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Economic and environmental factors determining carbon dioxide emissions in Lithuania

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Abstract. Carbon dioxide (CO_2) emissions are a key factor in climate change, closely linked to economic growth and energy consumption. This study examines the relationship between CO_2 emissions, GDP per capita, and renewable energy consumption in Lithuania from 2005 to 2023. The results indicate that renewable energy use has increased over the past two decades, while GDP has grown, except during periods of economic downturn. The econometric analysis reveals that GDP per capita significantly increases CO_2 emissions, whereas renewable energy consumption reduces them. The regression model explains 81.2% of the variation in emissions. These findings suggest that while economic growth contributes to higher emissions, investments in sustainable energy sources are an effective way to mitigate environmental impact. The study highlights the need for Lithuania to continue its transition to clean energy to reduce reliance on fossil fuels and minimize environmental harm. The research results emphasize that to reduce CO_2 emissions in Lithuania, it is necessary not only to increase the use of renewable energy but also to ensure effective environmental policies. Government intervention, such as subsidies for green energy or the regulation of pollution taxes, can be effective instruments in reducing greenhouse gas emissions.

Keywords: CO_2 emissions; Renewable energy; GDP per capita; Econometric analysis; Climate change.

1. Introduction

In recent decades, climate change has become one of the most pressing global issues, with carbon dioxide (CO_2) emissions being its primary driving factor. The increasing concentration of greenhouse gases in the atmosphere directly contributes to global warming, the consequences of which are already evident in various regions of the world. Rising average temperatures, extreme weather events, sea level rise, and ecosystem imbalances pose serious social, economic, and environmental challenges. As a result, increasing attention is being given to reducing greenhouse gas emissions and promoting sustainable development. To reduce greenhouse gas emissions, it is essential to conduct a comprehensive analysis of the economic and environmental factors influencing emission levels. This study examines CO_2 emissions per capita in Lithuania and their relationship with two key independent variables: gross domestic product (GDP) per capita and the share of renewable energy consumption. In

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Lithuania, as in other developed and developing countries, economic growth is often correlated with higher energy consumption and fossil fuel use, leading to increased CO_2 emissions (Ali et al., 2021). However, in some countries, a growing GDP can be compatible with lower pollution levels due to technological innovations, improved energy efficiency, and the expansion of sustainable energy sources (Raihan, Begum, Said, & Pereira, 2022). The use of renewable energy is considered one of the most crucial factors in reducing emissions, as energy sources such as wind, solar, hydro, and biofuels emit significantly less CO_2 compared to traditional fossil fuels.

In recent years, increasing attention has been given to the development of renewable energy sources in Lithuania. However, the impact of this transition on CO_2 emissions has not yet been thoroughly analyzed. Moreover, it is essential to assess not only the direct effects of renewable energy use on emission reduction but also other mediating factors, such as changes in economic structure, technological advancements, and government policies on climate change.

Thus, this study aim is to determine the impact of GDP per capita and renewable energy consumption on CO_2 emissions in Lithuania. The *research problem is*: what impact do the selected factors have on CO_2 emissions in Lithuania? The *subject* of this study is the factors influencing carbon dioxide (CO_2) emissions. The objective is to evaluate the influence of economic and environmental factors on CO_2 emissions per capita in Lithuania. The study will employ regression analysis to examine how GDP per capita and renewable energy consumption affect CO_2 emission levels. Based on the findings, recommendations will be provided to help shape more effective climate policies, promote sustainable economic growth, and reduce greenhouse gas emissions in Lithuania. The results of this study may be valuable not only for policymakers but also for the business sector aiming to reduce its environmental impact, as well as for society, fostering a more conscious approach to environmental challenges.

2. Literature review

Carbon dioxide (CO_2) emissions are one of the key factors contributing to climate change and environmental transformations. These emissions are linked to various economic, technological, political, and social aspects, making their analysis require an interdisciplinary approach. According to Tangato (2024), CO_2 emissions are a global issue faced not only by developing countries but also by economically strong nations. Table 1 presents research findings from different countries, analysing various factors over different periods.

Definitions and studies on CO_2 emissions generally agree that the main factors influencing these emissions are closely related to economic growth, energy consumption, industrial development, and technological changes. Research indicates that an increasing gross domestic product (GDP) often correlates with rising emissions; however, this relationship may vary depending on a country's economic structure and energy policies (Oluwaseun, 2025). Moreover, CO_2 emissions tend to

rise with intensive industrial production and inefficient energy use, particularly when fossil fuels serve as the primary energy source.

Table 1
Studies on factors influencing CO_2 emissions

Reference	Period	Region	Variables	Results
Oluwaseun (2025)	1972-2021	Kenya	GDP, population size, renewable energy use, fossil fuels, foreign direct investment (FDI), CO_2 emissions	CO_2 emissions in Kenya may increase due to rising GDP and population. The country can reduce harmful emissions by transitioning to renewable energy. Fossil fuels have a negative but insignificant impact. FDI has a slight positive effect on the environment.
Liu (2025)	1970-2022	China	Natural resources, fintech development, environmental taxes, green finance, urbanization, economic growth, CO_2 emissions	Environmental taxes temporarily increase CO_2 emissions but reduce them in the long run. Sustainable urbanization and green finance support the development of low-carbon technologies in China. Fintech and resource leasing temporarily reduce CO_2; negative shocks increase emissions.
Tangato (2024)	2005 - 2020	Developed and developing countries (190 countries)	Renewable energy consumption, new technologies, natural food, CO_2 emissions	The factors analyzed were found to have a negative impact on CO_2 emissions. Additionally, the level of development of countries does not significantly affect the CO_2 reduction impact of technologies between developed and developing nations.
Raihan (2023)	1990-2020	Philippines	Economic growth, renewable energy use, industrialization, urbanization, tourism, agricultural productivity, forest area, CO_2 emissions	Economic growth, urbanization, industrialization, and tourism will increase CO_2 emissions. Increased renewable energy use, agricultural productivity, and forest area could reduce CO_2 emissions.
Mikša et al. (2015)	2014	Lithuania	Soil CO_2 emissions	CO_2 emissions increase from June to August during plant vegetation.

Source: designed by the authors.

Studies emphasize that transitioning to renewable energy sources can significantly reduce emissions, but this largely depends on a country's investments in sustainable infrastructure and technologies (Raihan, 2023; Liu, 2025). The issue

of CO_2 emissions is not solely economic—it also encompasses social and political dimensions. International organizations such as the United Nations (UN) and the European Union (EU) stress the need to reduce greenhouse gas emissions and transition to more sustainable production and consumption models. According to UN data, in 2018, approximately 8.6% of the global population faced environmental pollution-related challenges, and by 2020, more than 100 million people experienced severe climate change impacts due to industrial pollution and unsustainable energy practices. These figures continue to rise due to economic globalization, the war in Ukraine, inflation, and other geopolitical factors (European Parliament, 2024).

In the context of Lithuania, unlike the studies discussed above, CO_2 emissions are predominantly analyzed in agroecosystems. Research suggests that CO_2 emissions in Lithuania increase notably during June–August, coinciding with the vegetation period of plants (Mikša et al., 2015). However, there are no studies in Lithuania that examine the factors influencing CO_2 emissions, as most research focuses on identifying which activities contribute the most to emissions. Therefore, it is crucial to investigate the environmental and economic factors that may impact CO_2 emissions in Lithuania. Overall, CO_2 emissions are widely analyzed across different countries from various perspectives. However, in Lithuania, there is a lack of studies exploring the impact of economic and environmental factors on CO_2 emissions, making this a valuable area for further research.

In summary, it can be stated that there are no studies in Lithuania that analyze the impact of GDP per capita and renewable energy consumption on CO_2 emissions. To fill this gap in scientific research, a regression analysis using Lithuanian data is being conducted. Based on the theoretical analysis, it can be concluded that CO_2 emissions are a complex phenomenon influenced by economic, technological, political, and social factors. This is one of the biggest challenges facing modern society, particularly relevant to both rapidly developing and developed countries.

3. Methods

This article analyzes carbon dioxide (CO_2) emissions (total quantity), excluding emissions from the land use, land-use change, and forestry (LULUCF) sector, as well as two independent variables – renewable energy consumption and GDP per capita. The aim is to assess the impact of these factors on CO_2 emissions. CO_2 emissions are a significant environmental issue as they are directly related to climate change. CO_2 emissions are measured as the change from 1990 (%) and are annually published in the World Bank database (World Bank, 2023a).

According to the scientific literature and research from other countries, one of the key factors of CO_2 emissions is renewable energy consumption, which is measured as a percentage of total final energy consumption. Increasing the use of renewable energy can reduce CO_2 emissions by replacing fossil fuels with cleaner energy sources (World Bank, 2023b). Another important factor is GDP per capita, which reflects economic activity and income levels. An increasing GDP can stimulate higher energy consumption, leading to higher CO_2 emissions. However, economic

growth can also create opportunities for investments in cleaner technologies and more sustainable infrastructure, thus reducing emissions (World Bank, 2023c).

This study was conducted using a multiple regression model with Lithuanian time series data from 2005 to 2023. A description of the study variables is provided in *Table 2*. Data sources: World Bank (2023a, 2023b, 2023c).

Table 2
Research variables

Variable	Notation	Description
CO_2 Emissions	CO2	Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)
Renewable Energy Consumption	RE	Renewable energy consumption (% of total final energy consumption)
GDP per Capita	GDP	GDP per capita (current US dollars)

Source: designed by the authors.

The general form of the multiple regression model is given as:

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \ldots + u_t, \quad (1)$$

where Y is the dependent variable, X1 and X2 are the independent variables; β0 is the constant; β1 and β2 are the regression coefficients, indicating the average change in Y when one of the Xs increases by one unit; t is the time period; ut is the error term (Hyndman, Athanasopoulos, 2018; Chumney, Simpson, 2006). In this study, the dependent variable is CO2 emissions (CO2), and the independent variables are renewable energy consumption (RE) and GDP per capita (GDP). The regression model is expressed as follows:

$$CO2_t = \beta_0 + \beta_1 RE_t + \beta_2 GDP_t + u_t. \quad (2)$$

The conceptual model of the study is presented in Figure 1.

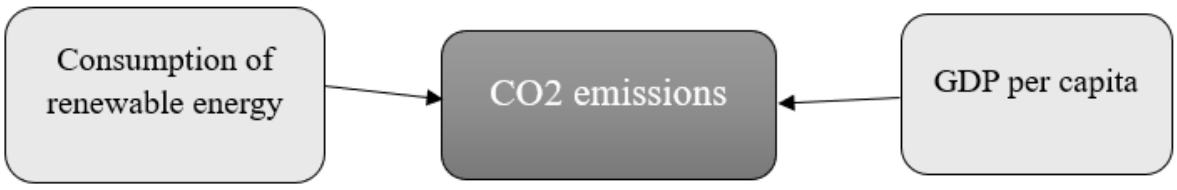

Figure 1. Conceptual model
Source: designed by the authors.

Based on the research problem, the literature review, and the conceptual model, the following hypotheses are proposed in this study:

H1: Renewable energy consumption has a negative and significant impact on CO2 emissions.

H2: GDP per capita has a positive and significant impact on CO2 emissions.

To test the research hypotheses, the regression model is evaluated using the Ordinary Least Squares (OLS) method. This method aims to minimize the sum of squared errors. The model's suitability is determined by the coefficient of determination (R^2), which ranges from 0 to 1 (the closer to 1, the better the model). The statistical significance of the model is tested using the F-test, and the significance of the variables is tested using the t-test ($p < 0.05$) (Chumney, Simpson, 2006). In addition, further diagnostic tests are performed:

Outlier: The standardized residuals method is used to identify outliers. If the absolute value of the standardized residual exceeds 3 standard deviations, the observation is considered an outlier.

Testing normality of residuals: The Shapiro-Wilk test is used to test for normality ($p \geq 0.05$). Multicollinearity check: If the independent variables are strongly correlated, there may be problems with model interpretation. The VIF test is used to detect multicollinearity; if VIF > 5, there is a problem (Daoud, 2017).

Multicollinearity: If the independent variables are strongly correlated, there may be problems with model interpretation. The VIF test is used to detect multicollinearity; if VIF > 5, there is a multicollinearity problem (Daoud, 2017).

Autocorrelation: The Durbin-Watson d test is used to determine the autocorrelation of residuals. Hypotheses:

H0: Errors are not autocorrelated.

H1: There is autocorrelation.

If the Durbin-Watson d statistic is between 1.5 and 2.5, there is no autocorrelation. If < 1.5, there is positive autocorrelation; if > 2.5, there is negative autocorrelation.

4. Results

Statistical and graphical data analysis. The main descriptive statistics of the collected variables from 2005 to 2023 are presented in Table 3. During the analyzed period, the average value of CO2 emissions per capita is 4.71 (t CO2e/capita). Meanwhile, the lowest value was in 2009 – 4.18 (t CO2e/capita) and the highest value was in 2019 – 5.19 (t CO2e/capita). The average value of GDP per capita during the analyzed period was 16,384.1 (US$), while renewable energy consumption was 23.59%.

Table 3
Descriptive statistics

Descriptive statistic	CO2 Emissions	GDP per capita	RE
Mean	4.71	16384.1	23.2
Median	4.71	14981.62	23.59
St. Deviation	0.29	5271.94	4.65
Minimum value	4.18	7857.03	16.48
Maximum value	5.12	27786.01	32.23

Source: designed by the authors.

It is important to discuss the changes in the variables over the analyzed period. In Fig. 2, the data on CO2 emissions and renewable energy consumption can be seen. The use of renewable energy in Lithuania increased, which aligns with the general trend, as Lithuania has made investments in wind, solar, and biomass energy in recent years. Especially after 2010, rapid growth was observed. CO2 emissions per capita in Lithuania remained relatively stable, but in recent years, a downward trend can be seen. This could be related to the energy sector's transition to cleaner energy sources and the electrification of transport (Bobinaite et al., 2023). The recent surge in renewable energy consumption (especially in 2022-2023) could be linked to increased investments in wind and solar power plants, as well as the goal of reducing dependence on imported energy resources.

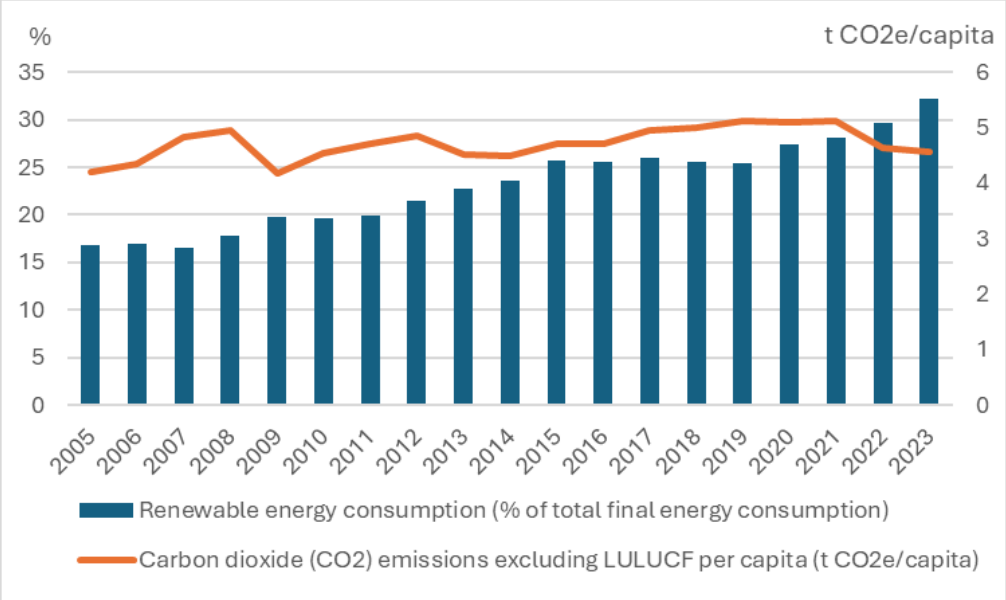

Figure 2. Renewable energy consumption and Carbon dioxide emissions excluding LULUCF per capita, 2005 - 2023
Source: designed by the authors.

Fig. 3 shows the Gross Domestic Product (GDP) per capita in US dollars from 2005 to 2023. A clear trend of economic growth is observed, although there were fluctuations during certain periods. A particularly noticeable growth was recorded from 2005 to 2008, followed by a sharp decline associated with the 2008–2009 global financial crisis. From 2010 onwards, the economy recovered, but the growth was not steady until around 2016. After this period, GDP per capita began to rise consistently, with particularly rapid growth observed after 2020, likely due to the economic recovery after the COVID-19 pandemic. In 2023, GDP reached the highest level of the analyzed period, indicating a strengthening economy and an increasing standard of living for the country's population.

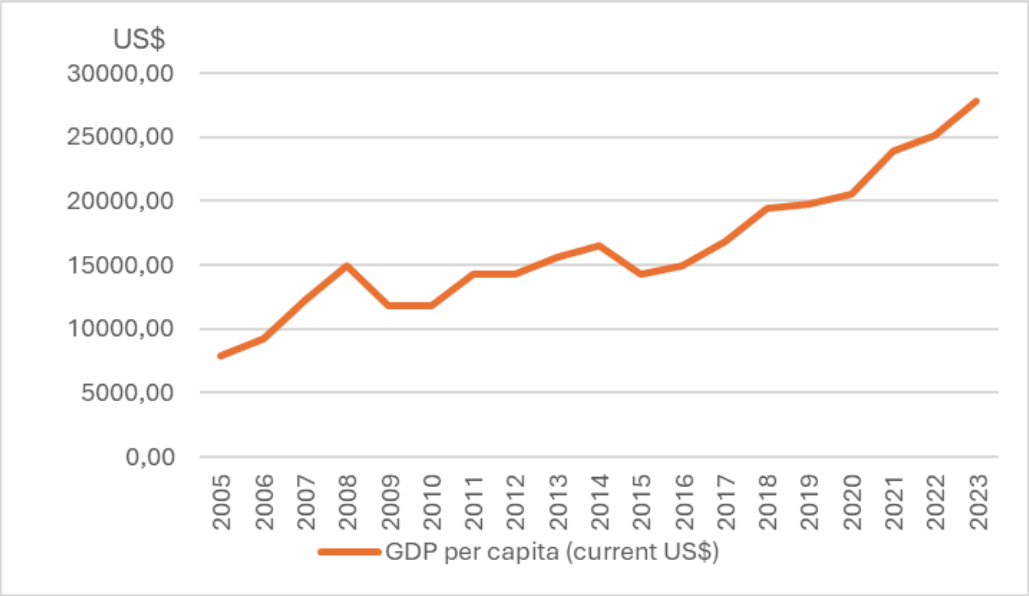

Figure 3. GDP per capita in Lithuania, 2005 - 2023
Source: designed by the authors.

Thus, during the analyzed period, a continuous increase in renewable energy consumption is observed in Lithuania, especially after 2010, when the country began investing in wind, solar, and biomass energy. The largest spike in renewable energy consumption occurred in 2022–2023, when Lithuania aimed to reduce its dependence on imported energy resources. Analyzing the data on GDP per capita, a clear economic growth trend is visible with some fluctuations, especially after the global financial crisis. Economic recovery after 2010 was slower until 2016, but after this period, consistent growth began, with a more rapid increase after 2020, resulting in the highest GDP level of the analyzed period being reached in 2023.

Econometric analysis. In this study, the dependent variable is CO2 emissions per capita (Y), and the independent variables are GDP per capita and renewable energy consumption (Xi). In performing the econometric analysis, the first step is to check the data for outliers. In this work, the standardized residuals method is used. The results obtained allow us to conclude that there are no outliers in the data (the obtained values are < 3). Next, the normality of the residuals is tested. To check if the

variable is normally distributed, the Shapiro-Wilk test is applied. The results suggest that the variable follows a normal distribution (p-value is greater than 0.05 – it is 0.68). In other words, the variable is normally distributed. It is also important to check whether the variables are not correlated with each other. The VIF method is used to test for multicollinearity. According to the VIF test results, the values of all independent variables are below 5, meaning that there is no multicollinearity issue in this model. It is also important to check for autocorrelation. For this, the Durbin-Watson d test is used. The hypotheses are: H0: the errors are not autocorrelated, and H1: positive or negative autocorrelation exists in the model. The results of the Durbin-Watson d test show that there is no autocorrelation issue in the model (the result is 1.98). Additionally, it is important to discuss the results of the F-test. Based on the study's data, it can be stated that the model is statistically significant – the p-value is 0.01 (less than 0.05). When evaluating the coefficient of determination, it can be concluded that the variables explain 81.2% of the variation in the dependent variable. The following regression equation is estimated:

$$CO2 = 4.43 + 0.042 * GDP – 0.02 * RE. \quad (3)$$

p-value (t-test) = (0.01) (0.02) (0.03)

The p-values for both independent variables are lower than 0.05, indicating that both variables are statistically significant. Therefore, based on this data, we can accept both hypotheses: H1: Renewable energy consumption has a negative and significant impact on CO2 emissions. H2: GDP per capita has a positive and significant impact on CO2 emissions.

5. Conclusions

CO_2 emissions are one of the key factors contributing to climate change and environmental transformations. The findings of various studies confirm that economic growth, energy consumption, industrial expansion, and technological advancements are among the primary determinants of CO_2 emissions. While economic development often correlates with higher emissions, this relationship varies depending on a country's economic structure and energy policies. The transition to renewable energy sources has been identified as an effective strategy for reducing emissions, but its success largely depends on a nation's investments in sustainable infrastructure and green technologies. Lithuania, like many other countries, faces challenges related to CO_2 emissions. However, unlike broader international studies that examine economic and environmental factors in relation to emissions, Lithuanian research has predominantly focused on CO_2 emissions in agroecosystems. Existing studies indicate that in Lithuania, CO_2 emissions tend to increase during the vegetation period from June to August. Despite the growing interest in environmental sustainability, there is a noticeable gap in research analyzing the relationship between GDP per capita, renewable energy consumption,

and CO_2 emissions in Lithuania. To address this gap, this study conducts an econometric analysis using Lithuanian data. The results confirm that renewable energy consumption has a significant negative effect on CO_2 emissions, supporting the hypothesis that increased reliance on clean energy reduces environmental pollution. Meanwhile, GDP per capita shows a positive and statistically significant impact on emissions, suggesting that economic growth, without sustainable energy policies, contributes to environmental degradation. In summary, CO_2 emissions remain a critical issue worldwide, influenced by economic, technological, political, and social factors. While developed nations have implemented measures to reduce emissions through sustainable energy initiatives and environmental policies, many countries, including Lithuania, still need further research and strategic policies to balance economic growth with ecological sustainability. Addressing CO_2 emissions requires a comprehensive approach, integrating economic planning with environmental protection measures to ensure long-term sustainability and climate resilience.

The study results confirm that economic growth and renewable energy consumption significantly impact CO_2 emissions per capita in Lithuania. The descriptive statistical analysis revealed that during the analyzed period (2005–2023), CO_2 emissions per capita remained relatively stable, with a slight decreasing trend in recent years. Meanwhile, GDP per capita showed consistent growth, despite fluctuations caused by the 2008–2009 financial crisis and the economic slowdown before 2016. Notably, renewable energy consumption increased considerably, particularly after 2010, due to investments in wind, solar, and biomass energy. The most significant growth in renewable energy use was observed in 2022–2023, aligning with Lithuania's efforts to reduce dependence on imported energy sources. The econometric analysis further supports the relationship between these factors. The regression model results indicate that GDP per capita has a positive and significant impact on CO_2 emissions, suggesting that economic growth is associated with higher emissions. This aligns with previous research findings that economic expansion, especially in industries reliant on fossil fuels, contributes to increased environmental pollution. On the other hand, renewable energy consumption has a negative and significant impact on CO_2 emissions, reinforcing the argument that transitioning to clean energy sources effectively reduces environmental harm.

To gain a deeper understanding of the impact of GDP and renewable energy on CO_2 emissions, it would be beneficial to analyze additional factors in the future, such as changes in industrial structure, the development of the transport sector, and consumer behaviour. It is also recommended to use a broader data sample and conduct long-term observations to identify more precise patterns.

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