ENVIRONMENTAL SUSTAINABILITY IN FRANCE: THE ROLE OF GDP GROWTH, GOVERNMENT FINAL CONSUMPTION EXPENDITURE, RENEWABLE ENERGY AND NUCLEAR ENERGY

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ABSTRACT

France, significantly impacted by climate change and pressured by international treaties on environmental protection, aims for net zero emissions by 2050, supported by the National Climate Change Strategy and the Just Energy Transition Partnership (JETP). This study examines the impact of alternative energy resources, natural resources, and government spending on France's ecological sustainability from 2000 to 2021, emphasizing the Environmental Kuznets Curve (EKC) framework and the theory of linear regression models. The findings reveal an inverse relationship between CO_2 emissions and renewable energy and nuclear share on both total energy supply and final consumption. While CO_2 emissions negatively correlate with economic growth, natural resources rent, total energy supply and usage proving the compatibility of France sustainable economy toward the EKC curve. Effective policies require equitable distribution and adherence to regulations. France should enhance renewable energy adoption, ensure the nuclear power security, enforce stricter regulations on natural resource exploitation, integrate environmental impact assessments into economic planning, developing more on energy transition, expanding further sustainable economic growth and foster public awareness and education on sustainable practices while maintaining a prosperous economy independent from natural resources extraction. These strategies will support France's transition to a sustainable economy, aligning economic growth with environmental preservation.

Keywords: *Alternative energy, carbon emissions, environmental sustainability, net zero emissions, EKC model.*

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1. INTRODUCTION

Global concerns include climate change, desertification, deforestation, coastal erosion, overfishing, biodiversity loss, and soil degradation, all driven by human activity. Energy conservation is key to reducing demand and environmental impact, as most energy comes from non-renewable fossil fuels. Cutting energy use saves money and benefits the environment. Environmental concerns, such as air quality and acid rain, have shaped energy practices and investments.

The energy sector, responsible for most global greenhouse gas emissions, faces climate change policy impacts. Promoting synergies between energy and environmental policies is crucial. Combating climate change requires investing in renewable energy and moving away from fossil fuels to keep temperatures below 2°C. Fossil fuel combustion causes significant air pollution and global environmental issues.

Energy is vital for economic prosperity but poses environmental challenges. Addressing air pollution and greenhouse gas emissions together offers comprehensive solutions. Many countries have made progress, but challenges remain. France aims for carbon neutrality by 2050 and is accelerating its energy transition with investments in hydrogen, sustainable mobility, and building retrofits as part of its recovery plan and 2030 strategy.

The objectives of this paper are to analyse the factors influencing the CO_2 emissions of France, to determine the pivotal impact of France's path toward sustainability, and how it is affected by key factors such as Government Final Consumption Expenditure (GFCEinUSD), Government

Total Expenditure on GDP (GOVE), GDP, Nuclear Share on Total Energy Supply (ESN), Renewable Energy Share on Total Energy Consumption (ECRE), and Natural Resources Rent (NR).

2. LITERATURE REVIEW

The measurement of carbon emissions employs various models and theories to assess the impact of climate change efficiently. Increased fossil fuel use and deforestation have led to the development of numerous CO_2 emission analysis methods. A key concept is the Environmental Kuznets Curve (EKC) model, which suggests a U-shaped relationship between economic growth and pollution. Initially conceptualized by Simon Kuznets in the 1950s in relation to income inequality, this concept was later adapted to environmental economics and gained prominence in the early 1990s with the work of Grossman and Krueger, who explored the impact of economic growth on environmental quality in their study on the North American Free Trade Agreement (NAFTA) [1]. They found empirical evidence suggesting that certain pollutants decreased after a threshold level of income was reached. Following this, the EKC hypothesis has been extensively studied and debated in the fields of environmental and development economics.

The paper "Economic Growth and Environmental Quality: Time-Series and Cross-Country Evidence" by Nemat Shafik and Sushenjit Bandyopadhyay [2] explores the relationship between economic growth and environmental quality through the analysis of patterns of environmental transformation at different income levels which posits that environmental degradation initially increases with economic growth but eventually decreases as income reaches higher levels. Studies of "Economic Growth and the Environment" by Theodore Panayotou [3] have shown that pollutants like sulphur dioxide (SO_2) and particulate matter (PM) follow the EKC pattern with turning points at various income levels. The hypothesis suggests that in the early stages of economic growth, environmental degradation and pollution levels increase, but after reaching a certain level of income per capita, further economic growth leads to environmental improvements. Economic growth initially leads to environmental degradation but eventually improves environmental quality. This theory has been validated in several studies showing that economic growth can either increase or reduce emissions.

Numerous studies have explored the relationship between energy efficiency, renewable energy intensity, and environmental sustainability, providing empirical evidence that supports the EKC hypothesis. In their 2015 study titled "How effective are energy efficiency and renewable energy in curbing CO_2 emissions in the long run? A heterogeneous panel data analysis" Özbuğday and Erbas [4] found that energy efficiency significantly reduces CO_2 emissions. Their research utilized a panel data approach, accounting for heterogeneity and cross-sectional dependence among countries, to reveal that improvements in energy efficiency have a long-term mitigating effect on CO_2 emissions. In their 2022 study titled "Impact of energy efficiency on CO_2 emissions: empirical evidence from developing countries" [5] published in Gondwana Research, Mirza et al. demonstrated that energy efficiency exerts a more significant influence on reducing CO_2 emissions in developing countries compared to structural shifts resulting from economic activities. Their research highlighted that while economic growth and industrialization contribute to carbon emissions, improvements in energy efficiency play a more crucial role in mitigating these emissions across the examined developing nations. Mirza et al. provided robust empirical evidence that enhancing energy efficiency can lead to substantial reductions in CO_2 emissions, thereby underscoring its importance in achieving sustainable environmental outcomes. Similarly, in the paper titled "Toward a sustainable mitigation approach of energy efficiency to greenhouse gas emissions in the European countries" [6] published in Heliyon in 2020, Akdag and Yildrim demonstrated that energy efficiency decreases greenhouse gas (GHG) emissions in the European Union and Turkey. By employing a combination of Granger causality and long-run estimators like fully modified and dynamic ordinary least squares (FMOLS and DOLS), they provided robust evidence that enhanced energy efficiency leads to significant reductions in GHG emissions.

In the context of France, Ridwan et al., in their paper titled "Environmental Sustainability in France: The Role of Alternative and Nuclear Energy, Natural Resources, and Government Spending" [8] examined the impacts of alternative and nuclear energy, natural resources, and government spending on France's ecological sustainability from 1990 to 2021. The study employed the EKC framework, using fully modified least squares (FMOLS) and dynamic ordinary least squares (DOLS) for long-run estimates. Their findings indicate an inverse relationship between CO_2 emissions and the use of alternative energies, natural resources, and government spending, while a positive relationship is observed between CO_2 emissions and natural resources rents. The results support the EKC hypothesis, suggesting that as the economy grows, environmental sustainability initially declines but improves in the long run underscoring the importance of promoting alternative and nuclear energy, implementing sustainable resource management policies, and directing government spending towards environmental protection and sustainable practices to achieve substantial environmental benefits and support sustainable development goals.

These studies collectively emphasize the importance of energy efficiency as a key factor in reducing environmental degradation and align with the principles of the EKC hypothesis. They highlight the potential for energy efficiency measures to achieve substantial environmental benefits, supporting sustainable development goals. Factors such as foreign direct investment, financial development, and energy research influence emissions.

France has implemented numerous policies aimed at balancing economic growth with environmental sustainability. The country's commitment to the Paris Agreement and its ambitious targets for reducing greenhouse gas emissions are pivotal. For instance, France aims to achieve carbon neutrality by 2050, with intermediate targets set for 2030. The implementation of carbon taxes, subsidies for renewable energy, and stringent environmental regulations are critical components influencing the EKC relationship in France. In recent years, France has achieved significant reductions in CO_2 emissions. Between 2015 and 2020, France reduced its greenhouse gas emissions by approximately 12%, driven by the transition towards cleaner energy sources and improved energy efficiency measures. The transportation and industrial sectors have seen notable declines in emissions due to technological advancements and stringent environmental policies. Despite its heavy reliance on nuclear power, France has been gradually decreasing its nuclear energy output as part of its broader energy transition strategy. It is noticeable that France is one of the world's leaders in nuclear energy, deriving approximately 70% of its electricity from nuclear power and the nuclear power provides an important role in energy production and account for approximately 40% of total energy supply. The Long-Term Energy Plan (Programmation Pluriannuelle de l'Énergie), issued in the context of Energy Transition for Green Growth Act (2015), sets a goal to reduce the share of nuclear energy in electricity production from 70% to 50% by 2035. This transition involves closing older reactors and investing in renewable energy sources to ensure energy security and sustainability.

While existing research literature provides a substantial understanding of the EKC model, there is a noticeable gap in studies specifically focusing on France's unique economic and environmental context. This study aims to fill this gap by analyzing these factors' impact on CO_2 emissions within the EKC context by expanding the evaluation of influential factors, introducing an empirical model which illustrates the environmental impacts of both renewable energy and nuclear energy shares separately. The study concludes with policy implications, identified research gaps, and future research suggestions.

3. METHODOLOGY

3.1. Data description

From 2000 through 2022, this research uses the Regression models to examine how the France Trade, GDP, Total Energy Supply, Total Energy Consumption and the usage of alternative energy sources including the nuclear share on total energy supply and renewable share in total final energy consumption. will affect France's environmental sustainability. Emissions of CO_2 are reported in Mt as illustrated in the Annex [9]. CO_2 emissions, expressed in megatonnes (Mt), refer to the carbon dioxide released from fuel combustion within the energy sector. The International Energy Agency publishes and provides access to these data on its official website. In France, the primary sources of CO_2 emissions are the combustion of fossil fuels -such as coal, oil, and natural gas - for power generation, transportation, residential heating, and industrial activities. The distribution of energy-related CO_2 emissions is influenced by the economy's structure and energy system. Emissions from power plants arise from burning fuels to produce electricity and heat. In the transportation sector, the majority of emissions come from cars, which, despite the increasing adoption of electric vehicles (EVs), still largely depend on oil-based fuels. In residential areas, fossil fuel heating is the main source of emissions. In the industrial sector, emissions are primarily due to burning fossil fuels to produce heat for processes like paper and steel manufacturing. Overall, most CO_2 emissions in the energy sector are the result of burning fossil fuels for power generation or to fuel vehicles and industrial machinery.

The percentage of ultimate energy consumption that came from renewable sources was calculated. GDP was used because it is a consistent indicator of economic growth in billions of US dollars. The total energy supply demonstrated in TJ is also taken into consideration because of their vital roles in regulating CO_2 emissions. This variable includes the sum of energy from biofuels and waste, coal, hydro, natural gas, nuclear, oil, and solar/wind sources. TotalES encompasses domestic production and imports, minus exports and changes in energy stock levels. It is crucial for understanding the overall energy landscape and its direct link to CO_2 emissions. The alternative share represented by nuclear energy and renewables were also assessed for their

Table 1. The CO_2 emissions, GDP, Natural Resources Rent, Energy Share, Energy Supply, Government Speeding of France from 2000 - 2022

	CO_2 Emission of all Fuel Combustion in Mt	Nuclear Share on Total Final Energy Supply (%)	Total Enery Supply in TJ	Renewables on Total Final Energy Consumption (%)	Natural Resources Rent in % of GDP	% Government Spending in GDP	General government final consumption expenditure Billion USD	Gross Domestic Products in Billions of USD
Year	**CO2**	**ESN**	**TotalES**	**ECRE**	**NR**	**GOVE**	**GFCEinUSD**	**GDP**
2000	364.67	42	10,784,301	9.32	0.07	44.13	304.89	1365.64
2001	368.21	41.23	11,140,737	9.45	0.06	44.37	305.04	1377.66
2002	362.52	42.54	11,199,298	8.73	0.06	45.35	341.14	1501.41
2003	368.28	42.07	11,437,030	8.9	0.05	45.64	426.89	1844.54
2004	368.88	42.21	11,583,634	8.95	0.04	45.02	488.46	2119.63
2005	371.71	42.36	11,628,007	8.66	0.04	45.14	506.77	2196.95
2006	362.43	42.88	11,453,804	8.52	0.05	44.7	528.14	2320.54
2007	353.57	42.43	11,306,591	9.45	0.05	44.2	596.85	2660.59
2008	349.33	42.33	11,324,916	10.6	0.05	44.68	661.15	2930.30
2009	336.2	41.53	10,762,910	11.31	0.05	48.02	650.4	2700.89
2010	340.05	42.07	11,110,690	11.99	0.05	49.32	634.56	2645.19
2011	326.6	43.89	10,995,233	10.65	0.05	47.59	680.32	2865.16
2012	330.45	42.39	10,946,798	12.34	0.05	48.07	642.75	2683.67
2013	330.85	41.99	11,008,516	13.43	0.05	48.12	677.99	2811.88
2014	298.72	44.69	10,654,015	13.18	0.05	48.29	689.03	2855.96
2015	304.19	44.19	10,798,734	13.33	0.04	47.99	580.72	2439.19
2016	306.63	41.82	10,517,898	14.25	0.04	47.88	586.89	2472.96
2017	310.73	41.37	10,505,201	14.12	0.04	47.71	613.6	2595.15
2018	299.95	42.82	10,521,390	15.2	0.04	46.77	649.5	2790.96
2019	293.46	42.04	10,354,691	15.53	0.03	46.3	627.19	2728.87
2020	260.54	41.58	9,284,160	16.86	0.03	51.87	657.74	2647.42
2021	291.76	41.31	10,017,436		0.03	49.88	722.37	2959.36
2022	275.75	36.5	8,808,300				667.24	2779.09

Sources: International Energy Agency for CO_2, ESN, TotalES, ECRE; The World Bank Data for GDP, NR, GOVE and GFCEinUSD contribution to CO_2 emissions. All the information for the yearly series comes from the World Bank Open Data Sources and International Energy Agency Reports. This comprehensive dataset allows for a robust analysis of how these variables influence France's CO_2 emissions and overall environmental sustainability.

3.2. Econometric model

The EKC model, or Environmental Kuznets Curve model, is a hypothesized relationship between environmental quality improvement and economic development growth. The model suggests that as an economy grows, environmental degradation increases up to a certain point (usually at middle-income levels). After reaching this peak, further economic growth leads to environmental improvement. We assume that the France GDP will follow the EKC model, and its economic growth will eventually lead to environmental improvements. However, relying solely on economic growth without active environmental policies may not lead to the desired outcomes. We need to consider other factors that may affect the France's Path toward sustainability represented by the CO_2 Emissions.

Based on the EKC hypothesis, this research paper investigates the impacts of GDP growth, nuclear share on total energy supply, alternative energy share on both energy supply and consumption, the use of renewable energies, natural resources, alongside with government expense and final consumption expenditure on France's ecological sustainability throughout the recorded period from 2000 - 2022. The initial suggested empirical model of CO_2 emissions is:

$$CO_2 = b0 + b1 \times GDP + b2 \times ECRE + b3 \times ESN + b4 \times TotalES + b5 \times NR + b6 \times GFCEinUSD$$

All the following factors are assumed to have impact on the total CO_2 emissions:

GDP is the Gross Domestic Products of France measured in Billions of USD. GDP is a consistent indicator of economic growth. While economic growth can lead to increased energy consumption and emissions, it can also drive investments in cleaner technologies and energy efficiency, impacting CO_2 emissions. According to the Environmental Kuznets Curve (EKC) model, economic growth initially leads to environmental degradation and increased emissions. However, after reaching a certain level of income, further economic growth results in environmental improvements and reduced emissions. Thus, GDP can both increase energy consumption and emissions and drive investments in cleaner technologies and energy efficiency, impacting CO_2 emissions.

ESN is the Nuclear Power Share on Total Energy Supply, measured in %, representing the proportion of total energy supply derived from nuclear energy. Nuclear power provides a stable and consistent energy output, making it more suitable for analysis based on total energy supply. Unlike renewable sources, nuclear power is less affected by weather and seasonal variations, providing a continuous and predictable supply of energy. This characteristic of stability makes it a reliable measure for the overall energy supply mix, reflecting its high energy density and long-term infrastructure planning.

ECRE is the Renewable Energy Share on the total Energy Consumption measured in %, represents the proportion of a country's total energy consumption that comes from renewable sources such as solar, wind, hydro, biomass, and geothermal energy. Renewable energy sources directly impact end-user consumption patterns due to their intermittent and variable nature. Therefore, measuring ECRE provides a more accurate reflection of how much of the consumed energy is derived from renewable sources. Its impact is more accurately captured in consumption patterns rather than a steady supply metric. This metric aligns with policies and incentives aimed at promoting renewable energy usage among consumers.

TotalES is the total Energy Supply of France measured in TJ, provides a comprehensive measure of all the energy available for use within France. It includes energy produced domestically as well as energy imports, minus energy exports and changes in energy stock levels. This includes all forms of energy such as fossil fuels, nuclear, and renewables, providing a holistic view of the energy landscape. By focusing on supply rather than just consumption. TotalES reflects the total energy inputs into the economy, accounting for both production and trade in energy resources. TotalES captures the effects of national energy policies, including efforts to increase domestic energy production, diversify energy sources, and reduce dependency on energy imports. It is a critical metric for understanding how policy changes impact overall energy availability and sustainability.

NR is the Natural Resources Rent as Percentage of GDP, measured in %, representing the economic value derived from natural resources relative to the country's GDP. Natural resources rent indicates the economic dependence on resource extraction. Higher natural resources rent can lead to increased CO_2 emissions due to extraction and processing activities, making it an important variable to consider.

GFCEinUSD is the Government Final Consumption Expenditure, measured in Billions of USD, representing the total government spending on goods and services consumed by the public. Government expenditure impacts CO_2 emissions through public investments in infrastructure, energy projects, and sustainability initiatives. Analyzing GFCEinUSD helps understand the role of government spending in promoting or mitigating CO_2 emissions.

The study employs several key variables to capture the impact of different energy sources and economic factors on CO_2 emissions. By incorporating these key variables, the study aims to provide a comprehensive analysis of the factors influencing CO_2 emissions in France, considering the direct and indirect effects of energy supply and economic activities. This approach captures the complex interactions between energy types, economic growth, government policies, and environmental outcomes, providing valuable insights for sustainable development and climate change mitigation strategies. Empirical evidence suggests that using total energy supply, nuclear share in energy supply and renewable share in energy consumption provides a better fit for the regression models, yielding more accurate and reliable results. This choice reflects the real-world dynamics of energy generation and consumption patterns.

3.3. Estimation strategies

Testing all the regression models by using the SPSS ought to be introduced to determine the most influencing factors. Sometimes, in economic and financial theory, it is assumed that non-stationary time series variables have some sort of long-term equilibrium relationship. By testing the model, we can find the most suitable model for explaining the correct sustainability factors in France.

Table 2. Regression Result 1 the CO2 Emissions affected by GDP, TotalES, ESN, ECRE, NR

Model Summary							
R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics			
				F Change	df1	df2	Sig. F Change
0.997[a]	0.995	0.993	2.6220887	576.033	5	15	0
ANOVA[a]							
	Sum of Squares	df	Mean Square	F	Sig.		
Regression	19802.1	5	3960.428	576.033	0.000[b]		
Residual	103.13	15	6.875				
Total	19905.3	20					
Coefficients[a]							
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	416.053	43.06		9.662	0		
ECRE	-5.428	0.627	-0.449	-8.662	0	0.129	7.771
ESN	-7.371	0.705	-0.209	-10.457	0	0.863	1.159
NR	362.157	84.075	0.112	4.308	0.001	0.515	1.942
TotalES	2.65E-05	0	0.445	10.431	0	0.19	5.275
GDP	-0.006	0.002	-0.088	-3.041	0.008	0.415	2.409
a. Dependent Variable: CO_2							
b. Predictors: (Constant), GDP, ESN, TotalES, NR, ECRE							

Regression Results SPSS [9]

4. RESULTS AND DISCUSSION

4.1. The CO_2 Emissions affected by the key factors of GDP, Total Energy Supply, Nuclear Share and Renewable Energy Share on Total Energy Supply, and Natural Resources Rent

The model demonstrates a high R-squared value of 0.995, indicating that 99.5% of the variance in CO_2 emissions is explained by the independent variables, with an adjusted R-squared value of 0.993 confirming the model's goodness of fit. The F-statistic of 576.033 and its significance ($p < 0.001$) show the model's statistical significance. Regression analysis shows that significant predictors include Total Energy Supply (positive coefficient), Nuclear Share (negative coefficient), and Renewable Energy Share (negative coefficient), emphasizing the impact of energy sources on CO_2 emissions. Specifically, ECRE has a significant negative effect on CO_2 emissions ($B = -5.428$, $p < 0.001$), suggesting increased renewable energy share on total energy consumption reduces CO_2 emissions significantly while ESN also negatively impacts CO_2 emissions ($B = -7.371$, $p < 0.001$) suggesting a more significant effect on the CO_2 emissions. Conversely, NR ($B = 362.157$, $p < 0.001$) and TotalES ($B = 2.654 \times 105$, $p < 0.001$) positively affect CO_2 emissions, indicating higher natural resource rents and total energy supply increase emissions tremendously. Otherwise, GDP shows a minor negative effect ($B = -0.006$, $p < 0.01$), implying economic growth slightly reduces CO_2 emissions. However, while the Natural resource rents as percentage of GDP will affect the CO_2 emissions extremely considering the current level of natural resource rents of 0.03% of total GDP, the GDP will make a very slight influence on the reductions of CO_2.

The correlation analysis reveals that CO_2 emissions are negatively correlated with ECRE (-0.959) and ESN (-0.095), suggesting that as these variables increase, CO_2 emissions decrease. Positive correlations are found with total energy supply (TotalES) (0.901) and natural resource rent as a percentage of GDP (NR) (0.722). All the VIFs values show no important multicollinearity enhancing the significance of the model.

The equations for predicting CO_2 emissions based on the regression results are as follows:

$$CO_2 = 416.053 - 5.428 \times ECRE - 7.371 \times ESN + 362.157 \times NR + 2.654 \times 10^{-5} \times TotalES - 0.006 \times GDP$$

The coefficient for ECRE (Renewable Energy Share on Total Energy Consumption) is -5.428, indicating that for each percentage point increase in the share of renewable energy, CO_2 emissions decrease by 5.428 megatonnes (Mt). This highlights the significant impact of renewable energy sources, such as wind, solar, hydro, and biomass, in reducing CO_2 emissions compared to fossil fuels. Similarly, the ESN (Nuclear Share on Total Energy Supply) has a coefficient of -7.371, suggesting that increasing the share of nuclear energy by one percentage point reduces CO_2 emissions by 7.371 Mt. Nuclear power plants do not emit CO_2 during electricity generation, making nuclear energy a crucial component in reducing emissions.

Conversely, the NR (Natural Resource Rent as a Percentage of GDP) has a coefficient of +362.157, indicating that a slight increase in natural resource rent leads to a significant rise in CO_2 emissions. This is due to the high emissions associated with extracting and utilizing natural resources, such as mining and deforestation. The TotalES (Total Energy Supply) has a small positive coefficient of $+2.654 \times 10^{-5}$, showing that an increase in total energy supply results in higher CO_2 emissions. This reflects the direct link between higher energy consumption and increased emissions, especially if the energy comes from fossil fuels. Since the TotalES is calculated in TJ and currently stands at the level of 10 million of TJ, an increase of 10% of energy supply will lead to eventual explosion of 26 Mt of CO_2 emission.

Finally, the GDP (Gross Domestic Product) has a coefficient of -0.006, indicating that each billion USD increase in GDP slightly decreases CO_2 emissions by 0.006 Mt, reaffirming the EKC theory to the context of France. This suggests that economic growth can lead to reduced emissions through improved efficiency, technology, and shifts to less carbon-intensive industries. However, this impact is relatively minor compared to other factors.

In summary, increasing the shares of renewable and nuclear energy significantly reduces CO_2 emissions, while greater reliance on natural resource extraction and higher total energy supply increases emissions. Economic growth has a minor but positive impact on reducing emissions. Therefore, policies should focus on promoting renewable and nuclear energy, managing natural resource rents, improving energy efficiency, and supporting sustainable economic growth to achieve substantial reductions in CO_2 emissions.

4.2. The CO_2 Emissions affected by the key factors of Government Final Consumption Expenditure, Total Energy Supply, Nuclear Share and Renewable Energy Share on Total Energy Supply, and Natural Resources Rent

Table 3. Regression Result 2 the CO_2 Emissions affected by GFCEinUSD, TotalES, ESN, ECRE, NR

Model Summary							
R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics			
				F Change	df1	df2	Sig. F Change
0.997[a]	0.995	0.993	2.66880119	555.941	5	15	0
ANOVA[a]							
	Sum of Squares	df	Mean Square	F	Sig.		
Regression	19798.434	5	3959.687	555.941	0.000[b]		
Residual	106.837	15	7.122				
Total	19905.271	20					
Coefficients[a]							
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	420.299	43.44		9.675	0		
ECRE	-5.467	0.637	-0.452	-8.588	0	0.129	7.74
ESN	-7.353	0.721	-0.209	-10.192	0	0.853	1.172
NR	363.561	85.626	0.112	4.246	0.001	0.514	1.944
TotalES	2.60E-05	0	0.437	10.29	0	0.199	5.035
GFCEinUSD	-0.022	0.008	-0.087	-2.9	0.011	0.393	2.543
a. Dependent Variable: CO_2							
b. Predictors: (Constant), GFCEinUSD, ESN, TotalES, NR, ECRE							

Regression Results SPSS [9]

The regression model demonstrates a strong relationship between CO_2 emissions and the independent variables: GDP, Total Energy Supply (TotalES), and the shares of nuclear and renewable energy. The model explains 99.5% of the variance in CO_2 emissions, with an adjusted R-squared value of 0.993, confirming its goodness of fit. The F-statistic of 555.941 and its significance ($p < 0.001$) further establish the model's statistical significance.

The coefficients table reveals that GFCEinUSD has a significant negative effect on CO_2 emissions (B = -0.022, p = 0.011), indicating that an increase in government final consumption expenditure (GFCE) is associated with a relative decrease in CO_2 emissions. TotalES has a small but significant positive effect on CO_2 emissions (B = 2.604E-5, $p < 0.001$), suggesting that higher total energy supply correlates with increased CO_2 emissions. ESN (B = -7.353, $p < 0.001$) and ECRE (B = -5.467, $p < 0.001$) both have significant negative effects on CO_2 emissions, highlighting the role of nuclear and renewable energy sources in reducing emissions.

Collinearity statistics indicate some multicollinearity, particularly for ECRE (VIF = 7.740) and TotalES (VIF = 5.035). However, these levels are not exceedingly high and the coefficients remain reliable. The significant predictors in this model underscore the impact of energy sources on CO_2 emissions. The findings suggest that increasing the share of renewable and nuclear energy in the energy mix is crucial for reducing CO_2 emissions, while government spending also contributes positively to emission reductions.

The equations for predicting CO_2 emissions based on the regression results are as follows:

CO_2 = 420.299 - 0.022 x GFCEinUSD + 2.604×10^{-5} x TotalES + 363.561 x NR - 7.353 x ESN - 5.467 x ECRE

The predictive equation for CO_2 emissions reveals how various factors influence emission levels, reaffirming the effect of various factors which were taken into consideration previously such us ESN, ECRE, NR and TotalES. The coefficient for GFCEinUSD (Government Final Consumption Expenditure) is -0.022, indicating that for every billion USD increase in government spending, CO_2 emissions decrease by 0.022 Mt, likely due to investments in sustainable infrastructure and public services. This emphasizes the importance of Government Spending in comparison with GDP by 10-time multiplier effect, showing a more pronounced impact. The TotalES (Total Energy Supply) coefficient of +2.604 x 10^{-5} suggests that as energy supply increases, CO_2 emissions also rise, reflecting the direct link between higher energy consumption and increased emissions, especially from fossil fuels. The NR (Natural Resource Rent as a Percentage of GDP) coefficient of +363.561 shows that an increase in natural resource rent significantly raises CO_2 emissions, highlighting the environmental impact of activities like mining and deforestation. Conversely, the ESN (Nuclear Share on Total Energy Supply) coefficient of -7.353 indicates that a higher share of nuclear energy reduces CO_2 emissions by 7.353 Mt per percentage point increase, underscoring the role of nuclear energy in lowering emissions. Similarly, the ECRE (Renewable Energy Share on Total Energy Consumption) coefficient of -5.467 demonstrates that increasing the share of renewable energy decreases CO_2 emissions by 5.467 Mt per percentage point increase, emphasizing the effectiveness of renewable energy sources in reducing emissions. This equation shows that promoting renewable and nuclear energy, managing natural resource rents, and increasing government spending on sustainable practices are crucial for reducing CO_2 emissions.

5. CONCLUSION AND POLICY IMPLICTIONS

From all the regressions results, it is suggested that the CO2 emissions can be predicted by using one or more of the following equations:

Equation 1:

CO_2 = 416.053 - 0.006 x **GDP** - 5.428 x **ECRE** - 7.371 x **ESN** + 2.654 × 10^{-5} x **TotalES** + 362.157 x **NR**

Equation 2:

CO_2 = 420.299 - 0.022 x **GFCEinUSD** - 7.353 x **ESN** - 5.467 x **ECRE** + 2.604×10^{-5} x **TotalES** + 363.561 x **NR**

Both two models illustrate a very strong reliability with the R^2 value of more than 99.5%. The two models may be used interchangeably since the variation of GFCEinUSD factor can be explained by the GDP and GOVE (Government Spending as percentage of GDP) as indicated by the following equation: **GFCEinUSD** = -393.346 + 0.23 x **GDP** + 8.639 x **GOVE** [9]. This relationship of GDP and GFCEinUSD further enhances the significance of mentioned models. While both equations highlight the importance of renewable and nuclear energy in reducing emissions and the detrimental effect of natural resource extraction, they differ in their economic indicators, with government spending showing a much stronger and more pronounced influence on reducing emissions than GDP.

These equations reveal significant relationships between economic and energy factors and CO_2 emissions:

Economic Growth (GDP): An increase in GDP consistently leads to a decrease in CO_2 emissions, suggesting that higher economic output is associated with more efficient energy use or cleaner energy technologies. For every increase of 1 billion USD in GDP, CO_2 emissions decrease by 0.006 million metric tons (Mt).

Government Final Consumption Expenditure (GFCE): An increase in GFCE consistently leads to a decrease in CO_2 emissions, suggesting that higher government expenditure on final consumption is associated with more efficient energy use or cleaner energy technologies. As the GFCE is measured in billions of USD, for every increase of 1 billion USD in GFCE, CO_2 emissions decrease by 0.022 million metric tons (Mt).

Total Energy Supply (TotalES): An increase in total energy supply results in a slight increase in CO_2 emissions. This is expected as more energy consumption typically leads to more emissions unless offset by cleaner energy sources. AS the total energy supply is measured in TJ and currently stands at approximately 10 million of TJ, for every increase of 1 million TJ or equivalent of 10% increase in Total Energy Supply, CO_2 emissions increase by approximately 27 Mt.

Energy Share Composition:

• **Nuclear Energy (ESN)**: Increasing the share of nuclear energy significantly reduces CO_2 emissions, highlighting the role of nuclear power as a low-emission energy source. For each 1% increase in the share of nuclear energy of total energy supply, the CO_2 emission will be reduced by approximately 7.4 Mt.

- **Renewable Energy (ECRE)**: Increasing the share of renewable energy has the most substantial impact on reducing CO_2 emissions, underscoring the importance of renewable energy in mitigating climate change. For each 1% increase in the share of renewables of total energy consumption, the CO_2 emission will be reduced by approximately 5.4 Mt.

In summary, to effectively reduce CO_2 emissions, policies should focus on promoting economic growth alongside increasing the shares of nuclear and renewable energy in the total energy mix. This combined approach can lead to substantial reductions in CO_2 emissions, contributing to climate change mitigation efforts. The mentioned results show valuable guidance for policymakers aiming to combat climate change effectively with the following implications for effectively implementing sustainability policy:

Increase the share of Nuclear Energy

- Investment in Nuclear Energy: Governments and private sectors should invest in the construction of new nuclear power plants and the maintenance of existing ones to ensure a stable and safe supply of nuclear energy.
- Regulatory Frameworks: Develop and implement regulatory frameworks that ensure the safety and efficiency of nuclear energy production while addressing public concerns about safety and waste management.
- Public Perception: Conduct public awareness campaigns to educate citizens about the benefits of nuclear energy in reducing CO_2 emissions and ensuring energy security. Address safety concerns transparently to build public trust.
- Research and Development: Invest in research and development to improve nuclear technologies, making them safer, more efficient, and cost-effective. This includes advancements in reactor designs and waste management solutions.

Reduce Energy Supply

- Energy Efficiency Measures: Implement strict energy efficiency standards for buildings, appliances, and industrial processes. Encourage retrofitting of old buildings with energy-efficient technologies.
- Behavioural Changes: Promote energy-saving behaviours among consumers through educational campaigns and incentives for reduced energy usage, such as lower utility rates for reduced consumption.
- Technology Adoption: Subsidize and incentivize the adoption of energy-efficient technologies, such as LED lighting, smart thermostats, and energy-efficient appliances.
- Smart Grids and Demand Response: Develop and deploy smart grid technologies that enhance the efficiency of electricity distribution and allow for demand response strategies to reduce peak energy consumption.

Increase Government Final Consumption Expenditure (GFCE)

- Public Transportation: Increase investments in public transportation systems, making them more efficient, accessible, and attractive to reduce reliance on private vehicles.
- Renewable Energy Projects: Allocate government spending towards renewable energy projects such as solar, wind, and hydroelectric power, ensuring a sustainable and clean energy supply.
- Sustainable Infrastructure: Develop and maintain sustainable infrastructure projects that prioritize low-carbon solutions, such as green buildings, smart cities, and efficient waste management systems.
- Public Services and Programs: Enhance public services that contribute to sustainability, such as recycling programs, energy-saving initiatives, and environmental conservation projects.

Increase the Share of Renewable Energy on total Energy Consumption

Subsidies and Tax Incentives: Provide financial incentives such as subsidies, tax credits, and grants to encourage the adoption of renewable energy technologies among businesses and households.

Renewable Energy Standards: Implement and enforce renewable energy standards that require a certain percentage of energy to come from renewable sources.

Grid Integration: Invest in grid infrastructure to support the integration of renewable energy sources, ensuring stability and reliability in energy supply.

Community Renewable Projects: Support community-based renewable energy projects that allow local communities to generate and use their own renewable energy, fostering local energy independence and sustainability.

Foster Economic Growth with a Focus on Sustainability

Green Economy: Promote the development of a green economy that prioritizes sustainable practices and low-carbon technologies across all sectors, including agriculture, manufacturing, and services.

Sustainable Business Practices: Encourage businesses to adopt sustainable practices through incentives, recognition programs, and regulatory requirements that promote environmental responsibility.

Research and Innovation: Invest in research and innovation to develop new technologies and processes that enhance economic growth while reducing carbon footprints.

Circular Economy: Promote circular economy principles that emphasize recycling, reuse, and reducing waste, ensuring that economic growth does not come at the expense of environmental health.

Foster GDP less dependent on Extracting Natural Resources (Economic Growth):

The negative relationship between GDP and CO_2 emissions suggests that economic growth can lead to reduced emissions. This might be due to more efficient technologies and better regulatory frameworks in wealthier economies.

Promote sustainable economic growth through investments in green technologies, infrastructure, and innovation to achieve a higher GDP while simultaneously reducing emissions.

Economic Diversification: Reducing reliance on natural resource extraction and promoting economic diversification can help lower CO_2 emissions. This includes investing in renewable energy and other low-emission sectors.

Adopting Sustainable Practices: Implementing sustainable practices in natural resource extraction and utilization is crucial to mitigate environmental impact.

By focusing on these strategies, policymakers and stakeholders can work towards achieving significant reductions in CO2 emissions, thereby contributing to the global efforts to combat climate change.

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