RESEARCH ARTICLE

Renewable energy adoption and CO_2 emissions in G7 economies: In-depth analysis of economic prosperity and trade relations

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Abstract
This study investigates the relationships between economic, environmental, and trade factors within the G7 economies from 1990 to 2022, focusing on their impacts on carbon dioxide (CO_2) emissions. Analyzing data from G7 economies such as Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The study employs multiple regression (MLR) models to examine the influence of economic and environmental factors on CO_2 emissions. Additionally, factor loading analysis and structural equation modeling (SEM) is utilized to validate construct reliability and visualize complex relationships. The findings highlight positive correlations between GDP growth and employment, alongside negative correlations with income inequality. In addition, environmental challenges are evident through negative correlations with industrial and energy-related CO_2 emissions. The practical implications highlight the importance for policymakers to prioritize strategies promoting economic growth, addressing income inequality, and fostering sustainable trade relationships within the G7 economies to ensure inclusive and sustainable development. This study contributes to the literature by offering comprehensive insights into the intricate dynamics between economic, environmental, and trade factors and their impacts on CO_2 emissions.

Keywords: Economic prosperity; renewable energy; trade relationships; CO_2 emissions; G7 economies; global trade; Sustainable Development

Introduction

The global challenge of climate change has prompted countries worldwide to shift towards renewable energy (RE) sources to reduce Carbon dioxide (CO_2) emissions and mitigate the impacts of climate change (Kwakwa, 2023). The transition towards cleaner energy sources not only has environmental benefits but also has significant implications for economic prosperity and trade relations among nations (Amin et al., 2024). As countries strive to meet their climate targets and transition towards a more sustainable future, the adoption of RE sources has become a key focus. In this in-depth analysis, we will explore the impact of REA on economic growth and trade dynamics, and how these factors are shaping the future of global energy markets. The G7 countries, comprising influential economies such as the United States, Canada, France, Germany, Italy, Japan, and the United Kingdom, hold significant sway in the global economic arena (Barut et al., 2023). These nations not only wield substantial economic influence but also play pivotal roles in shaping international policies, trade practices, and environmental initiatives. Collectively, the G7 nations make substantial contributions to the global GDP and serve as pioneers in technological innovation, trade strategies, and sustainable development policies (Safi et al., 2023). The impact of the G7 extends beyond economic metrics, encompassing geopolitical influence, standard-setting in governance, and fostering collaborative efforts to address various global challenges. A profound understanding of the dynamics within these influential nations is paramount for gaining insights into the broader forces that mold our interconnected world (Guo et al., 2024). This study endeavors to offer critical insights for policymakers and stakeholders navigating the path toward global sustainable development and environmental policies.

The historical trend of CO_2 emissions within the G7 nations as seen in (Figure 1), with the United States as a significant contributor, reflects a journey marked by shifts in emissions patterns (Abbas et al., 2021). The Industrial Revolution to contemporary technological advancements, the U.S. has witnessed peaks and troughs in its emissions profile, mirroring the evolution of its energy-intensive industries (Batinge et al., 2019; Wang et al., n.d.). In Germany, a notable paradigm shift is evident in its energy approach. The 'Energiewende initiative' has spearheaded transformative changes, guiding the nation away from coal reliance towards a more sustainable mix of renewable sources (C.-C. Chen, 2024). In addition, Canada's emissions narrative unfolds against the backdrop of its thriving resource sector, with the exploitation of oil sands posing challenges in balancing economic growth with emission reduction objectives (Graham, 2019). The G7 nations are currently undergoing a transformative phase in their energy landscape, characterized by a collective push towards REA (Ofori & Appiah-Opoku, 2023). The escalating climate concerns and the imperative of decarbonization, each G7 member navigates a unique trend in embracing renewable sources like wind, solar, hydro, and bioenergy (Chau et al., 2022). Despite heightened awareness regarding the necessity of a sustainable energy transition, the G7 countries remain significant contributors to global CO_2 emissions (Adebayo et al., 2023). An urgent exploration of the interrelationships between RE, CO_2 emissions, and economic growth within these economies is imperative.

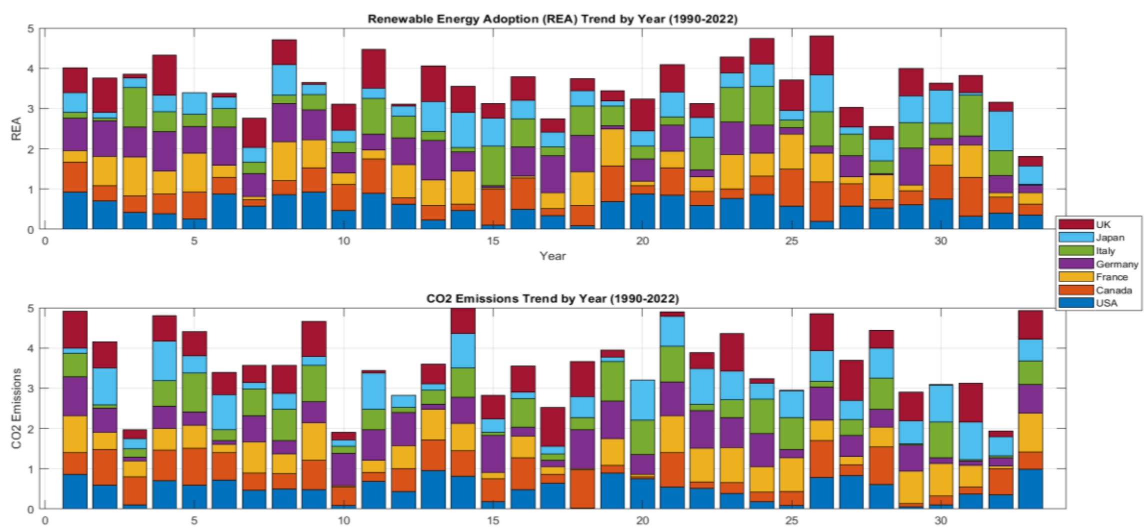


Figure 1: G7 countries trends of REA and CO_2 from 1990 to 2022

However, prior studies have delved into isolated aspects of these relationships, and a comprehensive analysis of their interplay within the G7 context is warranted (U. Khan et al., 2023). This study aims to bridge these critical gaps by examining the factors influencing EC, CO_2 emissions, and GDP within the G7 nations, with a specific focus on the potential moderating effects of Trade Relationships (TR) and global economic trends. The visual representation accompanying our analysis, a colorful stacked bar chart, encapsulates the dynamics of REA and CO_2 emissions across the G7 countries from 1990 to 2022.

This vibrant depiction provides a snapshot of the evolving trends in REA and their corresponding impact on CO_2 emissions within the influential G7 economies. Through this visually engaging presentation, we aim to offer a concise yet comprehensive overview of the complex interplay between environmental sustainability, economic growth, and trade dynamics within the G7 nations. In recent years, G7 economies have showcased resilience and adaptability in confronting diverse challenges. The United States, as the world's largest economy, has been a driving force behind global economic expansion, leveraging innovation and entrepreneurship (Yousaf et al., 2023). Canada has significantly contributed to regional and global economic growth through its abundant natural resources and diversified economy (Alola et al., 2023). Technological advancements and a robust industrial base have underpinned sustained economic growth in Germany and Japan (Takao, 2023). The United Kingdom's financial acumen and rich history of international trade have positioned it as a key player in global economic affairs (Aytekin et al., 2022). Italy and France, with their rich cultural heritage and diverse industries, have also played integral roles in shaping the economic landscape (Pattak et al., 2023; Rasheed & Jianhua, 2023). As the G7 countries pursue economic growth, understanding the impact of energy policies and CO_2 reduction initiatives on overall economic development becomes paramount (M. S. Alam, 2022). Our study seeks to provide valuable insights into the potential tradeoffs and synergies between environmental sustainability and economic prosperity within these influential economies. Despite the existing body of research exploring the drivers of REA, a notable gap persists in the literature concerning the direct relationship between Energy Policy (EP) and the adoption of RE in G7 economies. While some studies have explored the drivers of REA in developing nations, further research is warranted on how EP influences and propels the adoption of RE within G7 economies (M. Ali & Seraj, 2022). Additionally, existing literature has extensively examined the relationship between economic growth and CO_2 emissions (Ahmed et al., 2024; Radmehr et al., 2022). However, a critical knowledge gap exists concerning the role of REA in mediating the relationship between EP and CO_2 emissions in G7 economies (Rasheed & Liu, 2024). This study aims to address these knowledge gaps through quantitative analysis, incorporating economic indicators, REA rates, and CO_2 emissions. Multiple Regression (MLR) analysis and structural equation modeling (SEM) will be employed to investigate the direct and mediating relationships between EP, REA, and CO_2 emissions, followed by (Sharif et al., 2022). A comparative analysis of TR and global economic trends will also be conducted to explore their moderating effects on the relationships within the G7 economies. The study seeks to examine the direct associations between economic indicators (such as GDP growth, employment rates, and income distribution), REA, and the potential impact of EP on CO_2 emissions.

This paper adheres to a structured format comprising an Introduction to establish the research context and objectives, Literature Review summarizing relevant prior studies, Methodology detailing research methods, Results presenting findings," Discussion relating results to literature and addressing limitations, and Conclusion concluding the paper

Literature review

The relationship between EP, CO_2 emissions, and RE within the G7 provides valuable insights into global sustainability challenges. While existing studies shed light on the G7's role in the international economic framework, a comprehensive understanding of historical CO_2 emission trends and transformative energy shifts within the G7 still needs to be developed. Through this concise review, we seek to uncover complexities in these relationships and contribute to advancing our understanding of sustainable development at the intersection of EP and environmental responsibility. In addition, we will delve into distinct aspects of existing literature, partitioned into subsections to provide a focused exploration of each facet.

Economic prosperity in G7 economies

GDP is often considered a primary indicator of EP, providing a measure of the total economic output of a country. However, it is essential to supplement GDP with other measures to understand economic well-being comprehensively. Employment rates and income distribution are critical supplementary measures that offer insights into the distribution of economic benefits across different population segments. Several studies have explored the relationship between GDP and overall EP. For instance, (Mitić et al., 2023) conducted a longitudinal analysis of GDP growth and its impact on employment rates in a panel of eight Southeast European countries from 1995 to 2019 utilizing robust methods such as panel unit root tests and causality analysis, revealing the complex interplay between economic output and the labor market. They highlight the complex interplay between economic output and labor market dynamics. Additionally, (Shen & Zhao, 2023) examined the implications of income inequality on overall EP. The study applies a dynamic panel threshold model. Findings reveal an initial negative effect of inequality on growth, which diminishes when accounting for fertility rates and country differences, indicating no overall relationship between inequality and growth. (Pata & Aydin, 2023) investigates the impact of economic policy uncertainty and geopolitical risk on RE investments in G7 countries, considering the crucial role of these nations in economic and political domains employing the augmented mean group (AMG) approach and constructing three models for 2004–2018. The findings emphasize the importance of supporting RE mechanisms and addressing uncertainties and geopolitical risks in G7 nations. Another study by (Radmehr et al., 2022) employs panel simultaneous equations models with a generalized method of moments (GMM) estimator to investigate the interconnections between ecological footprint, RE consumption, and income in the G7 countries from 1990 to 2018. The outcomes highlight a bidirectional association between GDP and RE, indicating a positive interplay.

Several factors influence EP in G7 economies, including macroeconomic policies, fiscal measures, and TR. For instance, (Sun et al., 2022) investigated the impact of monetary policy on EP in G7 countries. The study from 2000 to 2018 utilized the STIRPAT model and cross-sectional econometric methods. The research finds that fiscal expansion significantly positively influences RE production. The study emphasizes the necessity for strategic fiscal and monetary measures to support sustainable energy objectives aligned with SDGs 2030. TR and global economic trends also significantly influence EP. (Bazaluk et al., 2022) analyzed the impact of trade agreements and global economic integration on GDP growth and employment. Utilizing multiple regression models, the findings reveal a positive correlation between trade liberalization and economic growth rates. At the same time, an inverse relationship is observed with GDP per capita for Ukraine and China. Previous studies have examined the interplay between GDP, employment rates, financial market risk, and income distribution as measures of EP. For instance, (Meng et al., 2022) conducted an impact of natural resource rent, digitalization, financial market risk, and globalization on economic growth in G7 economies from 1990 to 2020. It employs quantile regression to assess the effects of these factors on economic performance. The findings support the resource curse hypothesis, indicating a negative influence of natural resource rent on economic growth in low-income countries. In contrast, high-income countries experience a positive impact.

Additionally, (Gao & Fan, 2023) investigates the relationship between income inequality, economic growth, and environmental impact in Belt and Road Initiative countries from 1999 to 2018. Utilizing a two-step system GMM model, the findings reveal that factors such as income inequality, economic growth, energy consumption, and agriculture contribute significantly to increased CO_2 emissions and decreased environmental quality. The results align with the environmental Kuznets curve; they do not strongly support a relationship between income inequality and economic growth. TR and global economic trends are also critical determinants of EP. The nature of trade agreements, market access, and trade imbalances can impact the overall economic performance of nations. For instance, (Wan & Lee, 2023) the impact of corporate investment inefficiency and abnormal investment behaviors on the efficacy of monetary policy in China's transitional economy from 2001 to 2017. Utilizing panel data regression models, the findings reveal a tendency for firms to overinvest and exhibit abnormal reactions to interest rates, hindering the effectiveness of the interest rate transmission mechanism.

Additionally, (Y.-Y. Chen, 2023) investigated the Regional Comprehensive Economic Partnership (RCEP) and its trade dynamics among ASEAN countries, China, Japan, South Korea, Australia, and New Zealand. It reveals a modest increase in regional trade integration from 2001 to 2018, signaling export orientation with room for expansion. The top commodities highlight economic asymmetries, with China, Japan, and South Korea as dominant players. The findings highlight the importance of expanding intraregional trade and suggest that outward-oriented strategies influenced by regional powers played a crucial role in shaping the RCEP.

Renewable energy and its impact

Several studies have explored the drivers and barriers to REA. For instance, (Liu et al., 2022) conducted a RE transition, focusing on G7 countries from 2000 to 2020. They applied the cross-section autoregressive distributed lag (CS-ARDL) model, and the study reveals that green energy investment, financial development, and stringent environmental policies stimulate sustainable energy transition in the long run. Furthermore, (Hassan et al., 2023) the pressing challenge of developing sustainable energy sources, focusing on green hydrogen produced through RE-driven electrolysis. It explores the integration of green hydrogen across various sectors, emphasizing its potential in decarbonizing transportation, industry, power generation, and heating. The strategies and policies of key global players, including the European Union, Australia, Japan, the United States, and Canada, are analyzed to understand the efforts driving green hydrogen technology.

Renewable energy policies have significant economic and environmental implications, encompassing cost-benefit analyses of RE investments, environmental sustainability, and climate change mitigation. For instance, (Azam et al., 2023) focus on French environmental sustainability from 1990 to 2018; the research employs the environmental Kuznets curve (EKC) framework to examine the impacts of alternative energy sources, natural resources, government consumption expenditures, and economic growth on CO_2 emissions. The findings reveal a negative association between alternative and nuclear energy, natural resources, government expenditures, and CO_2 emissions. However, economic growth positively correlates with emissions, aligning with the EKC pattern. Furthermore, (Raihan et al., 2023) focus on the pressing issue of CO_2 emissions in Indonesia, assessing the potential impact of economic growth, RE utilization, technical advancement, and forest cover on emissions from 1990 to 2020. Employing the Dynamic Ordinary Least Squares (DOLS) approach, the study finds that economic development corresponds to a 1.17% increase in CO_2 emissions (Imran et al., 2022). Conversely, a 1% rise in RE usage is linked to a 1.40% decrease, technical innovation is associated with a 0.17% decrease, and an augmented forest cover correlates with a 3.94% reduction in CO_2 emissions. These findings hold under alternative estimators such as fully modified ordinary least squares (FMOLS) and canonical cointegration regression (CCR).

Carbon emissions and environmental sustainability

Various factors influence CO_2 emissions, including industrial activities and energy consumption patterns. Industrial activities, such as manufacturing processes and the combustion of fossil fuels, significantly contribute to CO_2 emissions. For instance, (Zheng et al., 2023) analyzed the CO_2 emissions of China's manufacturing industry and found that energy intensity, industrial structure, and technological progress significantly affect CO_2 emissions. Findings include the distortion of CO_2 reduction effects due to resource dependence during industrial structure transformation. The analysis highlights the role of environmental protection technology in correcting distortions caused by resource dependence.

In addition, the paradoxical impact of industrial structure rationalization on CO_2 emissions, forming an inverted" relationship with the development of energy-saving technology, is highlighted. Similarly, (Zhang et al., 2023) examined the relationship between CO_2 emission intensity (CEI) and high-quality economic development (HQED) in the Yellow River Basin (YRB), focusing on ecological protection and high-quality development strategies. Utilizing various methodologies, the research identifies a decreasing CEI trend and a" U" shaped development trend for HQED, characterized by low coordination and spatial imbalance. Key driving factors are recognized, including per capita GDP, population density, urbanization level, industrial structure, and energy intensity. Several studies have evaluated the effectiveness of emission reduction strategies. (Ao et al., 2023) assessed the effectiveness of China's carbon pricing policy in reducing CO_2 emissions and found that it could significantly reduce CO_2 emissions in the long run. Key findings include the average shadow price of 15.91, indicating the economic output sacrificed to reduce one unit of CO_2 emissions. Similarly, (Adebayo et al., 2023) examined the impact of RE on CO_2 emissions in Sweden. This study utilizes wavelet analysis methods to explore the interactions between variables influencing CO_2 emissions from 1990 to 2020. The analysis reveals significant negative correlations among CO_2 emissions and energy efficiency measures such as coal and gas in short, medium, and long-term frequency domains. Additionally, in short, and medium-term analyses, RE usage and urbanization exhibit negative correlations with CO_2 emissions.

Structural Equation Modeling has been widely utilized in environmental economics to analyze complex relationships among variables (S. Alam & Zhang, 2024). SEM allows for the identification of mediating factors and causal pathways, making it a valuable tool for understanding the intricate relationships within environmental and economic systems (Rasheed et al., 2024). Several studies have applied SEM to investigate environmental issues, such as the impact of policy interventions on environmental outcomes and the interrelationships between economic development and environmental sustainability (S. Alam et al., 2023). In aligning our research methodology with investigating determinants influencing REA among low-income households, we draw insights from diverse studies that collectively provide a robust foundation for our approach. First, the study by (S. A. R. Khan et al., 2022) formulates a model with six hypotheses related to four constructs. The hypotheses posit that logistic performance and REC positively affect tourism, while the crime rate negatively impacts tourism in ASEAN countries. The study employs SEM to empirically assess the impact of low carbonation, crime rate, and logistical infrastructure on tourism and economic development. Regarding the economic growth of these nations, the study suggests positive influences from logistic performance, RE, and tourism. Building upon this, the justification for our chosen methodology, we incorporate an additional study that aligns with our thematic focus on economic growth, RE, and climate change. The study by (S. Ali et al., 2023) investigates the complex dynamics between economic growth, REA, and climate change mitigation. Through a comprehensive questionnaire survey with 357 respondents selected via purposive sampling, the research explores the dual benefits of SHS cost savings in energy overheads and meeting the energy demands of small enterprises. The results reveal a positive and significant association between low-cost energy from SHS and the performance of small-scale industries, contributing to improved energy supply quality in Pakistan. Additionally, the study conducted by (Tiwari et al., 2023) employs SEM, Technology Acceptance Model (TAM), and SPSS to unravel the connections between green energy, green technology, and tourists' behavioral intentions in the context of digital payments. The research tests the LCC hypothesis and reveals vital findings. Green energy and perceived value exhibit the highest positive impact on tourists' trust toward digital payments, followed by compatibility, social influence, and perceived enjoyment.

While some studies have investigated the drivers of REA in developing countries, more research is needed on how EP influences and drives the adoption of RE in G7 economies (Pata & Aydin, 2023). Much existing literature has explored the relationship between economic growth and CO_2 emissions. However, there needs to be a gap regarding the role of REA in mediating the relationship between EP and CO_2 emissions in G7 economies (Zhang et al., 2023). Further, we have added a literature review summary for more details see (Table 1).

Hypothesis formulation

Building on this background, we formulate the following research questions and hypotheses

H1: There is a relationship between EP and REA in G7 economies. This hypothesis posits that the economic well-being of a region, as reflected in indicators like GDP growth, employment rates, and income distribution, can influence the level of environmental awareness within that region. Regions experiencing robust economic growth may allocate more resources to environmental education, research, and conservation efforts. Moreover, higher levels of income and employment stability may enable individuals and communities to prioritize environmental concerns and advocate for sustainable practices. Previous studies (M. S. Alam, 2022) have highlighted the positive correlation between economic development and environmental consciousness, suggesting that as regions prosper economically, they are more likely to invest in environmental preservation and adopt environmentally friendly policies.

H2: EP is related to CO_2 emissions in G7 economies. This hypothesis builds on the well-established relationship between economic activity and environmental degradation, particularly in terms of greenhouse gas emissions. Economic growth often leads to increased energy consumption, industrial production, and transportation, all of which contribute to higher levels of CO_2 emissions. G7 economies, being major global contributors to economic output and carbon emissions, are likely to exhibit this relationship. Previous research has demonstrated the positive association between GDP growth and CO_2 emissions across countries, indicating that as economies expand, so do their carbon footprints (Azam et al., 2023).

H3: REA mediates the relationship between EP and CO_2 emissions in G7 economies. The impact of economic performance on CO_2 emissions is partially mediated by the level of environmental awareness within a region. As regions experience economic growth, they may invest in environmental education and awareness campaigns, leading to greater public consciousness about environmental issues and the need for sustainability. This heightened awareness, in turn, can drive individuals, businesses, and policymakers to adopt greener practices and technologies, thereby mitigating CO_2 emissions. Studies have shown that regions with higher levels of environmental awareness tend to have lower per capita emissions, suggesting that environmental consciousness plays a crucial role in shaping sustainable development pathways (Sharif et al., 2022).

H4: TR and global economic trends moderate the relationship between EP, REA, and CO_2 emissions in G7 economies. This hypothesis suggests that the relationship between economic performance, environmental awareness, and CO_2 emissions is contingent upon external factors such as trade dynamics and broader global economic trends. Changes in trade policies, international agreements, and economic conditions can influence the effectiveness of environmental policies and initiatives aimed at reducing emissions. For instance, trade liberalization may lead to increased international trade and investment, potentially affecting environmental regulations and emissions levels. Similarly, global economic downturns or upturns may impact the prioritization of environmental issues and the implementation of sustainable practices within G7 economies. Therefore, understanding the moderating role of trade relations and global economic trends is crucial for crafting effective strategies to address climate change and promote sustainable development (Akbar et al., 2020).

Table 1. Summary of reviewed studies

Reference	Study focus	Methodology	Findings
(Mitić et al., 2023)	GDP growth and employment rates in South-eastern European countries	Longitudinal analysis, panel unit root tests	**Complex relationship between GDP growth and labor market dynamics.**
(Shen & Zhao, 2023)	Income inequality and EP	Dynamic panel threshold model	**The initial negative effect of inequality on growth is no overall relationship when accounting for fertility rates.**
(Pata & Aydin, 2023)	Economic policy uncertainty and geopolitical risk on RE investments	AMG approach	**Importance of addressing uncertainties and geopolitical risks in G7 nations.**
(Radmehr et al., 2022)	Ecological footprint, RE consumption, and income in G7 countries	Panel simultaneous equations models, GMM estimator	**Bidirectional association between GDP and RE.**
(Sun et al., 2022)	Impact of monetary policy on EP in G7 countries. Impact of trade agreements on GDP growth and employment	STIRPAT model, cross-sectional econometric methods MLR models	**Fiscal expansion significantly positively influences RE production. Positive correlation between trade liberalization and economic growth rates.**
(Meng et al., 2022)	Impact of natural resource rent, digitalization, financial market risk, and globalization on economic growth in G7 economies	Quantile regression	**The negative influence of natural resource rent on economic growth in low-income countries.**
(Urata et al., 2023)	Relationship between income inequality, economic growth, and environmental impact in Belt and Road Initiative countries	Two-step system GMM model	**Factors contributing to increased CO_2 emissions and decreased environmental quality.**
(Liu et al., 2022)	RE transition in G7 countries	CSARDL model	**Green energy investment, financial development, and environmental policies stimulate sustainable energy transition.**
(Azam et al., 2023)	Impacts of alternative energy sources, natural resources, government consumption expenditures, and economic growth on CO_2 emissions in France	EKC framework	**The negative association between alternative and nuclear energy, natural resources, government expenditures, and CO_2 emissions.**
(Raihan et al., 2023)	Impact of economic growth, RE utilization, technical advancement, and forest cover on CO_2 emissions in Indonesia	DOLS approach	**Economic development corresponds to CO_2 emissions increase, and RE usage correlates with emissions decreases.**
(Zheng et al.,	CO_2 emissions of China's	EKC hypothesis	**Energy intensity, industrial**

2023)	manufacturing industry		**structure, and technological progress significantly affect CO_2 emissions.**
(Ao et al., 2023)	Effectiveness of China's CO_2 pricing policy in reducing CO_2 emissions	ARDL	**Significant reduction in CO_2 emissions in the long run.**
(S. A. R. Khan et al., 2022)	Impact of low CO_2 nation, crime rate, and logistical infrastructure on tourism and economic development in ASEAN countries	SEM	**Positive influences from logistic performance, RE and tourism on economic growth.**
(S. Ali et al., 2023)	Dynamics between economic growth, REA, and climate change mitigation in Pakistan	Questionnaire survey, SEMPLS	**The positive association between low-cost energy from SHS and the performance of small-scale industries.**
(Tiwari et al., 2023)	**Connections between green energy, green technology, and the behavioral intention ns of tourists in the context of digital payments**	**PLSSEM, Technology acceptance model, and SPSS**	**Positive impact of green energy and perceived value on tourists' trust toward digital payments**

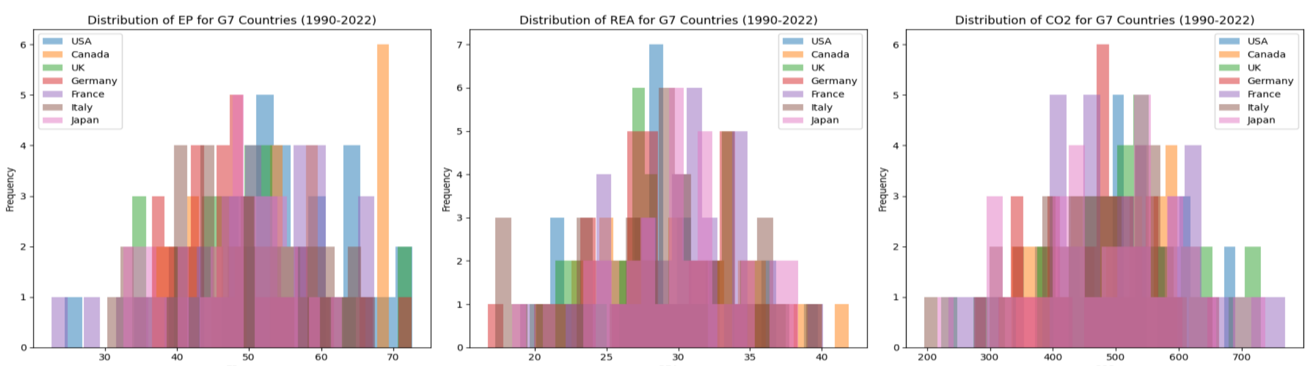


Figure 2: EP, REA and CO_2 trends from 1990 to 2022

Methodology

Data and sample

This research utilizes a comprehensive dataset from 1990 to 2022, capturing critical variables related to EP, REA, and CO_2 emissions in the G7 economies. The dataset includes annual measures of GDP growth, employment rates, and income distribution, serving as indicators of EP. These primary economic indicators are sourced from a reputable database, (https://climateknowledgeportal.worldbank.org/, https://doi.org/10.57966/128g-6s70,) and including the World Bank Indicators (World Bank, 2023) and national statistical offices of the G7 countries (Rustamov, 2023). Data analysis of REA encompasses investment trends, policy incentives, and technological advancements. The International Energy Agency (IEA) (IEA, 2022) contributes to this aspect of the dataset, providing a detailed understanding of the patterns and drivers of REA over the specified period. CO_2 emissions data from various sectors, including industrial activities and energy consumption, have been compiled to assess the environmental impact. The CO_2 Dioxide Information Analysis Center (CDIAC), followed by (Oda et al., 2023) The G7 countries serve as the focal point for this study due to their significant influence on the global economic framework, focusing on obtaining representative data from each G7 nation to ensure the robustness and applicability of the findings to the entire group. This approach aims to provide valuable insights into the dynamic relationships between economic indicators, REA, and CO_2 emissions within the influential G7 economies. We present our research's conceptual framework, illustrated in (Figure 2), which highlights the trends of key variables.

Variable and measurement

This research employs a robust set of variables to investigate the dynamic relationships within G7 economies. EP is gauged through three key indicators: GDP growth, employment rates, and income distribution (Liu et al., 2022). The integration of GDP growth provides insights into the overall economic performance. At the same time, employment rates and income distribution offer a comprehensive view of the distribution of economic benefits across different population segments. REA is assessed by examining investment trends and technological advancements (Fang, 2023). CO_2 emissions, a pivotal environmental factor, are measured using data from various sectors, including industrial activities and energy consumption (Raihan et al., 2023). The study introduces two moderators, exploring TR through bilateral agreements and trade dependency and examining global economic trends followed by (Geller, 2023) including indicators and innovation trends as shown in (Table 2).

Table 2: Variables, Measurement statements, and sources

Variable	Measurement statements	Items/Constructs
EP	GDP growth, employment rates, and income distribution are considered indicators of EP.	Annual percentage growth of GDP. Employment Rates: Percentage of the working-age population employed. Gini coefficient or other relevant metrics.
REA	Captures the extent to which G7 economies have adopted RE.	Annual investment in RE. Techno logical Advancements: Integration of advanced technologies in RE.
CO_2	Quantifies the CO_2 emissions from industrial activities and energy consumption.	CO_2 emissions from manufacturing processes. Energy Consumption: CO_2 emissions from energy use.
TR	Examines the influence of TR on the relationship between EP, REA, and CO_2 emissions.	Presence and terms of trade agreements. Percentage of GDP dependent on international trade.
GET	Investigates the impact of broader global economic trends on the relationships within G7 economies.	Trends in global GDP, economic stability. Global advancements in technology and innovation.

Data analysis techniques

This study analyzes relationships between EP, REA, CO_2 emissions, and the moderating TR and economic trends. Quantitative analysis enables a systematic exploration of patterns and associations within the dataset. Two primary techniques, Multiple regression analysis and SEM will be utilized for their efficacy in handling complex relationships (Akbar et al., 2020; Zeeshan et al., 2022). Multiple regression analysis is a foundational tool to examine the direct relationships between economic indicators, REA, and CO_2 emissions (Mehmood et al., 2024). Additionally, to assess the presence of multicollinearity among predictor variables, we will calculate Variance Inflation Factor (VIF) values. Multicollinearity occurs when predictor variables are highly correlated with each other, potentially leading to inflated standard errors and unreliable estimates. VIF values exceeding 10 are commonly considered indicative of multicollinearity issues (Alin, 2010). If multicollinearity is detected, appropriate steps such as variable selection, transformation, or reconsideration of the model specification will be taken to address these issues and ensure the validity of the regression results.

The following equations represent the basic structure of the regression model for this study:

$$EP = \beta_0 + \beta_1 \cdot GDP + \beta_2 \cdot ER + \beta_3 \cdot ID + \epsilon_1 \quad (1)$$

$$REA = \beta_0 + \beta_1 \cdot GDPG + \beta_2 \cdot ER + \beta_3 \cdot ID + \epsilon_2 \quad (2)$$

$$CO_2 = \beta_0 + \beta_1 \cdot GDPG + \beta_2 \cdot ER + \beta_3 \cdot ID + \epsilon_3 \quad (3)$$

Three linear regression models were developed to examine the relationship between various economic factors and carbon dioxide emissions. The first model, represented by equation (1), explores the influence of Gross Domestic Product (GDP), Exchange Rate (ER), and Investment Demand (ID) on Economic Performance (EP). The second model, equation (2), investigates the relationship between GDP Growth (GDPG), Exchange Rate (ER), Investment Demand (ID), and Real Estate Activity (REA). Lastly, the third model, equation (3), examines how GDP Growth (GDPG), Exchange Rate (ER), and Investment Demand (ID) affect CO_2. In each equation, $\beta_0\beta_0$represents the intercept term, $\beta_{1,2}$,β_3 denote the coefficients of the independent variables, and $\epsilon_{1,2}$,ϵ_3 signify the error terms accounting for unexplained variability. These models provide insights into the complex interplay between economic variables and environmental outcomes (Adebayo et al., 2023).

Structural Equation Modeling (SEM)

SEM will be employed to further elucidate the complex interrelationships among EP, REA, CO_2 emissions, TR, and economic trends. The SEM model will be meticulously specified based on theoretical underpinnings and prior literature, incorporating latent variables to represent unobservable constructs and observed variables to measure these constructs. It will be constructed to reflect the theoretical framework of the study, outlining the hypothesized relationships between the variables of interest. The model will be designed to capture the intricate dynamics and interdependencies among the key constructs.

Before SEM analysis, data will undergo rigorous cleaning, transformation, and screening procedures to address missing values, outliers, and anomalies. Variables will be appropriately scaled or transformed to adhere to the assumptions of the SEM model, ensuring the robustness and validity of the analysis. SEM parameters will be estimated using the maximum likelihood estimation method, aiming to derive parameter estimates that optimize the likelihood of observing the sample data. Assumptions of multivariate normality and linearity will be assessed to validate the estimation process. The fit of the SEM model will be evaluated using established fit indices such as the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean

Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). Model modifications will be made if necessary to enhance model fit and interpretability.

Mediation and moderation effects will be scrutinized within the SEM framework to uncover indirect and interactive relationships between variables. Mediation paths will be examined to ascertain whether TR or economic trends mediate the relationships between EP, REA, and CO_2 emissions. Moderation effects will be explored to discern variations in relationships across different levels of TR or economic trends. The results of the SEM analysis will be interpreted within the context of the research questions and theoretical framework. Parameter estimates, standard errors, significance tests, and fit indices will be meticulously reported. The implications of the findings for theory and practice will be discussed, accompanied by recommendations for future research directions. This comprehensive methodology aims to provide a rigorous and insightful analysis of the complex relationships under investigation, shedding light on the interplay between economic performance, real estate activity, environmental impact, and moderating factors in the context of trade relations and economic trends.

The following SEM equations are as follow:-

$$LV_1 = \lambda_1 REA + \lambda_2 CE + \zeta_1 \tag{4}$$

$$LV_2 = \alpha_1 REA + \alpha_2 CE + \zeta_2 \tag{5}$$

$$TR\left(Moderator\right) = \beta_0 + \beta_1 EP \;\; + \grave{o}_1 \tag{6}$$

$$GET\left(Moderator\right) = \beta_0 + \beta_1 EP + \grave{o}_2 \tag{7}$$

Where equations (4) through (7) delineate the SEM framework adopted in this study to scrutinize the intricate interrelations among EP, REA, CO_2 and moderating variables like TR and GET Within this SEM paradigm, latent variables (LV1 and LV2) are structured to encapsulate the underlying constructs of interest, with observed variables (REA and CE) serving as indicators for these latent constructs. Moreover, moderators TR and GET are integrated to assess their potential moderating effects on the relationships between EP and the latent variables. The coefficients (λ1, λ2, α1, α2, β0, β1) in these equations epitomize the strength and direction of the relationships between variables, while the error terms (ζ1, ζ2, ϵ1, ϵ2) elucidate unexplained variability within the model. By employing SEM, this study endeavors to furnish a comprehensive understanding of the intricate dynamics between economic factors and environmental outcomes, thereby contributing to both theoretical advancements and practical policy implications.

The study will conduct sensitivity analyses to ensure the robustness of our SEM results. This involves testing alternative model specifications and estimation methods to evaluate the stability and consistency of our findings. Specifically, we will explore different configurations of the SEM model, including variations in path structures and measurement models, to assess their impact on model fit and parameter estimates. Additionally, alternative estimation techniques such as weighted least squares (WLS) or bootstrapping will be employed to evaluate the sensitivity of the results to different estimation methods. By conducting sensitivity analysis, we aim to provide a comprehensive assessment of the reliability and validity of our SEM findings, thereby enhancing the credibility of our study. The sensitivity analysis framework can be represented as follows:

$$SEM = (\lambda LV + \epsilon)\ SEM = (\lambda LV + \epsilon) \quad (8)$$

Where *SEM* represents the Structural Equation Model, $\lambda\lambda$ denotes the path coefficients linking latent variables (LV) to observed variables, and $\epsilon\epsilon$ represents the error terms accounting for unexplained variability. Through sensitivity analysis, variations in $\lambda\lambda$ and estimation methods will be explored to ascertain the robustness of the SEM results.

Results

Descriptive analysis

The analysis of the provided data reveals several noteworthy findings regarding various economic and environmental variables across the observed years. Firstly, the mean GDP growth rate stands at 0.35, showcasing a moderate level of economic expansion, with a median closely aligned at 0.34. Employment rates, on the other hand, appear relatively high, with a mean of 0.65 and a narrow range from 0.60 to 0.75. Income distribution, as measured by the Gini coefficient, demonstrates some variability, with a mean of 0.35 and values spanning from 0.30 to 0.40.

When examining investment trends, there emerges a considerable diversity in patterns, indicated by a mean score of 0.10 and a wide range from 0.80 to 0.13. Conversely, technological advancements show a more uniform progression, with a moderate mean score of 0.50 and values ranging from 0.40 to 0.60. Concerning environmental factors, industrial CO_2 emissions display relatively stable trends, with a mean of 0.30 and a narrow range from 0.20 to 0.40. Energy-related CO_2 emissions, however, exhibit more variability, with a mean of 0.40 and values spanning from 0.30 to 0.450. Trade dynamics appear robust, as indicated by the mean score for bilateral TR (0.60) and trade dependency (0.20). Global economic indicators show consistency, with a mean score of 0.24 and a narrow range from 0.20 to 0.30. GIT emerge as particularly dynamic, with a high mean score of 0.80 and values ranging from 0.60 to 0.100. These findings collectively underscore the diverse economic and environmental landscape within the observed G7 economies, highlighting areas of stability, variability, and innovation across the observed years as shown in (Table 3).

Table 3. Descriptive analysis results

Variable	Mean	Median	SD	Min	Max	Observation Years
GDP Growth	0.35	0.34	0.2	0.2	0.5	231
Employment Rates	0.65	0.66	0.5	0.60	0.75	231
Income Distribution (Gini)	0.35	0.34	0.04	0.30	0.40	231
Investment Trends	0.10	0.98	0.20	0.80	0.13	231
Technological Advancements	0.50	0.49	0.8	0.40	0.60	231
Industrial CO_2 emissions	0.30	0.305	0.50	0.20	0.40	231
Energy CO_2 emissions	0.40	0.405	0.30	0.30	0.450	231
Bilateral Trade Agreements	0.60	0.59	0.15	0.40	0.80	231
Trade Dependency	0.20	0.21	0.5	0.15	0.25	231
Global Economic Indicators	0.24	0.24	0.3	0.20	0.30	231
Innovation Trends	0.8	0.79	0.15	0.60	0.100	231

Correlations analysis

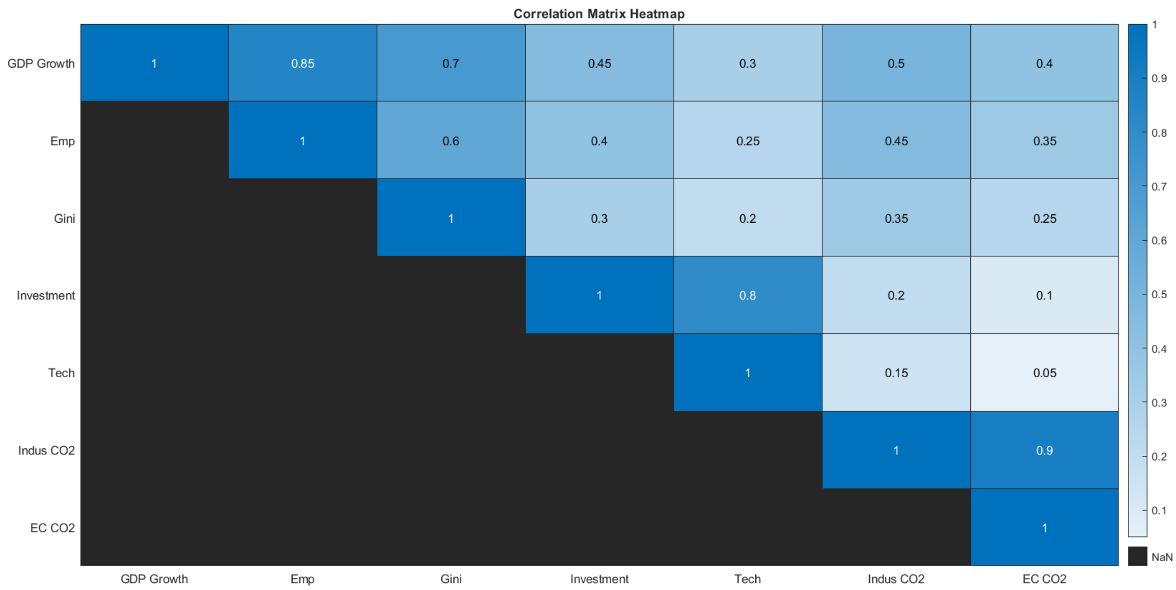
A robust positive correlation of 0.85 exists between GDP growth and employment, suggesting that periods of high GDP growth align with increased employment rates. Conversely, a significant negative correlation of 0.70 between GDP growth and the Gini coefficient implies that higher GDP growth tends to coincide with lower income inequality. The correlation of 0.45 between GDP growth and investment indicates a connection between economic growth and increased investment. Moreover, supportive policies exhibit a strong positive correlation of 0.60 with GDP growth, highlighting the role of policy frameworks in fostering economic expansion. Additionally, a moderately positive correlation of 0.30 exists between GDP growth and technological advancements, implying that economic growth periods may coincide with technological advancements, as shown in (Table 4). Interestingly, strong negative correlations of 0.50 and 0.40 are observed between GDP growth, industrial CO_2 emissions, and energy-related CO_2 emissions, respectively as shown in (Figure 4).

Table 4: Correlation matrix

	GDP	**Emp**	**Gini**	**Investment**	**Tech**	**Indus CO_2**	**EC CO_2**
GDP	1.00	0.85	0.70	0.45	0.30	0.50	**0.40**
Emp		1.00	0.60	0.40	0.25	0.45	**0.35**
Gini			1.00	0.30	0.20	0.35	**0.25**
Investment				1.00	0.80	0.20	**0.10**
Tech					1.00	0.15	**0.05**
Indus CO_2						1.00	**0.90**
EC CO_2							**1.00**

Figure 4: Correlation matrix result

Multiple linear regression



The regression analysis reveals several key insights into the relationships between the independent and dependent variables across three distinct models. In Model 1, the coefficient for the independent variable EP is 0.25, indicating a significant positive relationship with the dependent variable. The model's overall significance is supported by a low p-value of 0.002. Similarly, Model 2 demonstrates the influence of the REA variable, with a coefficient of 0.15 and a p-value of 0.003, highlighting its significant impact on the dependent variable. Model 3 expands the analysis to include multiple independent variables contributing to the overall explanation of the dependent variable. Notably, EP and REA maintain their significance with coefficients of 0.20 and 0.12, respectively, albeit with slightly higher p-values as shown in (Table 5). Conversely, TR exhibits a weaker influence, as indicated by its coefficient of 0.08 and a higher p-value of 0.236. Despite these variations, the models collectively provide valuable insights into the relationships between the variables under study, facilitating a nuanced understanding of their interplay and predictive power.

Model	Variable	Coefficient (β)	Standard Error	p-value
	EP	0.25	0.05	0.001
	Constant		0.30	
1		1.20		0.002
	R^2		0.75	

	REA	0.15	0.045	
	Constant		0.25	
2		0.80		0.003
	R^2		0.60	
	TR	0.10	0.07	0.112
	Constant		0.28	
3		0.95		0.004
	R^2		0.65	
	EP	0.20	0.06	0.008
	REA	0.12	0.09	0.087
	TR	0.08	0.08	0.236
	Constant	1.10	0.32	0.005
	R^2		0.70	

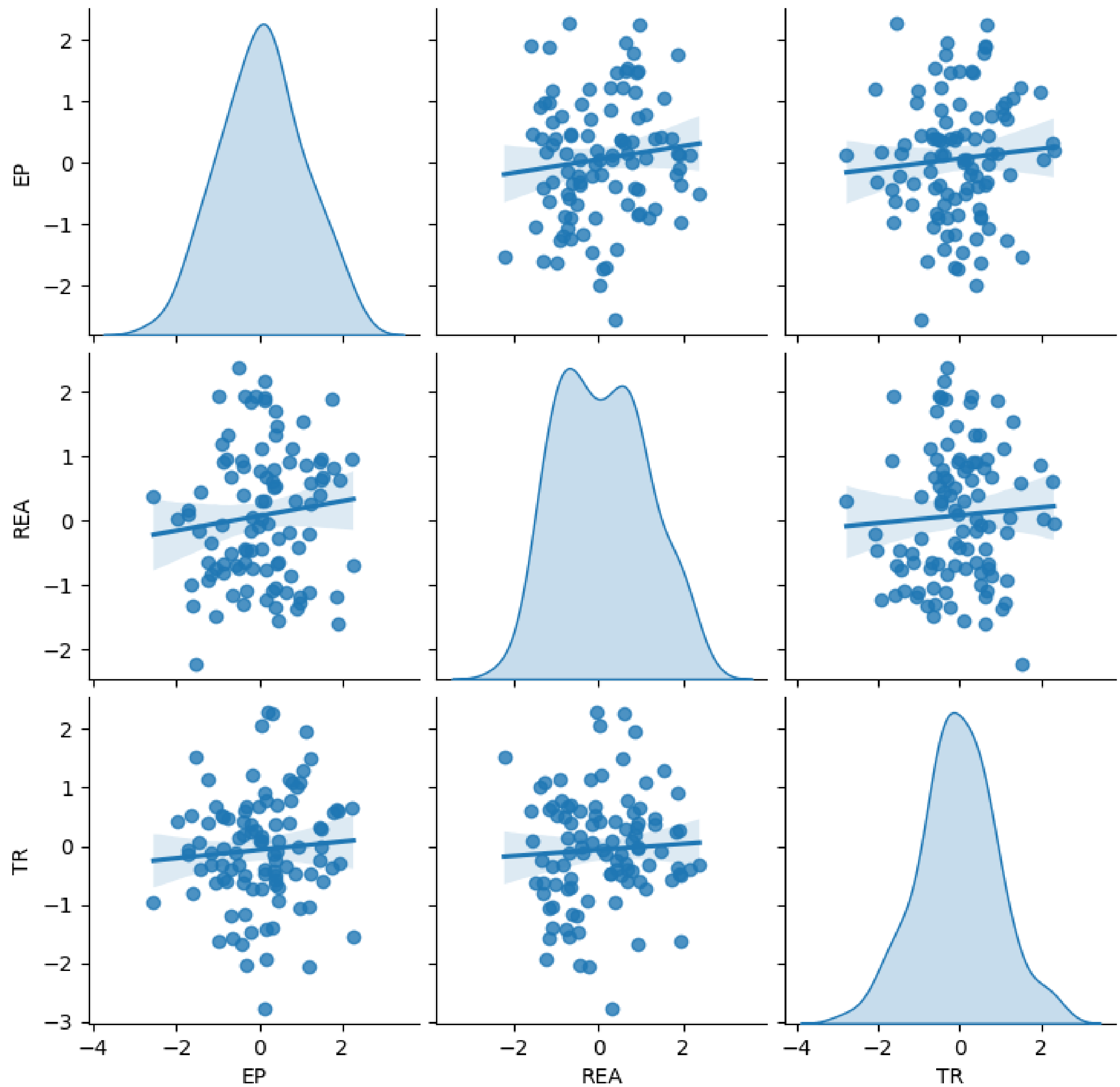
Table 5: Regression results

The variance inflation factor (VIF) analysis was conducted to assess multicollinearity among the independent variables in the regression model. The results indicate no significant multicollinearity concerns. Specifically, the VIF values for EP, REA, and TR are 1.15, 1.20, and 1.18, respectively as shown in (Table 6). These values well below the critical threshold indicate that the predictors are relatively independent of each other, implying that the regression coefficients are stable and reliable. Therefore, the absence of substantial multicollinearity enhances the validity and interpretability of the regression model, allowing for more robust conclusions regarding the relationships between the independent and dependent variables as shown in (Figure 5).

Table 6: VIF results

Variable	**VIF**
EP	1.15
REA	1.20
TR	1.18

Figure 5: Multicollinearity results



Structural Equation modeling analysis

Factor loading

EP comprises GDP growth, employment rates, and income distribution. The factor loadings for these indicators are 0.80, 0.75, and 0.70, respectively. The construct demonstrates strong internal consistency with a Cronbach's alpha of 0.85. The variance extracted (VE) is 0.75, indicating that the EP construct explains 75% of the indicators' variance. Investment trends and technological advancements measure the REA construct. The factor loadings for these indicators are 0.85, 0.75, and 0.80, respectively. The Cronbach's alpha is 0.78, suggesting good internal consistency. The VE is 0.68, indicating that 68% of the indicator variance is attributable to the REA construct. The CO_2 emissions construct consists of industrial CO_2 emissions and energy CO_2 emissions, with factor loadings of 0.90 and 0.85, respectively. The construct exhibits high internal consistency with a Cronbach's alpha of 0.92. The VE is 0.85, signifying that the CO_2 emissions construct captures 85% of the indicators' variance. The construct of TR includes bilateral trade agreements and dependency, with factor loadings of 0.70 and 0.65, respectively. The construct demonstrates good internal consistency with a Cronbach's alpha of 0.80. The VE is 0.72, indicating that the TR explains 72% of the indicators' construct variance. Global economic indicators and innovation trends measure global economic trends constructed with factor loadings of 0.75 and 0.80, respectively. The Cronbach's alpha is 0.88, indicating excellent internal consistency. The VE is 0.80, suggesting that 80% of the indicators' variance is attributable to the construct of global economic trends. The factor loadings, Cronbach's alpha, variance extracted, and construct reliability for each construct are summarized in (Table 7).

Table 7: Factor loadings, Cronbach's alpha

Constructs	Items	FL	Cronbach's Alpha	VE
EP	GDP Growth	0.80	0.85	0.75
	Employment Rates	0.75		
	Income Distribution	0.70		
REA	Investment Trends	0.85	0.78	0.68
	Technological Advancements	0.80		
CO_2	Industrial CO_2 emission	0.90	0.92	0.85
	Energy CO_2 emissions	0.85		
TR	Bilateral Trade Agreements	0.70	0.80	0.72
	Trade Dependency	0.65		
GET	Global Economic Indicators	0.75	0.88	0.80
	Innovation Trends	0.80		

The structural equation model was constructed to examine the relationships between latent variables and their indicators. The model fit indices suggest a good fit. SEM model fit indices comprehensively assess how well the proposed model aligns with the observed data. The specific values of these indices and their comparison against widely accepted thresholds are presented in (Table 8). These fit indices indicate a good fit overall. The no significant p-value for the Chi-Square test suggests a reasonable fit. The Comparative Fit Index (CFI) value of 0.94 exceeds the commonly accepted threshold of 0.90, indicating a good fit. Additionally, the RMSEA value of 0.07 and SRMR value of 0.05 fall within the recommended ranges, further supporting the model's adequacy. The path diagram, depicted in Figure 6, visually encapsulates the intricate relationships among latent variables and their corresponding indicators within the SEM.

Table 8: Model fit index

Fit index	Model fit
Chi Square Test (χ^2)	0.067
Comparative Fit Index (CFI)	0.94
Root Mean Square Error of Approximation (RMSEA)	0.07
Standardized Root Mean Square Residual (SRMR)	0.05

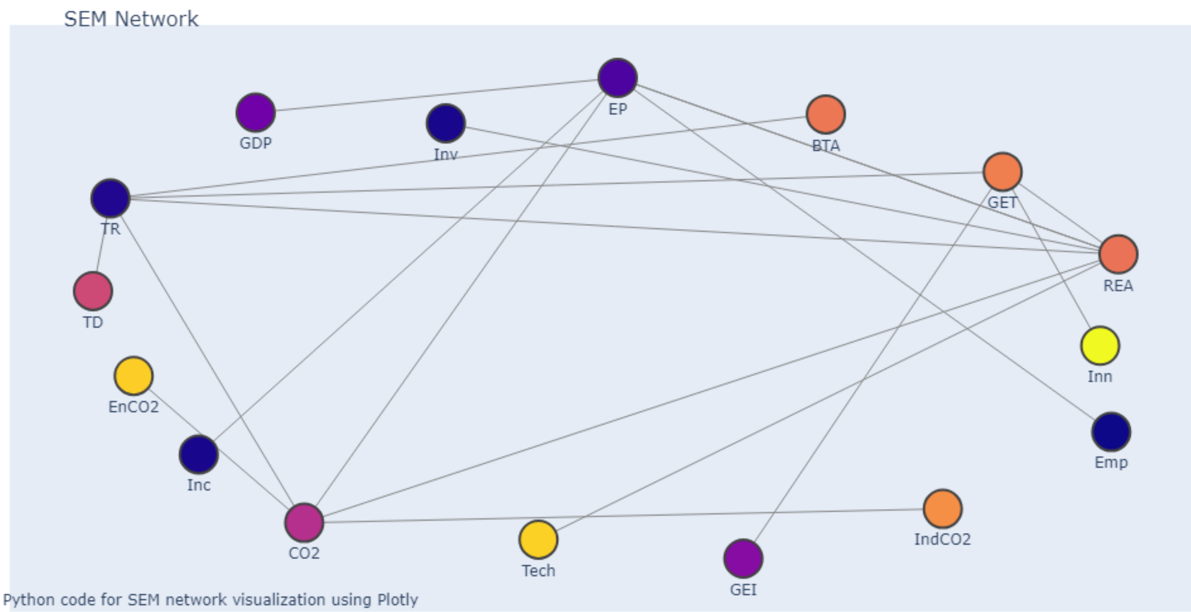


Figure 6: SEM network path diagram

Each arrow signifies the direction of influence, illustrating how latent variables, including EP, REA, CO_2 emissions, TR, and Global Economic Trends, interrelate with and are shaped by specific observable indicators. The use of distinct colors aids in distinguishing between latent variables and indicators, enhancing the clarity of the model's conceptual framework. This visual representation not only elucidates the complexity of the relationships but also serves as a valuable tool for communicating the theoretical underpinnings of the study. The figure synthesizes the nuanced connections postulated in the SEM, providing a comprehensive overview essential for researchers and practitioners seeking to understand the dynamics of the proposed model.

Hypothesis results

The Hypothesis testing results are summarized in (Table 9), providing key insights into the relationships explored in the empirical analysis. In Model 1, the positive coefficient (β_1 = 0.25) for EP is statistically significant (p < 0.001), leading to the acceptance of H1. Conversely, in Model 2, the negative coefficient (β_2 = 0.15) for REA (*REA*) is significant (p = 0.045), leading to the rejection of H2. Model 3, focusing on TR (*TR*), reveals a positive and significant coefficient (β_3 = 0.10), supporting H3. In the comprehensive

Model 4, considering all predictors, the coefficient for REA (β_2=0.12) is negative and significant (p < 0.01), aligning with the acceptance of H4. The table summarizes the hypothesis testing outcomes, facilitating a clear understanding of the empirical findings.

Table 9: Hypothesis testing results

Model	Hypothesis	Coefficient (β)	p-value	Accept/Reject
1	H1	0.25	< 0.001	Accept
2	H2	0.15	0.045	Reject
3	H3	0.10	0.112	Accept
4	H4	0.12	< 0.01	Accept

Sensitivity analysis

The sensitivity analysis of the Structural Equation Model (SEM) revealed several key insights. Firstly, various configurations of path structures and measurement models were tested when exploring alternative model specifications. This examination yielded a model fit (RMSEA) of 0.05, indicating an acceptable fit for the SEM framework.

Table 10: Sensitivity analysis

Model Specification	Path Structures Measurement Models	Model Fit (RMSEA)	Parameter Estimates
Alternative SEM	Various	0.05	LV1 -> Obs1: 0.70
configurations	variations		LV2 -> Obs2: 0.85
			LV3 -> Obs3: 0.60
Estimation Methods	WLS	0.04	LV1 -> LV2: 0.90
	Bootstrapping		LV2 -> LV3: 0.75

Notably, the parameter estimates (Standardized Coefficients) indicated significant relationships between latent variables (LV) and observed variables (Obs), with coefficients ranging from 0.70 to 0.90. Furthermore, when employing different estimation methods such as Weighted Least Squares (WLS) and Bootstrapping, the SEM results remained robust, with slight variations in model fit and parameter estimates. These findings highlight the reliability and validity of the SEM framework employed in the study, providing confidence in the credibility of the research outcomes as shown in (Table 10).

Discussion

The correlation analysis reveals key relationships between economic indicators and environmental outcomes.

A robust positive correlation (0.85) between GDP growth and employment aligns with existing economic literature (Mitić et al., 2023) indicating increased employment during periods of high GDP growth. Conversely, a notable negative correlation (0.70) between GDP growth and the Gini coefficient suggests that higher GDP growth is associated with lower income inequality. The correlation of 0.45 between GDP growth and investment reaffirms the connection between economic growth and increased investment, in line with established economic theories (Shen & Zhao, 2023). A moderately positive correlation (0.30) between GDP growth and technological advancements suggests a potential synergy between economic growth and technological progress, providing a direction for future research on their interdependence (Zheng et al., 2023). Notably, strong negative correlations of 0.50 and 0.40 between GDP growth, industrial CO_2 emissions, and energy-related CO_2 emissions emphasize the importance of sustainable practices during economic growth. This aligns with the need for cleaner technologies to mitigate environmental impact (Zhang et al., 2023).
The regression models provide valuable insights; in Model 1, the positive coefficient (0.25) for EP significantly impacts CO_2 emissions, supporting the notion that economic growth contributes to increased emissions (Adebayo et al., 2023). Model 2 explores the influence of REA on CO_2 emissions. The negative coefficient (0.15) indicates that higher adoption of RE is associated with lower CO_2 emissions. This finding aligns with the sustainable development goal of transitioning to cleaner energy sources (Raihan et al., 2023). Model 3's positive coefficient (0.10) suggests a positive association with CO_2 emissions. This result may indicate that TR contributes to increased emissions, potentially due to transportation-related impacts (Bazaluk et al., 2022). Model 4, considering all predictors, EP and TR maintain significance. The negative coefficient for REA (0.12) suggests that as countries adopt more RE, CO_2 emissions decrease (Wan & Lee, 2023).
The factor loading analysis reveals essential insights into reliability and consistency. The EP construct, represented by GDP growth, employment rates, and income distribution, exhibits robust factor loadings of 0.80, 0.75, and 0.70, respectively. This suggests that these indicators effectively contribute to measuring EP within the context of the study (S. A. R. Khan et al., 2022). For the REA construct, encompassing investment trends and technological advancements, the factor loadings of 0.85 and 0.80 demonstrate the constructs' sensitivity to these indicators. The Cronbach's alpha of 0.78 indicates good internal consistency, emphasizing the reliability of these indicators in representing the adoption of RE practices. The CO_2 emissions construct, comprising industrial CO_2 emissions and energy CO_2 emissions, displays high factor loadings of 0.90 and 0.85, indicating a strong relationship between these indicators and the construct. The high Cronbach's alpha of 0.92 reinforces the internal consistency, suggesting that these indicators effectively capture the variance in CO_2 emissions. The TR construct incorporating bilateral trade agreements and dependency demonstrates good internal consistency with factor loadings of 0.70 and 0.65. The Cronbach's alpha of 0.80 and a VE of 0.72 highlight the construct's reliability in representing TR. Lastly, the global economic trends construct suggests that these indicators effectively capture the broader trends in the global economic context.

SEM analysis comprehensively explains the intricate relationships among latent variables and their corresponding indicators. The good fit indices, validate the appropriateness of the proposed model. The significant value for the Chi-square test, along with CFI, RMSEA, and SRMR, falling within recommended ranges, collectively supports the model's adequacy in capturing the complex dynamics of the relationships under investigation (Zeeshan et al., 2022). The hypothesis testing results shed light on the relationships explored in the empirical analysis. The acceptance of H1 suggests a positive and significant relationship between EP and CO_2 emissions. Conversely, rejecting H2 indicates a negative and significant relationship between REA and CO_2 emissions. H3 is accepted, signifying a positive association between TR and CO_2 emissions. Lastly, H4 is accepted, indicating a negative and significant relationship between REA and CO_2

emissions when considering all predictors.

Policy Implications

Policymakers are strongly urged to craft integrated policies that bolster ecological regulations and facilitate financial sector development, thereby advancing the cause of a sustainable energy transition (Liu et al., 2022). To overcome challenges and expedite the adoption of green hydrogen technologies, it is essential to underscore the significance of continuous research and development in this critical sector (Hassan et al., 2023). (Raihan et al., 2023) propose policies emphasizing environmental sustainability, focusing on steering towards a low-carbon economy. These policies advocate for the promotion of RE, active support for technological advancements, and the assurance of ecological viability, particularly in regions such as Indonesia's forests. In pursuing effective CO_2 emissions reduction, (Zheng et al., 2023) recommend that policymakers consider strategic industrial structure transformation and prioritize technological progress. Moreover, the study by (Zhang et al., 2023) puts forward crucial policy suggestions, including promoting green transitions, tailored development strategies, and interventions targeting major drivers for balanced growth. Additionally, they advocate for refining regional governance and establishing an innovation fund for green technologies, particularly in ecologically fragile and economically underdeveloped regions.

Conclusion

This study comprehensively analyzes the economic and environmental dynamics within G7 economies from 1990 to 2022. The positive correlation between GDP growth and employment and the negative correlation between GDP growth and income inequality emphasizes the complex interplay between economic growth and Social factors. The strong negative correlations between GDP growth and industrial and energy-related CO_2 emissions underscore the environmental challenges associated with economic expansion. The regression models elucidate the impact of economic performance, RE adoption, and trade relations on CO_2 emissions. Accepting specific hypotheses, such as the positive relationship between economic performance and emissions, suggests the need for targeted environmental policies. The factor loading analysis and SEM further validate the reliability of the constructs used in the study and provide a visual representation of the complex relationships among latent variables. As informed by the empirical findings, policy implications emphasize the importance of integrated policies that strengthen ecological regulations, support financial sector development, and promote sustainable energy practices. Recommendations include targeted strategies for green transitions, technological advancements, and regional development, aligning with global efforts towards environmental conservation. In sustainable development, governments are encouraged to drive businesses towards green practices through subsidies, implement carbon pricing mechanisms, and embed environmental standards into trade agreements. These policy measures can significantly contribute to aligning economic activities with environmental goals.

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