounded upon in Section 4, with Section 5 devoted to presenting the Results and Discussion. Finally, Section 6 encapsulates the Conclusion.

2. Literature Review and hypothesis

2.1. Digital economy, environment, and economic growth

The digital economy has been demonstrated to significantly decrease carbon emissions due to several factors, including the influence on infrastructure, the effect on technical innovation, and the effect on resource allocation [21,22]. Yi et al. [23] conducted a study to examine the influence of the digital economy on the decrease of carbon emissions. They utilized panel data from various regions in China. The research findings suggest several remarkable outcomes. To begin with, the rapid growth of the digital economy exhibits a notable spatial impact on mitigating carbon emissions. Furthermore, the digital economy reduces carbon emissions by directly and indirectly altering the energy structure. Furthermore, the decrease in carbon emissions caused by the digital economy is especially beneficial for eastern regions. Dong et al. [24] found a significant variation in digital economy development among countries, highlighting a growing gap between highly digitalized nations and those with limited connectivity. Their research also indicates that although per capita carbon emissions are going up, the intensity of carbon emissions is going down as the digital economy grows. Their research also shows that improving economic growth acts as a mediator between the digital economy and emissions of carbon. Zhang et al. [25] evaluated the ecological footprint of digital trading and found that it correlates negatively with renewable energy usage; this finding has policy implications for environmental sustainability. According to Wang et al. [26], the digital economy significantly reduces carbon emissions per capita. The digital economy may also have an indirect effect on carbon emissions per capita via its influence on technical innovation.

2.2. Environmental technology, environment, and economic growth

Green technology presents a feasible strategy for the preservation of energy and the mitigation of carbon emissions. The study conducted by Ulucak [27] investigates the influence of environmental technology on the promotion of green growth in BRICS countries while accounting for the use of both renewable and non-renewable energy sources. The study utilizes sophisticated panel data estimation methodologies to demonstrate a favorable impact of environmental-related technology on the promotion of green growth. Sharif et al. [28] examine the relationships between investment in green energy, economic growth, and innovation in green technology in ASEAN-6 countries. Their research uses sophisticated panel methodologies to identify the positive long-term consequences of green energy and investment in innovation, as well as the favorable effects of economic growth and environmental levies. The focus is on regulatory policies that facilitate green investment and accelerate the development of green technology innovation in the ASEAN-6 countries. Meirun et al. [29] investigate the function of green technology innovation in promoting economic success while reducing ecological impacts. Using the innovative bootstrap autoregressive-distributed lag technique, they establish a positive and statistically significant correlation between green technological innovation and long-term economic growth. Additionally, they find a negative and statistically significant connection with short-term carbon emissions. The influence of sustainable technology transfer and innovation on green growth is analyzed by Fernandes et al. [30]. Their research reveals that the transfer of sustainable technology and innovation promotes environmentally friendly economic growth, offering new perspectives on the debate between green growth and economic growth and its policy consequences.

2.3. Institutions, environment, and economic growth

The existing body of literature indicates that the presence of a robust institutional framework is crucial in promoting economic development and facilitating growth [31,32]. Concurrently, there exists a substantial correlation between economic growth and environmental quality. Scholars have proved that the efficacy of environmental policy is contingent upon the strength of institutions. Political liberty, civil rights, and democracy have been found to have a favorable influence on ecological quality [33]. Additionally, the presence of secure property rights and legal protection has also been observed to have a good impact [34]. The enhancement of the rule of law is correlated with a decrease in environmental harm and an enhancement in the execution of sustainable policies [35]. Castiglione et al. [36] provide for a positive bilateral correlation between the rule of law and income, suggesting that an increase in income is associated with a more robust rule of law. Moreover, there is a clear inverse relationship between the rule of law and pollution, underscoring the significance of implementing legislation to regulate emissions.

3. Theoretical chain and methodology

The digital economy encompasses economic activity facilitated by digital technologies, such as trade, digital platforms, and data-driven innovations. Theoretical foundations derived from innovation theory, such as the spread of inventions and technology adoption models, offer valuable insights into the impact of digitalization on economic activity and its role in promoting growth. Environmental technology refers to a range of technologies and practices that are designed to minimize the adverse effects on the environment [37]. This component analyzes the impact of adopting and developing environmental technologies on resource use efficiency in the fields of environmental economics. The idea of the Environmental Kuznets Curve may be applicable, indicating a relationship between environmental deterioration and economic growth that follows an inverted U-shaped pattern [38]. This relationship is influenced by advancements in technology and interventions in policy [39]. Business planning and corporate social responsibility explain how a company's policies and actions impact its environment and financial performance. Porter's perspective on competitive advantage and the resource-based view offers valuable insights into how organizations can include environmental sustainability in their plans to improve their competitiveness and long-term sustainability [40]. Economic activity, technical advancements, and environmental policies operate inside institutions. This component uses institutional economics and governance theories to examine how regulatory frameworks, property rights, and governance structures mediate the relationship between the digital economy, environmental technology, business activity, and environmental and economic growth. Institutional theory explains how formal and informal institutions influence incentives, behavior, and outcomes in sustainable development. The framework integrates various theoretical views to comprehend the relationships between the digital economy, environmental technology, business activity, and institutions and their effects on the environment and economic growth in the G7 nations. It prepares for empirical analysis and policymaking to promote sustainable development and address environmental and economic issues.

3.1. Model construction

By leveraging theoretical reasoning, we incorporate the variables of the digital economy, environmental technology, and business activity. Moreover, the influence of institutions on moderation is significant in literature. To circumvent the incompetence model, we incorporate the economic growth impact as a quantitative measure of income, foreign direct investment, and government expenditure in the empirical approach. The baseline model for environment and economic growth can be defined as Equations (1) and (2).

$$CO2 = f\left(DigEco1, DigEco2, EnvTech, BusA, GDP, GDP^2, FDI, GovEX\right) \tag{1}$$

$$GDP = f(DigEco1, DigEco2, EnvTech, BusA, CO2, FDI, GovEX) \tag{2}$$

In eq (1), $CO2$ & GDP are environmental quality and economic growth. $DigEco1$ *and* $DigEco2$ are digital economy, measured with internet usage, mobile subscription respectively. $EnvTech$ is environmental technology. $BusA$ is a business activity proxied by time to start a business. GDP, stands for Gross Domestic Product per capita. GDP may increase at first, which might improve economic development but also worsen environmental quality. However, emissions can be reduced, and environmental conditions can be enhanced in subsequent stages as the economy develops, technology progresses, and better rules are put in place. Thus, GDP may have a positive initial influence. $\left(\frac{\partial CO2_{it}}{\partial GDP_{it}} > 0\right)$ while the second phase might result in a negative impact $\left(\frac{\partial CO2_{it}}{\partial GDP_{it}} < 0\right)$, representing an inverted U-shaped Environmental Kuznets Curve. FDI, *and* $GovEX$ are the foreign direct investment and government expenditure.

Next, models extended to evaluate the moderation impact of the digital economy, business activity, and institutions in terms of regulatory quality (see equations (3) and (4)).

$$CO2 = f\left(DigEco1, DigEco2, EnvTech, BusA, GDP, GDP^2, FDI, GovEX, (Moderator - 1\ to\ 5)\right) \tag{3}$$

$$GDP = f(DigEco, DigEco2, EnvTech, BusA, CO2, FDI, GovEX, (Moderator - 1\ to\ 5)) \tag{4}$$

Where $Moderator - 1\ to\ 5$ is the moderation impact of the $GDP * DigEco1$ ($Moderator - 1$), $GDP * DigEco1$ ($Moderator - 2$), $GDP * BusA$ ($Moderator - 3$), $BusA * RQ$ ($Moderator - 4$), $BusA * GDP * RQ$ ($Moderator - 5$).

4. Data and methodology

4.1. Data

Table A1 provides a summary of the descriptions of the variables and sources. Data for the G7 economies' variables have been collected from various sources for the period of 1996–2020 (See Table A1). The dependent and independent variables trend for the year 2020 is given in Figs. 1 and 2.

4.2. Econometric procedure

As a preliminary step, we conducted the panel slope heterogeneity test and the cross-sectional dependence test. Panel co-integration was then examined after panel stationarity. The final procedures included conducting a long-term study and verifying a causal relationship between the variables.

4.2.1. Step-first: SH-T & CD-T

As a result of energy assimilation and foreign direct investment, the panel of G7 countries may become dependent on one another. To prevent inefficient findings caused by model misspecification, we employed Pesaran's [41] CD test. It also handles the problem of

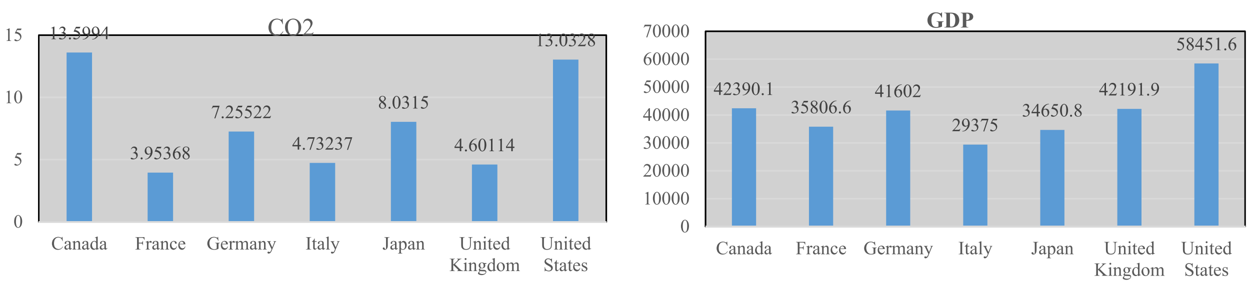

Fig. 1. Trend of dependent variables for 2020.

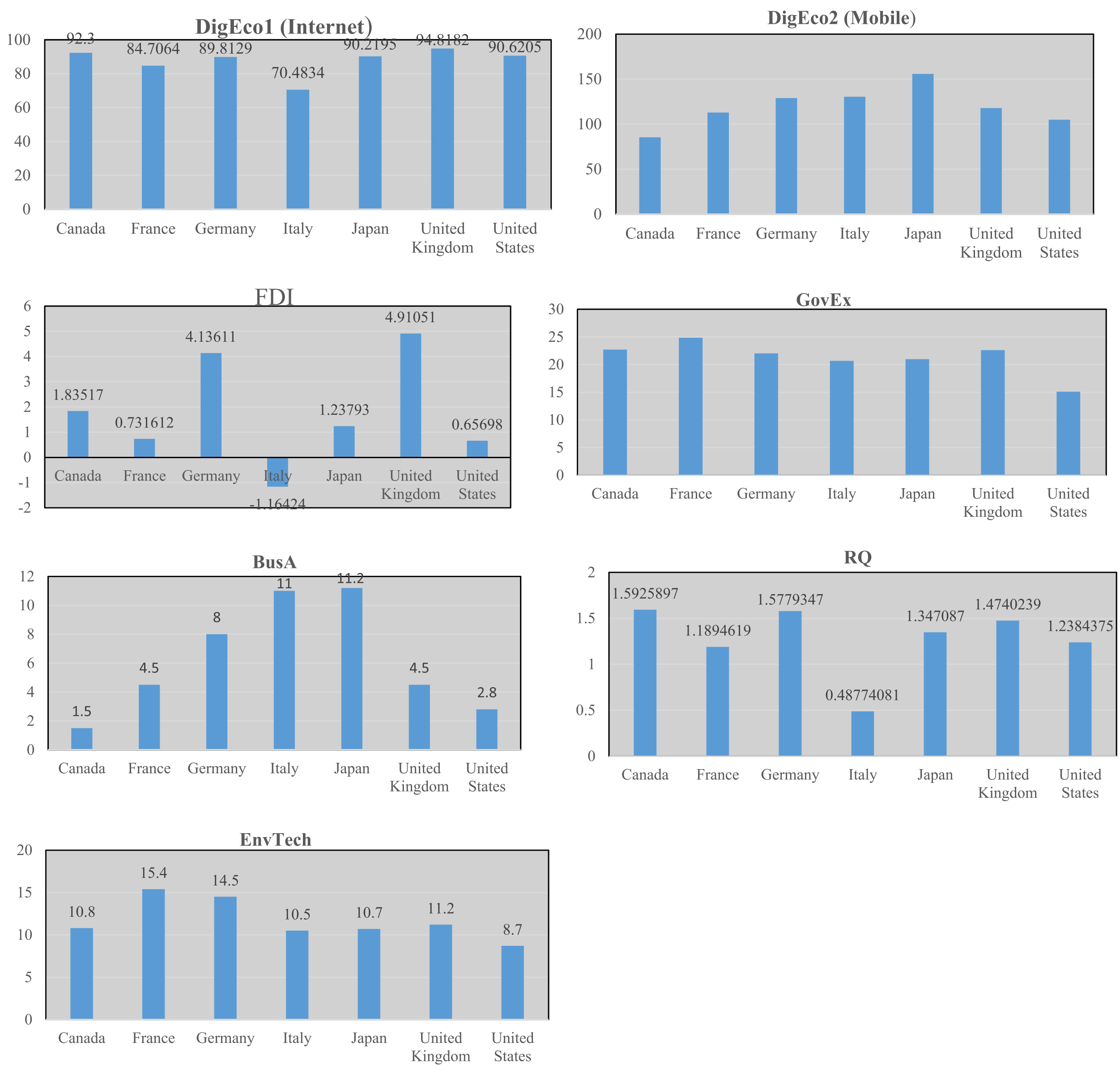

Fig. 2. Trend of independent variables for 2020.

size distortion. Secondly, there is the possibility that the slope coefficient varies among countries as a result of variations in technical development and growth rates. It is necessary to account for cross-sectional heterogeneity before doing the unit-roots test. Based on the possibility of homogeneity and country-specific effects, the current study uses the Pesaran & Yamagata [42] test to examine if the relevant variables have a uniform slope. This test is conducted using the "delta (Δ) and biased adjusted delta (Δ^{adj})."

4.2.2. Step-second: stationarity

In our analysis, we investigated the order of integration of the variable that adjusts for cross-sectional dependency and slope homogeneity concerning the panel unit root process. Traditional first-generation unit root tests, such as those by Phillip Perron, Levin, Lin, and Chu, often encounter challenges when dealing with cross-correlation. Therefore, we employed Pesaran's [43] "second-generation unit root tests" (CIPS) to overcome this limitation. The utilization of the CIPS test led to enhancements in both cross-dependency control and performance. The rejection of the null hypothesis by the CIPS test indicates that the variables are stationary (see equation (5)).

The average of the t-ratios, indicated by CIPS is.

$$CIPS(N,T_m)=\frac{\sum_{i=1}^{N}t_i(N,T_m)}{N} \tag{5}$$

4.2.3. Step-3: Co-integration identification

The subsequent critical step in the econometric method is confirming the presence of a long-term association among the variables chosen for investigation. Nevertheless, there are a few limitations to Johansen, Pedroni, and Kao's co-integration when it comes to the dependence of panels and the variability of co-integrated vectors across sections [44]. Westerlund co-integration is an alternate method that is better suited to CD problems and yields efficient solutions without residual dynamics. Because of its superior performance, even with a small sample size, the Westerlund [45] test was employed to achieve this goal. Westerlund relies on the application of two panel-specific autoregressive (AR) parameters (see equations (6) and (7)).

$$VR=\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{E}_{it}^{2}\widehat{R}_{i}^{-1} \tag{6}$$

And

$$VR=\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{E}_{it}^{2}\left(\sum_{t=1}^{n}\widehat{R}_{i}\right)^{-1} \tag{7}$$

4. Step-Fourth: Long run Driscoll & Kraay analysis.

The study estimates the long-term impacts using the Driscoll & Kraay (DK) [46] approach. It appears that panel data showing geographically related associations can be effectively analyzed using this approach. When an international or statistical connection is observed in the dataset, DK becomes effective. When two or more observations are physically close to each other, a phenomenon known as "spatial dependency" arises. Contrarily, the idea of temporal dependence states that observations that are geographically adjacent to one another are more likely to exhibit correlation. It may be helpful to take into account panel data that may not hold to the premise of independence. Spatial correlation might be used to improve the effectiveness of parameter estimations. The techniques mentioned above are pretty adaptable and can be made to work with a wide variety of datasets and correlation patterns.

5. Results and Discussion

Summary statistics for the variables are shown in Table 1. The average CO2 emissions for the G7 are roughly 10.34712 units, with a standard deviation of about 4.518884 units, suggesting significant variation in emissions levels. Similar patterns of variability are seen in other variables: GDP averages around 39007.89 units and varies from 29375.04 to 60698.01 units, while FDI averages about 2.157138 units and ranges from −1.16424 to 12.7315 units. The average government expenditure is 19.19584 units, with a narrow range of 13.92745–24.8446 units. With a range of 5.1–15.8, environmental technology has considerable variability, with an average of roughly 10.26 units. The data about internet usage and mobile subscriptions (DigEco2) exhibit significant variability and more extensive ranges, with respective means of roughly 60.52749 and 87.32169 units. Business activity ranges from 1.5 to 279 units, with an average of approximately 20.328 units but notable fluctuation. Lastly, the average regulating quality for the dataset is roughly 1.347213 units, which represents the typical level of environmental quality. These statistics help in comprehending the properties of each variable for additional analysis and interpretation by offering a thorough outline of the dataset's distribution, central tendency, and variability.

Table 2 presents the results of a cross-dependence test conducted on multiple variables within the dataset. The CD-test statistics reveal a significant presence of cross-sectional dependency among panel groups for all variables. The noteworthy test statistics and p-values provide compelling evidence against the null hypothesis of cross-section independence. The average correlation coefficients (mean ρ) range from 0.12 to 0.97, indicating varying degrees of linear association between panel groups for different variables.

Table 1
Descriptive summary.

Variable(S)	Mean	Std.dev	Min	Max
CO2	10.34712	4.518884	3.953682	20.4698
FDI	2.157138	2.221795	−1.16424	12.7315
GDP	39007.89	7270.51	29375.04	60698.01
GovEX	19.19584	2.592891	13.92745	24.8446
EnvTech	10.25714	2.702052	5.1	15.8
DigEco1	60.52749	27.71373	1.02329	94.8182
DigEco2	87.32169	39.52533	4.273801	161.4693
BusA	20.328	37.18824	1.5	279
RQ	1.347213	0.360362	0.487741	2.020525

Moreover, the average absolute values of the correlation coefficients (mean abs(ρ)) consistently demonstrate a high level of correlation, ranging from 0.3 to 0.97. This underscores a substantial overall correlation between panel groups, irrespective of the direction of the relationship. These findings suggest the existence of interdependence or shared factors influencing the variables across distinct groups. It underscores the importance of considering cross-sectional dependencies in future studies and modeling endeavors.

Table 3 displays the findings of a set of studies that investigate variations in slope across different panel specifications in various models. The provided information consists of the test statistic (Δ) and its corresponding p-value. The null hypothesis (H0) being investigated is that the slope coefficients are uniform across panels. All the given p-values are extremely low, showing compelling evidence against the null hypothesis in support of slope heterogeneity. This indicates that there are notable variations in the inclinations of the regression models among various panel specifications. These findings emphasize the need to take into account and adjust for variations in slope when examining the correlation between variables in the stated models.

Table 4 shows CIPS unit root test results for the concerned variables. The "Level" and "First-Difference" test scores for each variable are reported in the statistics. For reference, the test statistics critical values at 10 %, 5 %, and 1 % significance levels are given. The statistically significant test statistics with absolute values greater than the crucial values show that all variables become stationary after first differencing. For time series analysis and modeling, it indicates that the variables have a stochastic tendency in their values but become stationary when differentiated.

Table 5 shows Westerlund's co-integration test results for the study panel. The test statistic and p-value for each model and panel specification are presented. Westerlund findings shed light on the long-term dynamics and interactions among the variables being studied, which can guide future modeling and analysis, especially in the field of economics and finance.

5.1. Long run findings

Initial findings lead us to the long-run analysis to determine the positive or negative dynamics of the concerned variables in the long run. Accordingly, the study applied the Driscoll & Kraay. Table 6 shows the environmental quality assessment findings. The coefficient impact of GDP and its squared term are statistically significant at the 1 % level. This indicates that economic growth has a significant effect on environmental quality. The positive coefficient for GDP suggests that as GDP increases, CO2 emissions also tend to rise, albeit at a diminishing rate, as indicated by the negative coefficient for the squared term. This implies that while economic growth initially leads to higher emissions, further growth may result in more efficient resource usage or adoption of cleaner technologies, mitigating emissions growth [47]. Further, at the initial stage, economies are not committed to environmental quality but instead are more concerned about production activities. However, with time, economies grow, and technological advancements improve environmental quality. Thus, the study endorsed the inverted U-shaped EKC in the G7 economies. Apart from that, economic growth may lead to a decrease in environmental quality in the long run. The results can be validated [1,48].

The study used two important representative proxies (Internet usage-DigEco1 and Mobile subscription-DigEco2). The coefficient for internet usage is statistically significant at the 1 % level. The negative coefficient suggests that higher internet usage is associated with lower CO2 emissions. This could be due to factors such as increased telecommuting, which reduces the need for physical commuting, or the use of digital technologies to optimize energy usage in various sectors. Similarly, the coefficient for mobile subscriptions is statistically significant at the 1 % level and negatively associated with CO2 emissions. This indicates that higher mobile subscriptions are correlated with lower CO2 emissions, possibly reflecting a shift towards more efficient and environmentally friendly modes of communication and business in the long run [49]. When electronic devices are frequently used, they reduce traveling, thereby reducing carbon emissions in the air. Such things as telecommuting, virtual meetings, and online shopping can lead to a reduction in the need for physical travel. This reduction in travel can result in lower carbon emissions, as fewer vehicles are being used, thus reducing pollution from exhaust emissions. Overall, digital economy findings highlight the potential benefits of technology adoption in reducing environmental impact. At the 1 % level of significance, the environmental technology coefficient shows a negative association with CO2 emissions.

This provides more evidence that technological approaches to environmental problems are effective and that investments in such approaches are associated with reduced emissions. Government spending has a negative correlation with CO2 emissions, and this association is statistically significant at the 1 % level. This suggests that reduced CO_2 emissions are associated with increased government spending, maybe on green infrastructure or environmental protection initiatives. The coefficient for business activity indicates that if the time required to start a business is higher due to regulations, then it can be advantageous for controlling carbon

Table 2
Cross-dependence test (CD).

Variable(S)	CD-test	p-value	average Joint T	mean ρ	mean abs(ρ)
CO2	17.541	0	25	0.77	0.77
FDI	5.617	0	25	0.25	0.3
GDP	15.712	0	25	0.69	0.71
GovEX	13.156	0	25	0.57	0.59
EnvTech	21.522	0	25	0.94	0.94
DigEco1	22.123	0	25	0.97	0.97
DigEco2	21.474	0	25	0.94	0.94
BusA	14.097	0	25	0.62	0.62
RQ	2.763	0.006	25	0.12	0.48

Table 3
Slop heterogeneity testing.

Model(S)	Panels- specification	Statistic	p-value
CO_2 (Models)			
Model-1	Δ	7.647	0.000
	$Adj\Delta$	9.012	0.000
Model-2	Δ	8.122	0.000
	$Adj\Delta$	9.572	0.000
Model-3	Δ	10.574	0.000
	$Adj\Delta$	12.461	0.000
Model-4	Δ	7.055	0.000
	$Adj\Delta$	8.314	0.000
Economic Growth (Models)			
Model-5	Δ	11.899	0.000
	$Adj\Delta$	13.650	0.000
Model-6	Δ	11.548	0.000
	$Adj\Delta$	13.247	0.000
Model-7	Δ	11.600	0.000
	$Adj\Delta$	13.306	0.000
Model-8	Δ	7.343	0.000
	$Adj\Delta$	8.423	0.000

Note: H0: slope coefficients are homogenous.

Table 4
Unit root test.

Variable(S)	Unit-CIPS		Decision
	Level	First-Difference	Order
$CO2$	−2.209	−5.014	(I)
FDI	−3.007	−5.518	(O)
GDP	−0.935	−3.176	(I)
$GovEX$	−1.542	−2.989	(I)
$EnvTech$	−2.199	−3.752	(I)
$DigEco1$	−1.958	−4.437	(I)
$DigEco2$	−1.715	−3.302	(I)
$BusA$	−1.728	−4.684	(I)
RQ	−1.979	−4.893	(I)
Critical values at			
10 %	−2.21		
5 %	−2.33		
1 %	−2.57		

Table 5
Westerlund Co-integration 2005.

Model (S)	Panels- specification	Statistic	p-value
CO_2 (Models)			
Model-1	Some panels	−1.6479	0.0497
	All panels	−1.3944	0.0816
Model-2	Some panels	−1.5131	0.0651
	All panels	−1.3326	0.0913
Model-3	Some panels	−1.4963	0.0673
	All panels	−1.2932	0.0980
Model-4	Some panels	−1.3236	0.0928
	All panels	−1.2986	0.0970
Economic Growth (Models)			
Model-4	Some panels	2.0180	0.0218
	All panels	2.4448	0.0072
Model-5	Some panels	4.5956	0.0000
	All panels	5.4398	0.0000
Model-6	Some panels	3.2481	0.0006
	All panels	4.1073	0.0000
Model-7	Some panels	1.4613	0.0720
	All panels	1.5162	0.0647

Table 6
Digital economy, environment technology on environment assessment.

Variable(S)	*CO2*	*CO2*	*CO2*	*CO2*	*CO2*
GDP	1.029[a]	0.000176[a]	1.042[a]	0.000153[a]	0.000158[a]
	(0.146)	(3.09e-05)	(0.130)	(2.25e-05)	(4.30e-05)
GDP^2		−4.163[a]		−3.655[a]	−1.559[b]
		(0.647)		(0.460)	(0.660)
DigEco1	−0.0331	−0.0918[a]			−0.330[a]
	(0.0222)	(0.0158)			(0.0339)
DigEco2			−0.262[a]	−0.264[a]	−0.504[a]
			(0.0576)	(0.0429)	(0.0460)
EnvTech	−0.0594	−0.0329	−0.273[a]	−0.261[a]	−0.131[a]
	(0.123)	(0.105)	(0.0892)	(0.0817)	(0.0160)
FDI	−0.00357	−0.0244	−0.00525	−0.0203	−0.0109
	(0.0261)	(0.0249)	(0.0224)	(0.0193)	(0.0183)
GovEX	−1.239[a]	−1.666[a]	−1.296[a]	−1.677[a]	−1.558[a]
	(0.223)	(0.237)	(0.162)	(0.213)	(0.258)
BusA					−0.0954[a]
					(0.00885)
Constant	−4.703[b]	−73.58[a]	−4.432[b]	−63.45[a]	−22.73[c]
	(1.900)	(11.88)	(1.722)	(8.397)	(12.07)
Observations	168	168	168	168	168
R-squared	0.493	0.544	0.602	0.645	0.704
Number of groups	7	7	7	7	7

Note: Standard errors in parentheses.
[a] $p < 0.01$.
[b] $p < 0.05$.
[c] $p < 0.1$.

emissions.

This could be attributed to the potential increase in the adoption of environmentally sustainable practices during the operational period. For instance, if regulations mandate a longer time for business setup, companies may utilize this extended duration to implement more eco-friendly measures in their operations, thereby reducing carbon emissions. The impact of foreign direct investment is negative and insignificant throughout the regression models. It highlights the need for policies that balance FDI economic expansion with environmental sustainability. Policymakers could use FDI to encourage green practices while ensuring that regulations and incentives reduce any negative environmental repercussions. The results are consistent with past research [50,51].

Table 7 represents the assessment of economic growth, environmental technology, and economic growth. CO2 emissions, foreign direct investment, environmental technology, and government expenditure show statistically significant relationships with GDP in many scenarios. The results highlight the diverse aspects of economic growth, demonstrating how several factors, including environmental effects, technological progress, government expenditure, and corporate activity, influence the dynamics of GDP. Hence, the results provide valuable insights for policymakers and scholars who aim to comprehend and promote economic development under diverse circumstances.

Table 7
Digital economy, environment technology on economic growth Assessment.

Variable(S)	*GDP*	*GDP*	*GDP*
CO2	0.111***	0.154***	0.0817**
	(0.0140)	(0.0244)	(0.0308)
DigEco1	0.0662***		0.0932**
	(0.0188)		(0.0369)
DigEco2		0.0503**	0.617***
		(0.0184)	(0.0861)
FDI	0.0501***	0.0552***	0.0493***
	(0.00728)	(0.00778)	(0.00729)
EnvTech	0.130***	0.203***	0.130***
	(0.0404)	(0.0533)	(0.0407)
GovEX	0.532***	0.508***	0.573***
	(0.0676)	(0.0965)	(0.108)
BusA			0.000684***
			(0.000232)
Constant	11.31***	11.01***	11.55***
	(0.163)	(0.290)	(0.399)
Observations	168	168	168
R-squared	0.672	0.647	0.676
Number of groups	7	7	7

Note: See Table 6.

Further, the study explores the moderation effects (Table 8) by introducing interaction terms between GDP and different moderators: digital economy indicators such as internet usage (Moderator-1) and mobile subscriptions (Moderator-2), as well as business activity (Moderator-3). The introduction of moderators reveals moderation effects, where the presence of these moderators influences the relationship between GDP and CO2 emissions. For instance, the negative coefficient for Moderator-1 suggests that the positive association between GDP and CO2 emissions weakens when interacting with internet usage. Similarly, Moderator-2 (mobile subscriptions) and Moderator-3 (business activity) also show significant moderation impacts, implying that the relationship between GDP and emissions is contingent upon levels of mobile subscriptions and business activity. These moderation effects highlight the importance of considering contextual factors such as digital economy indicators and business activity when examining the relationship between GDP and CO2 emissions. The findings underscore the multi-faceted interplay between economic growth, technological advancements, and environmental factors, emphasizing the need for nuanced policies that account for these interactions to address environmental challenges while promoting sustainable economic development effectively.

Table 9 displays the moderating effects of institutional impact in terms of the quality of regulations and business activity. The inclusion of moderating effects uncovers interesting trends. The negative values for Moderator-4 and Moderator-5 indicate that the positive relationship between business activity (time required for business) and CO2 emissions becomes less intense when combined with higher quality restrictions. Stringent rules on quality can moderate and mitigate the impact of emissions on economic operations. The results of this study have important policy implications, indicating that carefully constructed regulatory frameworks can minimize the environmental effects of economic expansion. Policymakers can promote environmentally responsible economic development by creating a legislative framework that fosters sustainability and effectively reduces emissions resulting from company activity. Furthermore, comprehending the relationship between corporate activity, the quality of laws, and emissions might provide insights for specific policy interventions aimed at attaining both economic growth and environmental sustainability objectives. Hence, these discoveries emphasize the significance of taking into account regulatory issues in conjunction with economic activity when tackling climate change and advancing sustainable development. Our study results are allied with the recent literature [52,53].

6. Conclusion

This paper introduces a novel perspective on the simultaneous effect of the digital economy, environment technology, and business activity on environment and economic growth in G7 economies from (1996–2020). Further, the study explores the moderation effects by introducing interaction terms between GDP, digital economy, as well as business activity). Additionally, the moderating effects of institutional impact in terms of the quality of regulations and business activity are explored.

The study commences with a comprehensive preliminary analysis of multiple aspects, covering examinations for correlation, cross-sectional dependence, and the appropriate order of integration. Subsequently, we performed a thorough investigation of long-term analysis utilizing Driscoll & Kraay regression estimators. The study employed multi-faceted digital economy indicators, including metrics such as internet usage and mobile subscriptions. The study's significant findings disclose that digital economies reduce carbon emissions in G7 economies and play an important role in speeding up economic growth. Business activity findings highlighted that if the time required to start a business is higher due to regulations, then it can be advantageous for controlling carbon emissions on one side, simultaneously uplifting economic growth. The study endorsed the inverted U-shaped EKC for G7 economies. However, overall economic activities increase carbon emissions. Foreign direct investment needs to balance FDI-facilitated economic expansion with environmental sustainability. Environmental technology can regulate emissions. An important finding of the study is that G7 economies can improve environmental quality and economic growth if the quality of institutional regulation implementation is better. Given this, the study has significant implications for the subject.

To effectively balance economic development and environmental preservation in G7 nations, policymakers must adopt a comprehensive strategy comprising tailored policy interventions. Firstly, governments should recognize the symbiotic relationship between digitization and environmental conservation. They should incentivize the integration of digital technologies across industries to mitigate carbon emissions and spur economic growth. Additionally, authorities should streamline regulatory processes while upholding environmental standards to promote adherence to sustainability practices, acknowledging the potential trade-offs between stringent regulations and economic activity. Investing in research and development initiatives to advance environmental technology can drive sustainable economic growth by fostering the emergence of new industries and employment opportunities. Governments should also adeptly manage the nexus between foreign direct investment (FDI) and sustainability goals. Leveraging FDI to encourage the adoption of eco-friendly technologies while enforcing rigorous environmental regulations for foreign investors is essential. Ultimately, prioritizing improvements in transparency, accountability, and enforcement mechanisms is crucial to enhance the effectiveness of institutional regulation and ensure the successful implementation of environmental policies. By adopting these policy proposals, G7 economies may synchronize economic expansion with environmental conservation, establishing the groundwork for a sustainable and prosperous future. Data availability is a limitation of the study. The more countries and time spam can generalize the results.

Data availability statement

Data is freely available at: https://databank.worldbank.org/source/world-development-indicators. OECD states.

Table 8
Moderation impact of GDP, Business, and digital economy.

Variable(S)	*CO2*	*CO2*	*CO2*
GDP	1.838***	1.304***	0.812***
	(0.338)	(0.123)	(0.160)
EnvTech	−0.204	−0.273***	−0.224*
	(0.156)	(0.0892)	(0.110)
FDI	−0.0112	0.00525	0.00328
	(0.0225)	(0.0224)	(0.0227)
GovEX	−1.062***	−1.296***	−1.338***
	(0.229)	(0.162)	(0.234)
Moderator – 1	−2.073***		
	(0.181)		
Moderator – 2		−0.262***	
		(0.0576)	
Moderator – 3			−0.0928***
			(0.0128)
Constant	−14.12***	−4.432**	−0.660
	(4.185)	(1.722)	(2.095)
Observations	168	168	168
R-squared	0.518	0.602	0.518
Number of groups	7	7	7

Note: see under Table 6.

Table 9
Moderation business and regulations quality.

Variable(S)	*CO2*	*CO2*	*CO2*	*GDP*
GDP	0.250	0.882***	0.935***	
	(0.209)	(0.176)	(0.164)	
ENTech	−0.212**	−0.179*	−0.179*	0.247***
	(0.0905)	(0.102)	(0.102)	(0.0387)
FDI	−0.0346	0.00702	0.00702	0.0589***
	(0.0227)	(0.0258)	(0.0258)	(0.00812)
GovEX	−1.503***	−1.279***	−1.279***	−0.608***
	(0.264)	(0.231)	(0.231)	(0.0710)
BusA	−0.0747***			
	(0.0174)			
RQ	−0.502***			
	(0.135)			
Moderator – 4		−0.0526**		−0.0276*
		(0.0237)		(0.0156)
Moderator – 5			−0.0526**	
			(0.0237)	
CO2				0.106***
				(0.0183)
Constant	4.586	−2.749	−2.749	11.60***
	(2.833)	(2.268)	(2.268)	(0.276)
Observations	168	168	168	168
R-squared	0.574	0.500	0.500	0.641
Number of groups	7	7	7	7

Note: See Table 6.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Rizwana Yasmeen: Writing – original draft, Formal analysis. **Tian Tian:** Writing – review & editing, Visualization, Validation, Supervision, Methodology. **Hong Yan:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis. **Wasi Ul Hassan Shah:** Writing – review & editing, Writing – original draft, Resources, Data curation, Conceptualization.

Declaration of competing interest

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.

Appendix

Table A1
Data description

Variable(S)	Measurement	Data Source
Carbon Emission	CO2 emissions (metric tons per capita)	World Development Indicators
Foreign Direct Investment	Foreign direct investment, net inflows (% of GDP)	
Economic Growth	GDP per capita (constant 2015 US$)	
Government Expenditure	Percentage of GDP spent on final consumption expenditure by the government.	
Digital Economy1	Percentage of the population using the Internet	
Digital Economy2	Mobile cellular subscriptions (per 100 people)	
Business Activity	Time required to start a business (days)	
Institutional Impact	Regulatory Quality	
Environmental Technology	Patents on environment technologies Total, Percentage	OECD Stats

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