Impact Of Energy Use and Renewables on Global CO_2 Emissions

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Abstract: In the current global context, which is characterized by intensifying climate change and the depletion of non-renewable resources, increasing the use of renewable energy sources is a strategic priority for sustainable development, both economically, socially and environmentally. This study analyzes the impact of renewable energy sources (such as solar, wind, hydropower and biomass) on global carbon dioxide emissions. Using three datasets downloaded from the World Bank, the research quantitatively assesses the relationship between total energy consumption per capita (measured in kilograms of oil equivalent per capita), the share of renewable energy in final consumption and CO2 emissions per capita (tons/person), in order to identify the main drivers of the increase in emissions. The econometric results show that about 64% of the variation in CO_2 emissions per capita is explained by energy consumption, share of renewables and GDP per capita, and the model is statistically significant. The study thus provides a quantitative perspective on the role that sustainable energy policies can play in tackling climate change and supporting the promotion of clean energy sources in global decarbonization strategies.

Key words: CO_2 Emissions, Energy Consumption, Renewable Energy, GDP Per Capita, Energy Sustainability

JEL classification: B23, C31, P18

1. Introduction

In recent decades, growing concerns about climate change and environmental degradation have prompted a profound reassessment of how energy is produced and consumed globally (Onea et al., 2022). The increasing consumption of energy that comes from non-renewable sources is one of the main drivers of rising CO_2 emissions with direct impact on global warming (Alam et al., 2016; Acheampong, 2018).

Thus, the choice of the present research topic is motivated by the growing interest of the international community in the climate challenges posed by the increasing use of non-renewable energy resources. In the context where carbon dioxide emissions have reached record levels and recent energy crises have marked the vulnerability of current production and consumption systems, analyzing the relationship between energy consumption, the share of renewable sources and carbon dioxide emissions becomes essential.

The aim of this study is to provide a quantitative analysis, using an econometric model, of the relationship between per capita CO_2 emissions and three explanatory variables: energy consumption per capita, share of renewable energy in total consumption and GDP per capita, by applying statistical and econometric methods.

The main objective is to investigate the relationship between energy consumption, renewable energy use and CO_2 emissions per capita at the global level.

The paper is structured in four parts which are organized as follows: the first part outlines the theoretical background and literature, the second part describes the data used and the research methodology, the third part is devoted to the analysis of the results and their interpretation, and the last section provides conclusions and recommendations for future research.

2. Literature review

This section will present the most relevant ideas from the literature on the impact of energy consumption, renewable energy sources and GDP per capita on carbon dioxide (CO_2) emissions.

Balogh and Jámbor (2017) find that a country's economic development is closely linked to the CO2 emissions generated, but there is also the possibility that a nation is also energy efficient while economic indicators linking to welfare are increasing. Countries that are developing should be the most interested in minimizing the effects of CO2 increases as they will suffer the most severe expected impacts of climate change (Stern, 2006; IPCC, 2014).

Several authors are of the opinion that encouraging the development of solar, wind, hydropower, as well as promoting the use of geothermal, biomass and marine energy are essential for CO_2 reduction (Alvarez-Herranz et al., 2017; Abbasi et al., 2021; Ali et al., 2022).

The rapid growth in demand for electricity, fueled also by industrial development and accelerated urbanization, has led to an intensification of CO_2 emissions, thus heightening climate change concerns (Alam et al., 2013; Ang, 2007). Although electricity consumption is essential for economic progress, the type of energy sources used determines the impacts that exist on the environment. Non-renewable sources (such as oil, coal and natural gas) are the main contributors to greenhouse gas emissions. Renewable energy sources have been recognized worldwide as sustainable solutions to reduce emissions and increase energy security (Ahmed et al., 2022; Antonakakis et al., 2017). The use of innovative technologies and increasing the share of renewables in the energy mix can facilitate lower CO_2 emissions (Balsalobre-Lorente et al., 2018).

At the same time, several studies emphasize that energy efficiency plays a crucial role in mitigating carbon emissions, regardless of the energy source used. In this regard, Bui et al. (2020) argue that policies aimed at increasing energy efficiency, particularly in the industrial and residential sectors, can lead to significant reductions in emissions without compromising economic development. Also, the integration of smart energy management technologies, such as smart grids, enables more efficient use of resources and better integration of renewable sources (IEA, 2021).

On the other hand, the relationship between energy consumption, GDP and CO_2 emissions is not linear and universally valid. Depending on a country's level of development, this relationship can differ significantly. Pata's (2021) study indicates that in advanced economies, the transition to clean sources is often accompanied by a partial decoupling between economic growth and CO_2 emissions, whereas in emerging economies, economic growth remains closely linked to energy intensity. In addition, Guo et al. (2021) show that carbon-pricing policies, such as carbon taxes or emissions trading schemes, help to encourage investment in green technologies and decrease the attractiveness of fossil-fuel projects. Such public policy instruments have proven effective in EU Member States, where a steady reduction in emissions has been observed in parallel with the expansion of renewable energy capacities. The literature converges on the idea that energy transition, energy efficiency and coherent climate policies are key factors for reducing CO_2 emissions. At the same time, a differentiated approach, tailored to the economic and institutional context of each country, is needed to ensure that the measures adopted are effective and sustainable in the long term.

According to studies conducted by Mardani et al. (2019), Dogan et al. (2015), Odhiambo (2009), where the links between economic growth and CO_2 emissions were analyzed, it was concluded that economic growth is often accompanied by an increase in energy consumption and hence pollution. According to the Environmental Kuznets Curve (EKC) hypothesis, in the initial stages of economic growth, CO_2 emissions increase, but after reaching a certain level of per capita income, they start to decrease due to energy efficiency and environmental policies (Stern, 2017; Dinda., 2004; Mahmood et al., 2023).

3. Research methodology

The present study is based on a multiple linear regression model with the aim of identifying the main factors influencing the level of carbon dioxide emissions per capita at the global level.

The analysis is based on a sample of 150 countries, for which data have been collected from the most recent periods available (2023). The main data source is the World Bank and Our World in Data, and the following indicators are used: CO_2 emissions per capita (tons per person) (Our World in Data: https://ourworldindata.org/co2-emissions), energy consumption per capita (kg oil equivalent per person) (WorldBank: https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE), share of renewable energy (% of total energy consumption) (WorldBank: https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS), GDP per capita (WorldBank: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD).

The model equation is:

$$Emissions\_CO_2\_per\_capita = \beta_0 + \beta_1 * Energy\_Use\_per\_capita + \beta_2 * Energie\_Regenerabilă + GDP\_Per\_Capita\_USD + \varepsilon$$

This model structure was chosen because it allows the simultaneous testing of the quantitative effect of energy consumption and the share of renewable energy on emissions, taking into account the income level.

The econometric model was developed using EViews 12 Student Version Lite software (https://www.eviews.com/EViews12/EViews12Univ/evuniv12.html).

4. Results and discussions

Figure 1 presents the results of the multiple linear regression applied to a global sample of countries for the year 2023. The model aims to estimate the impact of per capita energy consumption, renewable energy share and per capita GDP on per capita CO_2 emissions. The estimation was performed by the least squares (OLS) method, using cross-section data. The obtained coefficients provide statistical clues on the direction and intensity of the relationships between the analyzed variables.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.890265	0.473555	8.215023	0.0000
ENERGIE_REGENERABILA__	-0.065866	0.009108	-7.231421	0.0000
ENERGY_USE__KG_OF_OIL_EQUIVALE...	0.001184	0.000112	10.53627	0.0000
GDP_PER_CAPITA_USD	2.97E-05	9.43E-06	3.149110	0.0019

R-squared	0.641140	Mean dependent var	4.304861
Adjusted R-squared	0.634693	S.D. dependent var	5.150064
S.E. of regression	3.112731	Akaike info criterion	5.131992
Sum squared resid	1618.079	Schwarz criterion	5.205481
Log likelihood	-434.7853	Hannan-Quinn criter.	5.161811
F-statistic	99.45397	Durbin-Watson stat	2.283794
Prob(F-statistic)	0.000000		

Figure 1. Least Squares Method.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

R-squared shows how much of the variation in CO2 emissions is explained by the independent variables, R-squared = 0.641140, Adjusted R-squared = 0,634693. Approximately 64.1% of the variation in CO_2 emissions is explained by the three independent variables.

Adjusted R^2 is almost equal to R^2, a sign that the model is not overloaded with unnecessary variables.

The model is statistically significant. With an extremely small Prob (F-statistic) 0.00 < 0.05, we reject the null hypothesis that all coefficients are simultaneously equal to zero. So, at least one variable has a significant influence on CO_2 emissions.

Durbin-Watson has a value of 2.28, being close to 2, suggesting that there is no significant autocorrelation between the model errors.

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.224254	3.957797	NA
ENERGIE_REGENE...	8.30E-05	2.647122	1.093097
ENERGY_USE__KG...	1.26E-08	1.861236	1.242272
GDP_PER_CAPITA_...	8.90E-11	1.854741	1.240966

Figure 2. Variance Inflation Factors Test.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

VIF < 5, which indicates that there is no problematic multicollinearity between the variables. All values are around 1.10-1,25, which is a very good thing, this means that the explanatory variables are not very correlated with each other.

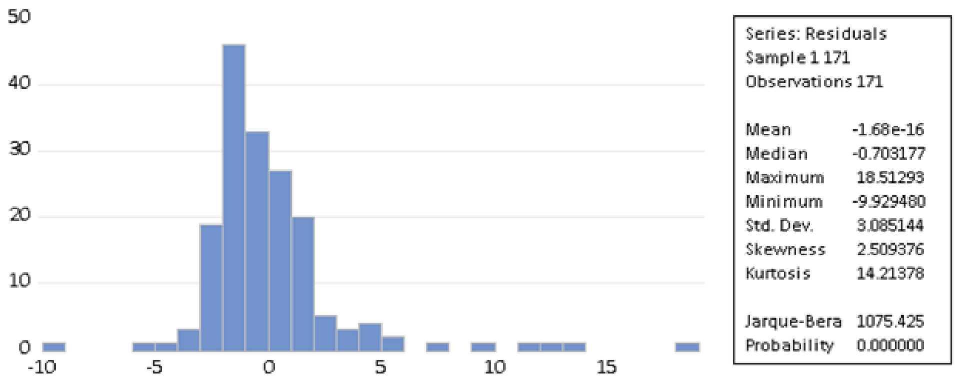

Figure 3. Testing the normality of the residuals.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

The mean of the residuals is close to 0, which is good; a correct model should have a mean of errors close to 0.

Skewness (2.509976) is positive, so the distribution is skewed to the right. The model tends to underestimate large values. Kurtosis (14.21378) is much larger than the 3 normal value, so the distribution has thick tails (frequent outliers).

Jarque-Bera (1075.425) and probability (0.00) show that the residuals are not normally distributed ($p < 0.05$).

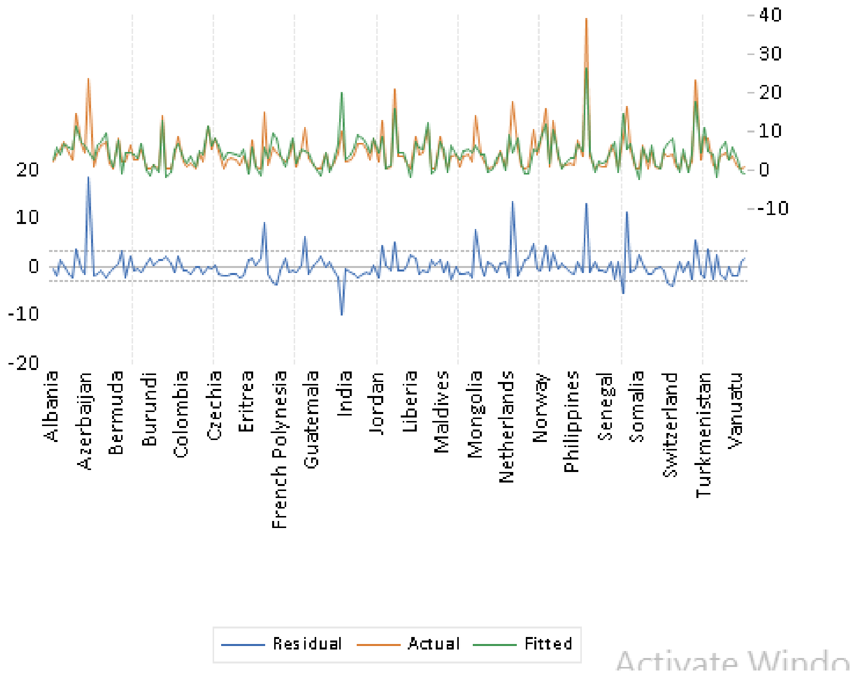

Figure 4. Residual Graph.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

In many cases, the estimated values follow the true values well, which is indicated. However, there are countries (e.g. Eritrea, Liberia, Mongolia) where the residuals are very large (whether positive or negative), meaning that the model has considerable errors in those cases.

The residuals are not perfectly distributed around the value 0, and some countries have systematic errors.

Heteroskedasticity Test: White
Null hypothesis: Homoskedasticity

F-statistic	9.488155	Prob. F(9,161)	0.0000
Obs*R-squared	59.26405	Prob. Chi-Square(9)	0.0000
Scaled explained SS	373.4472	Prob. Chi-Square(9)	0.0000

Figure 5. Heteroskedasticity Test White.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

All p-values are 0.00, indicating that we can reject the null hypothesis of homoscedasticity. There is heteroscedasticity, the variance of the residuals is not constant.

This may affect the validity of the standard error estimates and the statistical inferences derived from the model.

Heteroscedasticity is frequently encountered in cross-section data, as is the case with this model estimated for 150 countries, due to significant differences between economies in terms of size, development, and energy structure.

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.016	-0.016	0.0456	0.831
		2	-0.052	-0.052	0.5106	0.775
		3	-0.022	-0.024	0.5975	0.897
		4	-0.035	-0.039	0.8181	0.936
		5	-0.033	-0.037	1.0108	0.962
		6	-0.056	-0.062	1.5724	0.955
		7	-0.047	-0.056	1.9788	0.961
		8	-0.018	-0.031	2.0367	0.980
		9	0.039	0.027	2.3202	0.985
		10	0.110	0.101	4.5299	0.920
		11	-0.030	-0.031	4.6943	0.945
		12	-0.045	-0.043	5.0634	0.956
		13	-0.010	-0.016	5.0825	0.973
		14	-0.035	-0.037	5.3079	0.981
		15	-0.033	-0.033	5.5192	0.987
		16	-0.037	-0.034	5.7767	0.990
		17	-0.014	-0.017	5.8128	0.994
		18	0.109	0.097	8.0916	0.977
		19	0.013	-0.003	8.1262	0.985
		20	-0.013	-0.025	8.1602	0.991
		21	-0.025	-0.025	8.2873	0.994
		22	-0.030	-0.029	8.4672	0.996
		23	-0.023	-0.027	8.5759	0.997
		24	-0.037	-0.030	8.8457	0.998
		25	-0.028	-0.023	9.0082	0.999
		26	-0.041	-0.046	9.3465	0.999
		27	0.052	0.029	9.8926	0.999
		28	0.073	0.034	10.994	0.998
		29	-0.010	-0.015	11.017	0.999
		30	-0.032	-0.030	11.234	0.999
		31	-0.034	-0.040	11.479	0.999
		32	-0.013	-0.014	11.516	1.000
		33	0.002	0.006	11.517	1.000
		34	-0.023	-0.014	11.635	1.000
		35	-0.033	-0.032	11.877	1.000
		36	-0.029	-0.053	12.060	1.000

Figure 6. Correlogram.
Source: Own elaboration based on data analysis conducted with EViews 12 Student Version Lite

The residuals do not show significant autocorrelation, which is a positive sign for the validity of the model. The results obtained highlight relevant economic relationships between CO_2 emissions and the main determinants. GDP per capita is positively associated with CO_2 emissions, reflecting the fact that economic development is still dependent on activities with a high degree of pollution.

The share of renewable energy in the energy mix has a negative effect on emissions, highlighting the essential role of the transition to clean energy sources.

Energy consumption proves to be a strong determinant of emissions, showing that, regardless of the source, energy intensity remains a problem for sustainability.

Although the model provides a good overall picture, several methodological limitations should be mentioned. The model uses cross-section data, which does not allow for the analysis of dynamics over time. The presence of heteroscedasticity implies that inferences must be based on robust estimates.

The results support the idea that decarbonizing the economy is possible, but requires firm and targeted interventions.

5. Conclusions

This research aimed to investigate, through a rigorous econometric approach, the influence of energy consumption and the share of renewable sources in the energy mix on per capita CO_2 emissions, while accounting for the level of economic development (measured by GDP per capita) as a control variable. The results obtained from the multiple linear regression model applied to a sample of 150 countries for the year 2023 reveal several findings of both scientific and policy relevance.

Firstly, the adjusted R^2 value of approximately 64% indicates that the included variables explain a substantial portion of the variation in per capita CO_2 emissions, validating their selection as key determinants in emissions analysis. Specifically, per capita energy consumption was found to have a positive and statistically significant effect on emissions, confirming the hypothesis that energy intensity remains a major environmental concern.

Secondly, the share of renewable energy in total consumption is negatively associated with emissions, supporting the notion that the transition to clean energy sources effectively contributes to reducing environmental pressures. Moreover, GDP per capita is positively correlated with CO_2 emissions, suggesting that, on average, economic growth at the global level continues to rely heavily on high-emission activities.

However, the interpretation of these results must take into account certain methodological limitations. The presence of heteroskedasticity and non-normal distribution of residuals may affect the accuracy of classical statistical inferences, and the use of cross-sectional data limits the ability to capture the dynamic and temporal dimensions of the analyzed relationships. Future research could address these issues by employing panel data or time series models, as well as robust estimation techniques.

In conclusion, the findings strongly support the idea that energy transition is essential for achieving global climate goals. Nevertheless, this transition cannot be realized without coherent public policies tailored to the specific economic and institutional contexts of each country. An integrated approach—combining investments in renewable energy, energy efficiency measures, and carbon pricing mechanisms—can serve as an effective framework for global decarbonization and sustainable environmental protection.

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