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Original Research Article

Environmental Investments and Climate Change: How Environmental Protection Expenditure and Gross Domestic Product Affect Emissions in the European Union

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ABSTRACT

This study analyses the relationships between economic development, environmental investments, and greenhouse gas emissions in the European Union for the period 2008−2022. Using correlation and regression analysis of data from Eurostat, the study assesses the impact of environmental protection expenditure and gross domestic product on greenhouse gas emissions. The results reveal a stable upward trend in environmental protection expenditure, especially in recent years, reflecting the European Union's growing commitment to sustainable development. At the same time, greenhouse gas emissions show an overall downward trend, with the sharpest decline between 2019 and 2020, likely due to the impact of the coronavirus disease pandemic. The correlation analysis confirms a significant inverse relationship between environmental investments and emissions, demonstrating the positive effect of "green" spending on reducing the carbon footprint. An important observation is that in many years, environmental expenditure has grown at a faster rate than the European Union's gross domestic product, emphasising the increased commitment to environmental issues even in conditions of economic growth. The regression analysis shows a strong relationship between the predictors (gross domestic product and environmental expenditure) and greenhouse gas emissions. Despite the expectation that economic growth would increase emissions, the results show that effective measures and technologies for reducing the carbon footprint in the European Union mitigate this effect. Based on these findings, the study proposes strategies for promoting investments in clean technologies, integrating environmental goals into economic policies, intensifying research and innovation, raising public awareness, and strengthening international cooperation.

KEYWORDS

Economic growth, Environmental expenditure, Greenhouse gas emissions, Carbon footprint, Sustainable development, European Union, Climate change mitigation.

INTRODUCTION

In the modern world, where climate change poses an ever-increasing threat, developing sustainable environmental protection strategies has become imperative and a priority for international communities and governments. Within the European Union (EU), environmental investments play a central role in the transition towards a green economy and in combating the negative consequences of climate change. These efforts not only contribute to reducing greenhouse gas emissions and preserving biodiversity but also drive significant economic changes that impact the Union's Gross Domestic Product (GDP).

The present study analyses the dynamics between environmental expenditure, climate change, and their impact on emissions and the economy in the EU, examining how expenditure on the environment and changes in GDP affect greenhouse gas emissions. The focus is on the interrelationships between economic development, investments in environmental initiatives, and their effect on the climate in the EU, without analysing individual member states. Attention is directed towards the diverse policies and measures at the European level to identify effective strategies for reducing carbon emissions through economic incentives and investments in green technologies.

Through an analysis of existing scientific research and the collection of up-to-date data, this document aims to contribute to the understanding of the complex relationships between environmental expenditure, economic growth, and climate change at the European level. It emphasises the need for coordinated action at all levels − from local to international − to ensure a sustainable future where economic progress is achieved in harmony with environmental protection.

Given the EU's role as a leading force in the global fight against climate change, it is critical to understand how strategic investments in environmental protection and the transition to a green economy can support growth, innovation, and sustainable development. In this context, scientific dialogue and the study of effective policies and practices are essential for achieving a balance between economic goals and environmental sustainability at the European level.

Research highlights that increasing concentrations of greenhouse gases play a key role in enhancing the greenhouse effect and global warming. Lashof and Ahuja [1] note that these emissions are causing significant changes in the climate. Schneider [2] adds that this is leading to rising global temperatures. Hughes [3] emphasises changes in species distribution as one of the consequences. Oeschger [4] also underscores the significance of atmospheric trends, while Metcalf [5] examines the effects on the environment as a whole. Onofrei *et al.* [6] summarise by pointing out that all these changes are directly linked to human activities. According to Wang *et al.* [7], European countries face the dilemma of economic development or environmental protection. Based on these studies, it becomes clear that human activity significantly contributes to climate change, and a complex interaction between economic and environmental factors is necessary to address these challenges. Actions to reduce emissions are needed to limit future climate changes and their impacts on the environment.

Contemporary scientific research examines the complex interrelationship between greenhouse gas emissions, economic growth, environmental protection expenditures, and gross domestic product in the European Union countries. At the centre of these analyses is the Environmental Kuznets Curve (EKC) hypothesis. Lapinskienė *et al*. [8] investigate the dynamics of the Environmental Kuznets Curve, analysing how economic growth affects greenhouse gas emissions within the European Union. They find that as per capita income increases, emissions initially rise, but after reaching a critical point, they begin to decrease, offering potential for sustainable development. Lapinskienė *et al.* [9] expand the scope of previous studies by including additional economic and environmental indicators to support the EKC hypothesis. Their results also emphasise that achieving a certain level of economic prosperity is key to reversing the trend of increasing emissions. The addition of analyses related to various economic contexts and sectoral policies may broaden the understanding of potential pathways to sustainable development. Vlahinić Lenz and Fajdetić [10] bring a new perspective to the discussion by examining specific sectoral policies and their impact on environmental indicators in the context of the Environmental Kuznets Curve. Their work provides further evidence that sustainable economic growth can lead to reduced emissions with properly targeted policies. Another study by Chovancová *et al.* [11] analyses the relationship between transport-related greenhouse gas emissions and economic growth in European Union countries using the decomposition method, finding that despite different decoupling stages achieved in the observed periods, only eight countries achieve absolute decoupling over a 20-year period, which is insufficient to meet the EU's ambitious climate goals. Onofrei *et al.* [12] further enrich the understanding of the relationship between economic growth and environmental degradation by conducting a comprehensive study that examines different geographic regions and economic contexts within the European Union. They support the thesis that economic growth and increased use of renewable energy sources can lead to significant reductions in greenhouse gas emissions, especially in developed economies. Vasylieva *et al.* [13] find that increasing renewable energy consumption in the European Union and Ukraine can reduce greenhouse gas emissions, confirming the EKC hypothesis. These studies emphasise the importance of renewable energy sources and show that achieving sustainable development requires concerted efforts across various economic sectors and geographical regions. Cavaliere *et al.* [14] examine the long-term relationship between economic activities and environmental degradation, highlighting the complexity of these relationships within the European Union, while Sterpu *et al.* [15] focus on the short-term aspects of the same relationship, emphasising the need for further efforts to curb environmental degradation in European economies.

Neves *et al.* [16] emphasise the importance of environmental regulations for reducing emissions in the EU, highlighting the role of renewable energy sources and the effectiveness of market instruments, including emissions trading. Qi *et al.* [17] also examine the influence of environmental regulations on pollution reduction and efficiency improvement, stressing that such policies can stimulate both environmental and economic benefits. Pakere *et al.* [18] further underscore the importance of mandatory standards for achieving lower emissions while also highlighting the significance of market mechanisms in this process. Expanding the analysis to the interaction between different types of environmental policies and their long-term impact on economic development may contribute to a better understanding of the effectiveness of these policies. The transition to a circular economy and the implementation of resource efficiency practices are also emerging as essential strategies for reducing emissions and achieving environmental protection goals. The adoption and diffusion of eco-innovations, supported by environmental policies and green demand, are significant for the development of a circular economy that promotes recycling, reduces waste, and limits material use, contributing to resource efficiency and a decline in emissions [19]. Over time, circular economy practices prove effective in reducing carbon dioxide (CO_2) emissions in Europe despite potential rebound effects in the short term [20]. The transition from a linear to a circular model in agri-food systems is also key to restoring biodiversity and reducing the negative environmental impact, with research and innovation playing an essential role in facilitating this process [21]. Progress towards a circular economy requires policies that encourage reuse, repair, and remanufacturing, improve secondary material markets, and introduce green public procurement to close material loops [22]. Reducing the resource intensity of production is also critical for economic growth without harming nature [23]. However, there is heterogeneity among member states, requiring coordinated initiatives from the private and public sectors for an effective reform towards a circular model [24].

Funding from the European Union through structural funds for projects related to energy efficiency, renewable sources, and low-carbon technologies plays a significant role in reducing emissions in member states. It is a major instrument for promoting territorial development and competitiveness and eliminating regional disparities, with countries with lower funding levels achieving higher efficiency [25]. Although available clean energy financing sources can provide funds between two and six times more than needed, investors often hesitate due to expected policy disruptions [26]. However, structural funds are important for financing decarbonisation in sectors such as energy, contributing to the transition to a low-carbon economy [27]. While EU funding plays a key role, national policies and investments are also crucial. Some countries manage to achieve greater emission reductions with less funding, highlighting the importance of efficient resource use and adapting strategies to the local context.

An EU study on the impact of environmental taxation on sustainable development underscores the importance of European policy and environmental taxation in promoting sustainable development through ambitious goals for reducing greenhouse gas emissions and encouraging renewable energy and circular economy practices [28]. Dietz & Rosa [29] find that increasing energy taxes and imports can contribute to reducing greenhouse gas emissions. Ghazouani *et al.* [30] discovered that carbon tax policies can be effective in reducing CO_2 emissions in Europe. Zioło *et al.* [31] examine the interrelationships between financial development, fiscal instruments, and environmental degradation and find that energy taxes can reduce environmental degradation. Ghazouani *et al.* [32] establish that GDP growth often leads to an increase in greenhouse gas emissions. Sharma *et al.* [33] discuss how GDP growth in the Bay of Bengal region leads to increased emissions, especially in the agricultural sectors. Adebayo *et al.* [34] also find that increased economic activity in South Korea leads to higher greenhouse gas emissions. Andrew [35] notes that in Global South countries, increasing export intensity leads to increased emissions. Tu *et al.* [36] find that carbon emission taxes can have both positive and negative effects on environmental and economic systems. However, Hao *et al.* [37] indicate that in G7 countries, the effect of energy taxes on greenhouse gas emissions is complex and depends on multiple factors. He *et al.* [38] discover that in countries with lower GDP per capita, the effect of energy taxes on emissions is negative, highlighting the need for tailored policies for each specific economy. The analysis of the interaction between tax policies and economic factors shows that the effectiveness of tax instruments varies depending on the country's economic development, requiring a flexible and adaptive approach in formulating tax policies. According to Firtescu *et al.* [39], taxes alone are not sufficient to combat greenhouse gas emissions, and additional levers such as expanding green technologies, using public subsidies to finance them, and others are needed.

In developing economies, exogenous technological factors such as imports of machinery and equipment, foreign direct investment, and imports of knowledge for research and development play an important role in reducing greenhouse gas emissions, in addition to the use of renewable energy [40]. A study by Koziol and Mendecka [41] highlights the importance of substituting non-renewable with renewable energy sources for energy efficiency and emission reductions in Europe, emphasising the social effectiveness of this transition.

Investments, trade, and innovations are highlighted as key levers for reducing greenhouse gas emissions in the long term. Horobet *et al.* [42] consider the importance of investments in innovation and low-carbon technologies. Farrell and Lave [43] emphasise the importance of green investments for sustainable development. Neves *et al.* [16] also underscore the role of investments in improving environmental efficiency. Lyeonov *et al.* [44] discuss how trade and innovations can contribute to environmental sustainability. Xiao *et al.* [45] examine the impact of green innovations on emission reductions, while Acevedo-Ramos *et al.* [46] investigate the specific contribution of green investments in the context of sustainable development.

Buceti [47] examines the interaction between climate change and the energy sector in Europe. Mert *et al.* [48] analyse how different energy sources impact emissions and the environmental footprint, emphasising the importance of energy resource choice. Alola *et al.* [49] also consider the impact of consumption patterns on emissions, underscoring the importance of consumer habits for the environmental footprint. Additionally, Ven *et al.* [50] investigate the potential for behaviour and lifestyle changes as a means of reducing emissions in the EU, noting that this can occur without the need for personal investments from citizens.

Apetri & Mihalciuc [51] note that improving environmental efficiency in the emissions sector can contribute to sustainable environmental development, but often at the expense of economic development, pointing to the high initial costs of implementing environmental technologies. Brodny & Tutak [52] expand this analysis by also highlighting the potential job losses in fossil fuel-dependent sectors as a possible downside of transitioning to cleaner energy solutions. Li *et al.* [53] add that while environmental efficiency supports environmental sustainability, it may impose constraints on production processes, which in turn may reduce the competitiveness of enterprises.

Environmental protection expenditures can play a significant role in reducing greenhouse gas emissions. A study by Dziubanovska & Maslii [54] finds that increasing such expenditures in EU countries reduces the negative environmental impact and has a positive effect on innovation and the social component of the economy. In the agricultural sector, there are also opportunities to reduce emissions. Johnson *et al.* [55] note that agriculture is a source of CO_2, CH_4, and N_2O but can also act as a CO_2 sink through carbon sequestration. Conservation practices, nitrogen management, changes in animal feeding, and manure management are some measures to reduce agricultural emissions. The analysis of the role of environmental protection expenditures, both in agriculture and other sectors, emphasises the need for an integrated approach to emission reduction. In addition to environmental protection expenditures, research and development expenditures also contribute positively to reducing CO_2 emissions, especially in developed countries, according to a study by Fernández *et al.* [56]. This finding underscores the importance of promoting research and development expenditures from both the public and private sectors.

Newmark and Witko [57] find that political factors, such as the strength of environmental movements, influence state expenditures on environmental protection more than the severity of pollution itself. They emphasise that the political process often determines environmental protection expenditures, which may not match environmental needs. Kleijn and Sutherland [58] find that the effectiveness of European agri-environmental schemes for biodiversity conservation varies, depending on political and economic factors.

In summary, the literature review outlines the complex interrelationship between greenhouse gas emissions, economic growth, and environmental influencing factors in European Union countries. Key among these factors are policies around renewable energy sources and the circular economy, environmental taxation, investments in innovation, and environmental protection expenditures. While the existing literature provides valuable studies on these linkages, the present research has the potential to fill several gaps.

First, it can provide a more comprehensive empirical analysis of the interrelationships between environmental protection expenditures, GDP, and greenhouse gas emissions, specifically for EU countries. Second, the study could contribute quantitative estimates of the impact of environmental protection expenditures and GDP on emissions, complementing the existing more general conclusions. Third, the results would empirically test the hypothesised notions that increasing environmental protection expenditures will lead to reduced emissions and increasing GDP will lead to increased emissions in the EU context. Finally, the research may shed further light on the significance of political-economic factors such as environmental protection expenditures and GDP in achieving environmental goals in the region, such as limiting greenhouse gas emissions.

The study emphasises the importance of environmental protection expenditures and economic growth in reducing greenhouse gas emissions. However, it is important to consider other possible scenarios and factors that may explain the observed trends. One such factor is the effect of the COVID-19 pandemic, which led to a sharp decrease in economic activity and transport operations in 2020, temporarily reducing greenhouse gas emissions. This global crisis provides a unique context for analysing the impact of non-economic events on environmental indicators.

Furthermore, international agreements and political commitments such as the Paris Agreement play a key role in promoting emission reductions. European Union countries actively participate in global efforts to combat climate change, which may explain some of the observed emission reductions. These international commitments often include strict regulations and targets for reducing carbon footprints, which stimulate the adoption of green technologies and practices.

Changes in economic structure are also significant. The transition from an industrial to a service-oriented sector in many EU countries may lead to a reduction in carbon emissions, as service sectors typically have lower carbon intensity compared to industrial sectors. Sectoral changes and economic restructuring, including the increasing share of high-tech and information services, contribute to reducing overall emissions.

Further analyses are necessary to provide evidence that the tested scenarios and correlations are not the only explanation for the observed emission reductions. These analyses should include an assessment of the influence of non-economic events such as pandemics, the effects of international agreements and regulations, as well as sectoral changes and technological innovations. Including these factors in the analysis will allow for a more complete understanding of the dynamics leading to greenhouse gas emission reductions and will support the development of more effective sustainable development policies. Despite the numerous possible factors and scenarios, the current study focuses on the interactions between environmental protection expenditures and gross domestic product to determine their direct effects on greenhouse gases in the EU.

The present study aims to analyse the influence of environmental protection expenditures and gross domestic product on greenhouse gas emissions within the European Union. Through empirical analysis, it sheds light on the role of environmental investments in achieving sustainable development in the region in the face of climate change.

METHODS

The current study covers the period from 2008 to 2022 and analyses annual data on greenhouse gas emissions, GDP, and environmental protection expenditures in the EU. The data are extracted from Eurostat and refer to the "European Union − 27 countries" configuration, which reflects the current composition of the EU. Methodologically, greenhouse gas emissions (carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), freons, etc.) are quantified in thousands of tonnes of CO_2 equivalent. GDP is expressed in millions of euros (EUR) at current prices, and environmental protection expenditures are presented as annual sums in millions of EUR. An important methodological clarification is related to changes in the EU's composition during the study period. Croatia joined the EU in 2013, while the United Kingdom left the Union in 2020. The study uses retrospectively recalculated data from Eurostat to ensure data consistency and comparability. These data include Croatia for the entire period, including before its official accession, and exclude the United Kingdom for the entire period, including before its official departure. This approach allows for an analysis of long-term trends in the indicators studied for the current 27 member states while taking into account the methodological limitations arising from historical changes in the EU's composition. When interpreting the results, especially for the periods before 2013 and after 2020, these methodological peculiarities should be taken into account.

The period 2008−2022 is chosen for several key reasons. First, it covers significant economic and political events that influence greenhouse gas emissions and environmental protection policies in the EU. During this period, the world financial crisis of 2008 occurred, leading to significant economic changes. Moreover, many of the EU's current environmental policies and initiatives began to be implemented or were significantly reformed during this period, including the EU's commitments under the Paris Agreement in 2015. Second, the period allows for the analysis of long-term trends and interrelationships between the variables under consideration, which is essential for understanding the sustainability of environmental protection policies. Finally, using the most up-to-date data available up to 2022 ensures that the study provides a contemporary picture of the issues under consideration.

The analysis begins by examining the trends in greenhouse gas emissions, GDP, and environmental expenditures through visualisation with line graphs. It allows for the identification of the overall patterns of movement of these variables during the studied period.

The Pearson correlation coefficient is calculated to establish the strength and direction of the relationship between environmental expenditures and emissions. Additionally, year-over-year percentage changes for expenditures and emissions are calculated to compare the rates of their changes.

An important aspect of the analysis is the assessment of the share of environmental expenditures in relation to GDP. This ratio shows what portion of the economic output is reinvested in environmental initiatives. On the other hand, by calculating greenhouse gas emissions per million EUR of GDP, an assessment of the carbon efficiency of the economy is made.

The methodology also includes linear regression analysis to estimate the impact of environmental protection expenditures and GDP on greenhouse gas emissions. The regression model is defined as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \quad (1)$$

Where y represents greenhouse gas emissions, and x_1 and x_2 are environmental protection expenditures and GDP, respectively. The model is analysed using statistical analysis software. The data are checked for outliers and normality, followed by an assessment of the regression coefficients, standard errors, and t-statistics. The effectiveness of the model is evaluated with R-squared and adjusted R-squared, with the F-test checking for overall statistical significance and p-values assessing the statistical significance of the results.

The interpretation of the analysis results is made in light of potential global and economic events, such as the 2008 financial crisis and the COVID-19 pandemic, which may have influenced the data. The aim is to identify policies and practices that successfully combine economic growth with the reduction of carbon emissions in the EU.

While providing valuable initial results, the present study has several limitations that should be acknowledged. First, the analysis focuses only on aggregated data for the entire European Union, without accounting for potential differences between individual member states. Second, despite the inclusion of key factors such as GDP and environmental expenditures, certain other variables such as energy mix, industrial structure, and demographic factors are not considered in the model. Additionally, the available data cover a limited period, with a longer-term analysis allowing for a more comprehensive examination of long-term trends and interrelationships. Finally, potential time lags between investments in environmental protection and their actual reflection on emissions are not fully accounted for when using annual data.

Future research could expand the scope of the analysis by including a richer set of data from various sources. Extending the geographical coverage beyond the European Union, using information from the World Bank, the Organisation for Economic Cooperation and Development, and national statistical offices, would allow for a comparative analysis on a global level. Supplementing the time horizon with the most up-to-date available data would help assess the impact of recent environmental policies and economic trends. These expansions of the study would contribute to a deeper understanding of the interrelationships between economic growth, investments in environmental protection, and greenhouse gas emissions in various contexts and time frames. Potential sources for the additional data include the official websites and databases of international organisations, as well as specialised platforms for statistical information.

RESULTS AND DISCUSSION

In the following sections, several key aspects related to environmental protection expenditures, greenhouse gas emissions, and economic growth in the European Union for the period 2008−2022 are analysed. The aim is to evaluate the effectiveness of policies for sustainable and low-carbon development in the EU. First, the dynamics of environmental protection expenditures and greenhouse gas emissions, as well as the relationship between them, are examined. This procedure provides insight into the trends in these key indicators and the achievements in the areas of environmental protection and combating climate change. Subsequently, the share of environmental expenditures in GDP and the carbon efficiency of the economy through greenhouse gas emissions per unit of GDP are analysed to assess the priorities and effectiveness of environmental policies. A regression analysis investigates the influence of GDP and environmental protection expenditures on the level of greenhouse gas emissions. Finally, the significance and implications of the results for future policies aimed at sustainable and low-carbon growth in the European Union are discussed.

Analysis of the dynamics of environmental protection expenditures and greenhouse gas emissions

The present analysis examines the trends in environmental protection expenditures and greenhouse gas emissions in the European Union for the period 2008−2022. The obtained results provide important insights into the priorities and achievements in the areas of environmental protection and climate change mitigation.

Environmental protection expenditures demonstrate an overall upward trend during the analysed period, which is indicative of the increasing commitment to environmental issues (**Figure 1**). The lack of significant declines in investments suggests a sustained or even intensifying interest and allocation of resources toward this sector. Particularly notable are the substantial increases in 2018 (9.44%) and 2022 (6.55%), signalling an accelerating dynamic of investments in environmental protection measures in recent years.

On the other hand, an overall downward trend is observed in greenhouse gas emissions in the European Union over the same period (**Figure 1**). It is a positive sign of the effectiveness of the measures taken to reduce the carbon footprint. The decline in emissions from 2019 to 2020 is particularly sharp, which is likely due to the impact of the COVID-19 pandemic and the associated economic slowdown. Despite the overall downward trend, the greenhouse gas emissions data demonstrate significant volatility, with increases observed in some years, which are likely due to specific economic and global circumstances affecting industrial activity, energy consumption, and other emission-related factors.

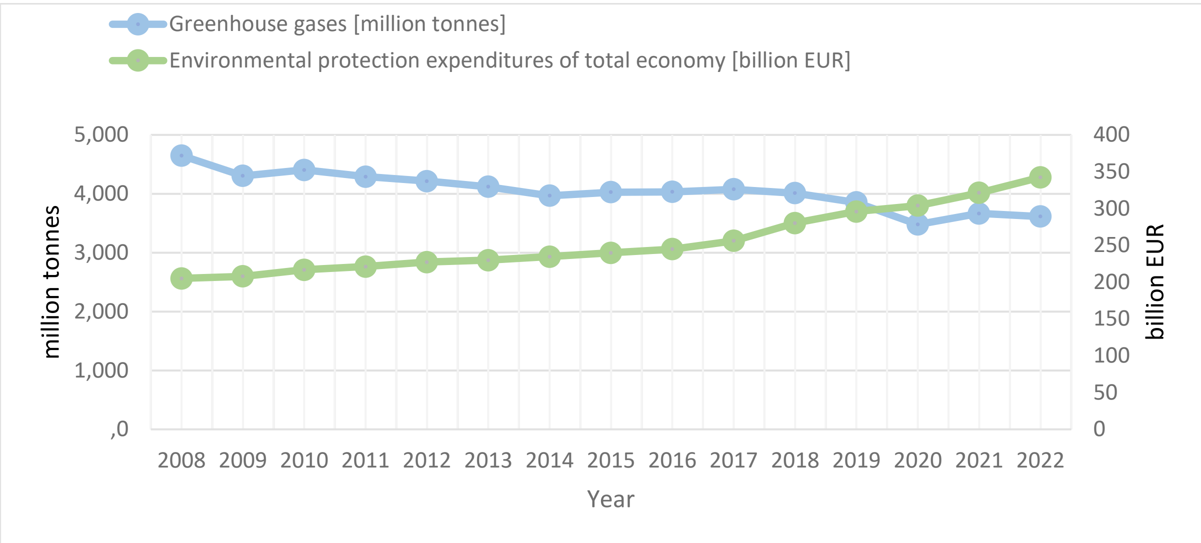

Figure 1. Environmental protection expenditure and greenhouse gas emissions in the EU for the period 2008−2022

The analysis reveals a strong negative correlation (Pearson coefficient of −0.893) between environmental protection expenditures and greenhouse gas emissions. This result aligns with the expectation that higher investments in environmental initiatives would lead to more effective measures for reducing greenhouse gas emissions. An overall pattern emerges where increases in environmental expenditures are often associated with decreases in emissions, albeit with some deviations that could result from other economic and global events.

In addition to the overall trends, it is important to examine the annual percentage changes in environmental protection expenditures and greenhouse gas emissions to gain a deeper understanding of the dynamics. An analysis of the year-on-year data reveals the following:

- Environmental Protection Expenditures: A consistent positive change is observed each year, with particularly significant increases in 2018 (10.95%) and 2022 (6.55%). The increase is especially robust over the last three years of the period, which could be interpreted as an accelerating commitment to environmental protection.
- Greenhouse Gas Emissions: The emissions data exhibit much greater volatility, with significant decreases in some years (such as 2009 and 2020) and increases in others (e.g., 2021). The largest drop occurred in 2020, likely due to the global economic slowdown resulting from the COVID-19 pandemic.

This analysis of the annual fluctuations reinforces the negative correlation between environmental expenditures and greenhouse gas emissions. Increases in expenditures often coincide with decreases in emissions, but some deviations are observed, which could be attributed to other economic and global events.

Examining GDP changes in parallel with the previous analysis of environmental protection expenditures and greenhouse gas emissions can provide deeper insights. Expanding the analysis to focus on comparing the growth rate of environmental protection expenditures to the GDP growth rate allows us to explore in depth how economic priorities reflect on the commitment to the environment (**Figure 2**). The pursuit of sustainable development implies investments in environmental protection that grow rapidly or even outpace economic growth. It is an important indicator of the transition towards a "green" economy, where economic prosperity goes hand-in-hand with environmental responsibility. In the period analysed, we observe that in many years, environmental protection expenditures do indeed grow at a faster rate compared to GDP. This trend could be interpreted as a sign of heightened commitment by governments, businesses, and societies to environmental issues.

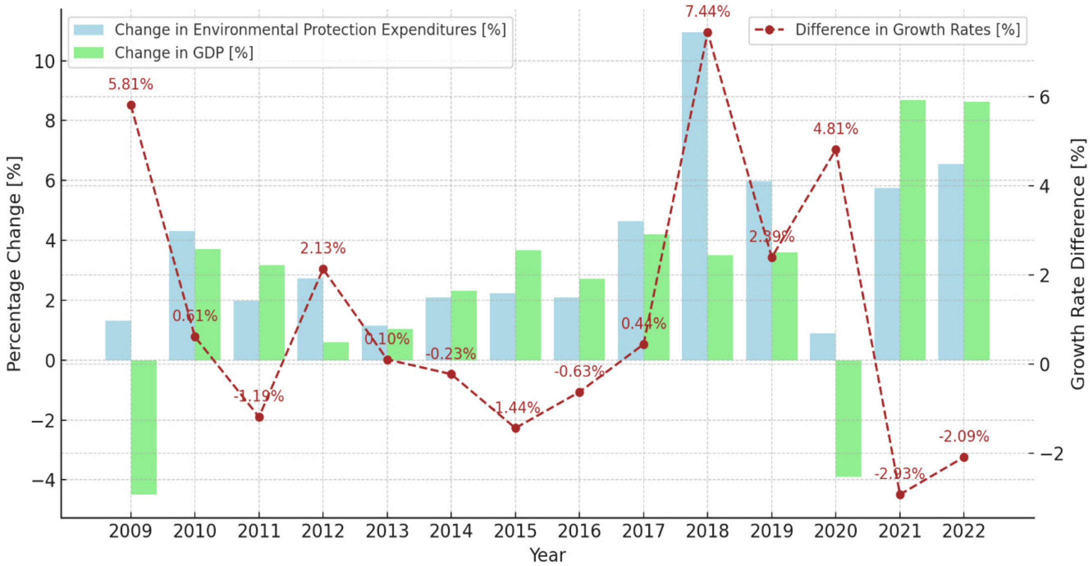

Figure 2. Environmental spending and GDP growth comparison with growth rate difference (2009-2022)

One of the key conclusions from this analysis is that even in conditions of economic growth, it is possible and important to invest in environmental sustainability. This model of behaviour supports the thesis that sustainable development is not only possible but also desirable for achieving long-term economic prosperity.

The analysis of the ratio between the GDP growth rate and the rate of greenhouse gas emissions reduction in different years reveals important observations about the interaction between economic activity and environmental efforts (**Figure 3**). In 2009 and 2020, the economic downturns caused by the global financial crisis and the COVID-19 pandemic, respectively, led to a simultaneous reduction in greenhouse gas emissions and GDP. This development shows that extreme economic shocks can lead to unintended emissions reduction due to a slowdown in industrial activity and consumption.

However, the more positive side of the analysis manifests itself in the years when, despite the reduction in greenhouse gas emissions, GDP continued to grow. Such examples are observed in 2011, 2012, 2013, 2014, 2018, 2019, and 2022, with 2022 being particularly remarkable, with GDP growth of 8.64% and a 1.37% reduction in emissions. These observations underscore that economic growth and environmental sustainability are not mutually exclusive goals. Rather, they can coexist, supporting the idea of a transition towards cleaner and more efficient technologies and industrial processes.

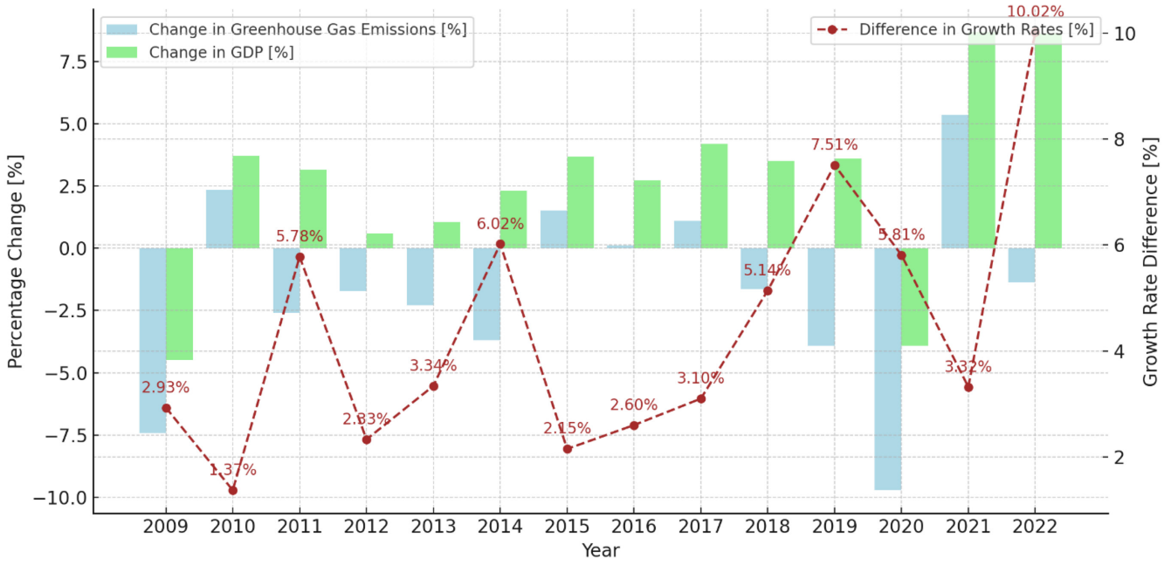

Figure 3. Greenhouse gas emissions and GDP growth comparison with growth rate difference (2009-2022)

This analysis confirms the importance of investing in sustainability and developing policies that promote economic growth while simultaneously addressing environmental challenges. The examples from the studied period show that it is possible to achieve a combination of maintaining economic prosperity and reducing the carbon footprint, which is critical in the fight against climate change.

The share of environmental protection expenditures in GDP and greenhouse gas emissions per million EUR of GDP and their dynamics

The analysis of the share of expenditures on environmental initiatives in the GDP and greenhouse gas emissions per million EUR of GDP provides valuable information about environmental policy and the degree of sustainability of economic growth. The percentage of environmental protection expenditures out of GDP shows what portion of economic resources is allocated to environmental protection measures. During the period under review, this share gradually increased, reaching its highest level in 2020. The ratio of environmental expenditures to GDP fluctuates slightly, remaining in the range of 1.95% to 2.25%, but it demonstrates an upward trend starting in 2017. The peak value of around 2.26% in 2020 can be explained by the fact that despite the decline in GDP, likely due to the COVID-19 pandemic, absolute expenditures on environmental initiatives remained stable or even increased. It can be viewed as a positive indicator of the growing attention to environmental issues and sustainable development.

On the other hand, greenhouse gas emissions per million EUR of GDP provide an insight into the efficiency of the economy in terms of carbon footprint. The data show a steady decreasing trend in this indicator throughout the analysed period. It means that for every million EUR of GDP, fewer greenhouse gas emissions are generated. The most significant decrease was observed after 2019, which again may be related to the impact of the pandemic on economic activity and the corresponding reduced emissions. The decreasing values of this indicator are a sign of increasing the environmental efficiency of the economy – a greater economic result is achieved with fewer harmful emissions.

Regression analysis

In the present study, a regression analysis was performed to investigate the relationship between greenhouse gas emissions as the dependent variable and two main predictors − GDP and environmental protection expenditures. The analysis is based on observations from the period between 2008 and 2022.

The regression model showed a strong positive correlation coefficient (Multiple R) of 0.909, which suggests a strong relationship between the predictors and the dependent variable. The coefficient of determination (R^2) is 0.827, indicating that 82.7% of the variation in emissions can be explained by the proposed independent variables. After adjusting for the number of variables (Adjusted R^2), this indicator is 0.798, which still indicates the strong adequacy of the model.

Through ANOVA, an F-statistic value of 28.717 was obtained, which confirmed the overall statistical significance of the model (Significance $F < 0.00003$), showing that the model has significant predictive value. The constant of the model (Intercept) is significant ($p < 0.0001$) and was estimated at 4,941,913, which represents the baseline level of greenhouse gas emissions in the absence of economic growth and investments in environmental protection (**Table 1**).

The coefficient for environmental protection expenditures is −12.765 and is statistically significant ($p = 0.00856$), indicating that investments in this area contribute to the reduction of greenhouse gas emissions. The negative coefficient shows us that as investments in environmental protection measures increase, greenhouse gas emissions in the European Union decrease. This is in line with expectations that higher environmental protection expenditures should lead to improvements in environmental standards and technologies that reduce emissions.

On the other hand, the coefficient for GDP is 0.189 and has a positive sign, which suggests that as GDP increases, greenhouse gas emissions also increase. This reflects the classic view that economic growth is often associated with an increase in production and consumption, which can lead to higher emissions. However, the p-value of this coefficient is $p = 0.13002$, which shows that the relationship between GDP and greenhouse gas emissions is not statistically significant at traditional levels (e.g., 5% or 1%). This can be interpreted in several ways:

- The lower statistical significance may be due to the fact that technologies and practices have been implemented in the European Union that decouple GDP growth from emissions, i.e., the economy is growing, but with less of an increase in emissions, known as "decoupling."
- It is possible that there are structural changes in the EU economy that lead to a greater contribution from low-emission sectors, such as services, compared to heavy industry.
- The relatively small sample size (number of observations) may also contribute to the lack of statistical significance for the GDP coefficient, as larger sample sizes generally lead to more precise estimates and higher statistical power.

Overall, while the positive coefficient for GDP suggests that economic growth is still associated with some increase in emissions, the lack of statistical significance and the negative, significant coefficient for environmental protection expenditures indicate that investments in sustainability can help mitigate the environmental impact of economic growth in the EU.

Confidence Interval (CI) represents the range within which, with a certain level of confidence (usually 95%), the true value of the coefficient is expected to lie. In **Table 1**, the columns "Lower 95% CI" and "Upper 95% CI" present the lower and upper bounds of this interval, respectively. The CI provides information about the precision of the coefficient estimate and is an important indicator of the reliability of the results from the regression analysis.

Table 1. Results from the linear regression analysis

Predictor	Coefficient	Standard error	t-statistic	p-value	Lower 95% CI	Upper 95% CI
Intercept	4,941,913	492,947	10.03	<0.0001	3,867,875	6,015,951
Environmental protection expenditures [million EUR]	−12.765	4.068	−3.14	0.00856	−21.627	−3.902
Gross domestic product at current market prices [million EUR]	0.189	0.116	1.63	0.13003	−0.064	0.442

Overall, the analysis shows a positive trend towards a more sustainable economic model in the European Union. The data confirm that economic growth and the reduction of greenhouse gas emissions can go hand in hand through appropriate policies, investments in the environment, and restructuring of the economy towards more environmentally friendly sectors. Although GDP growth still has some impact on emissions, this influence is relatively limited, and its statistical significance is lower.

On the other hand, environmental protection expenditures show a strong negative relationship with emissions, confirming the effectiveness of environmental protection measures. The combination of economic growth and increasing investments in sustainability appears to be a successful strategy for achieving the EU's climate goals.

Overall, these findings demonstrate the gradual development of the European economy in a more environmentally friendly direction, although there is still room for improvement. Continuing this trend by deepening green policies and investments could lead to the achievement of climate neutrality goals while maintaining economic prosperity.

CONCLUSIONS AND FUTURE OUTLOOK

The analysis of data for the European Union reveals several key observations and trends. Environmental protection expenditures show a steady upward trend during the studied period, with an acceleration of investments in environmental protection measures in recent years. This reflects the EU's growing attention and commitment to environmental issues and sustainable development. On the other hand, greenhouse gas emissions demonstrate an overall downward trend, which is an indication of the effectiveness of the measures taken to reduce the carbon footprint in the Union. The sharpest decline is observed between 2019 and 2020, likely due to the impact of the COVID-19 pandemic. The correlation analysis reveals an inverse relationship between environmental protection expenditures and emissions − higher investments in environmental initiatives are associated with lower greenhouse gas emissions. This confirms the positive effect of "green" spending on combating climate change.

An important observation is that in many years, environmental expenditures have been increasing at a faster rate than the EU's GDP. This underscores the heightened commitment to environmental issues and the transition to a low-carbon economy, even in conditions of economic growth. In fact, the data show that it is possible to combine economic prosperity and emissions reduction.

The regression analysis shows a strong positive relationship between the predictors (GDP and environmental protection expenditures) and the dependent variable (greenhouse gas emissions), highlighting the importance of these factors in emissions management. Investments in environmental protection contribute to reducing emissions, supporting the idea of investing in cleaner technologies and improved environmental standards. Although economic growth is expected to have a positive effect on emissions, the statistical significance of this factor is not as strong, which may reflect the effective measures and technologies for reducing the carbon footprint in the EU.

These results demonstrate that the European Union is successfully balancing economic goals and environmental sustainability in the fight against climate change. Coordinated efforts and investments in environmental protection contribute to long-term prosperity, combined with lower carbon emissions and a more sustainable future.

To maintain and strengthen this positive trend, it is essential for the European Union and its member states to continue to pursue consistent and ambitious policies in this direction. Based on the findings of the present analysis, the following key recommendations can be made:

- Continue and increase investments in environmental initiatives and green technologies. The results show a clear link between higher environmental protection expenditures and lower greenhouse gas emissions. The European Union should continue to allocate resources towards energy efficiency programs, renewable energy sources, circular economy, and other decarbonisation measures.
- Integrate environmental goals into economic policies. The analysis demonstrates that it is possible to achieve economic growth combined with a reduction in carbon emissions. The EU should continue to encourage this trend through tax incentives, regulations, and standards that steer the economy towards more sustainable practices.
- Strengthen scientific research and innovation. The continuous development of new decarbonisation technologies and processes requires stable funding for research and development in the areas of clean technologies, renewable sources, and energy efficiency.
- Increase public awareness and engagement. A successful transition to a low-carbon economy requires the active participation of citizens, businesses, and all stakeholders. The EU can undertake awareness campaigns and promote environmentally friendly behavior.
- International cooperation and leadership. As climate change is a global issue, the European Union should continue to demonstrate leadership and actively cooperate with other countries and regions to achieve global goals for emissions reduction and adaptation to climate change.

NOMENCLATURE

Abbreviations

CI	Confidence Interval
EKC	Environmental Kuznets Curve
EU	European Union
GDP	Gross Domestic Product

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