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Economic Analysis of Fossil CO_2 Emissions: A European Perspective on Sustainable Development

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Abstract: The economic assessment of CO_2 emissions from fossil fuels is gaining importance in the context of sustainable development. Climate change, driven by excessive greenhouse gas emissions, poses a significant threat to humanity, requiring an integrated approach that considers both environmental and economic factors. The European Union (EU) plays a key role in global efforts to reduce CO_2 emissions and promote sustainability. This study explores economic approaches to analyzing CO_2 emissions in Europe, focusing on trends in fossil fuel use and their economic drivers. The research highlights the connection between economic activity, energy consumption, and emissions, contributing to a better understanding of climate change mitigation strategies. The findings emphasize the strong influence of demographic factors on carbon emissions, stressing the need for targeted policies to address the environmental impact of population growth. This study presents a literature-based assessment of CO_2 emissions from fossil fuel consumption in the context of sustainable development, with a focus on Europe. Recognizing the urgent threat posed by climate change, the paper explores how economic and demographic factors influence emissions trends and energy consumption. Through the synthesis of recent research and statistical data, it examines the relationship between economic activity and CO_2 emissions across EU countries. Special attention is given to national policy frameworks, particularly Germany's "Energiewende", as a successful example of emission reduction through building-sector reform. The study highlights that while economic growth remains a driver of emissions, strategic investments in renewable energy, energy efficiency, and sectoral transformation can decouple growth from environmental degradation. The findings support the need for country-specific mitigation strategies, emphasizing that uniform approaches may not address the diverse challenges faced by EU member states. This work contributes to the broader understanding of climate policy design by linking empirical evidence with policy implications in the transition to a low-carbon economy.

Keywords: CO_2; energy economics; population; carbon emissions

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Academic Editors: Cuiyang Feng and Yi Jin

Received: 17 March 2025
Revised: 13 April 2025
Accepted: 16 April 2025
Published: 18 April 2025

Citation: Yakymchuk, A.; Rataj, M.A. Economic Analysis of Fossil CO_2 Emissions: A European Perspective on Sustainable Development. *Energies* **2025**, *18*, 2106. https://doi.org/10.3390/en18082106

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1. Introduction

In the face of global climate change, evaluating carbon dioxide (CO_2) emissions remains crucial for developing effective mitigation strategies [1–4]. The continued reliance on fossil fuel combustion significantly contributes to CO_2 emissions worldwide, necessitating an in-depth economic and environmental analysis to assess its broader implications. This study explores CO_2 emissions resulting from the consumption of coal, oil, and natural gas,

with a specific emphasis on the European region. By analyzing emission trends, key influencing factors, and economic consequences, this research aims to provide valuable insights for policymakers in crafting strategies that promote emission reduction and sustainable development.

The aim of this study is to provide a comprehensive literature review on energy performance in the context of climate mitigation efforts in European countries, supported by descriptive statistical data. This study does not engage in empirical regression analysis but rather synthesizes existing knowledge and identifies patterns from raw data sources.

A growing body of research underscores the complex relationship between population growth and carbon emissions, albeit with differing perspectives on causality [5]. Some studies argue that population expansion drives energy demand and consequently elevates CO_2 emissions, while others highlight how environmental degradation, exacerbated by emissions, can indirectly affect population dynamics [6–8]. Further discourse surrounds the need to limit the expansion of high-carbon industries and advance the long-term adoption of renewable energy sources [9]. Additionally, socio-economic factors, technological progress, and policy frameworks play significant roles in shaping this intricate relationship.

The rapid pace of industrialization and urbanization has significantly influenced global energy consumption patterns, leading to a surge in fossil fuel-based CO_2 emissions. Simultaneously, the global population continues to grow, with projections indicating further increases in the coming decades [10–12]. This trend raises critical questions regarding the intersection of demographic changes and CO_2 emissions, necessitating comprehensive investigations into their underlying dynamics. Preliminary findings suggest a strong positive correlation between population growth and fossil fuel-based emissions, with socio-economic variables—such as rapid urbanization and industrial expansion—further exacerbating energy demand. Additionally, disparities in energy access and consumption patterns across different regions contribute to variations in emission intensity.

Existing scientific literature has explored the role of green enterprises in promoting sustainability, particularly their impact on environmental performance, business innovation, and challenges faced by small and medium-sized enterprises in adopting sustainable practices. Le Quéré et al. (2021) offer a detailed analysis of global carbon emissions, examining the role of fossil fuel consumption, land-use changes, and atmospheric CO_2 concentrations [13]. Their findings provide critical insights into global emission trends and their implications for climate mitigation strategies.

The economic analysis of CO_2 emissions from fossil energy sources is based on the application of different theories, such as the theory of externalities, ecological economics, and the theory of sustainable development. According to the theory of externalities, CO_2 emissions are an external effect, as they impact the environment and public health, but these costs are not accounted for in the market prices of energy produced from fossil fuels. Assessing these costs is an important step in economic analysis, as it helps determine the fair cost of energy resources while considering their negative environmental impact [14].

Ecological economics, in turn, advocates for the integration of economic processes with natural systems. This includes not only analyzing direct economic costs associated with CO_2 emissions but also considering long-term environmental consequences, such as climate change and resource depletion. Within this theory, key aspects include resource efficiency and minimizing harmful environmental impacts through regulating greenhouse gas emissions [15].

The theory of sustainable development focuses on achieving a balance between economic growth, social equity, and environmental protection. It assumes that any economic progress must occur with due regard to limited natural resources and the need to preserve ecosystems for future generations [16–18]. Therefore, to achieve sustainable development,

it is crucial to reduce CO_2 emissions from fossil energy sources and transition to cleaner, renewable energy sources. The European Union actively works to reduce CO_2 emissions through various economic instruments, policies, and programs. One of the main mechanisms is the Emissions Trading System (ETS), which allows companies to trade CO_2 emission allowances. This encourages emission reductions through market mechanisms, as companies that can reduce emissions at a lower cost sell allowances to companies with higher reduction costs [19,20].

The EU also implements policies aimed at transitioning to renewable energy sources such as solar, wind, and hydroelectric energy. Decarbonization strategies, such as the "European Green Deal", aim to achieve carbon neutrality by 2050. As part of this strategy, the EU plans significant investments in technologies to reduce CO_2 emissions and foster innovation in clean energy [17,21–23].

The economic analysis of CO_2 emissions in the EU also includes assessing the effectiveness of different policies. Research shows that the most effective strategies include not only financial incentives for businesses but also changes in consumer behavior through increased awareness and support for eco-friendly technologies [18,24]. Despite the progress made, economic analysis of CO_2 emissions in Europe faces several challenges. One of the main issues is political will, as tackling CO_2 emissions often requires significant financial investments and may affect traditional industries. Additionally, an important issue is ensuring fairness during the transition period, where vulnerable populations may be negatively affected by changes in the energy sector [24–26]. However, there are significant opportunities for the development of green technologies and innovations in the energy sector, which could lead to a significant reduction in CO_2 emissions and the achievement of sustainable development. Since Europe is a leader in the field of sustainable development, its experience can serve as an example for other countries in the fight against climate change [16,27–29].

The rapid increase in global population has been widely recognized as a significant factor influencing environmental degradation, particularly through rising CO_2 emissions [5,6,8–10,22]. This study aims to address a specific research gap by examining the nuanced interactions between population growth and CO_2 emissions within the EU context. Unlike previous studies that have primarily focused on aggregate global trends [9,24,30–36], this research provides a region-specific analysis, offering a more detailed understanding of the EU's role in global emission reduction.

This study contributes to the fields of energy economics and sustainable development by introducing a comprehensive methodological approach to assess the causality between population growth and CO_2 emissions. Moreover, it builds upon the existing literature by integrating theoretical perspectives such as the theory of externalities, ecological economics, and sustainability frameworks, which were previously only briefly referenced. For instance, the theory of externalities helps contextualize CO_2 emissions as a market failure, while ecological economics provides a holistic framework for evaluating long-term sustainability. The EU's leadership in environmental policies, carbon taxation, and renewable energy transitions makes it a valuable model for assessing the broader implications of sustainable development strategies. This study not only evaluates the EU's effectiveness in emission reductions but also draws lessons that can inform global policy frameworks.

The remainder of this paper is structured as follows: Section 2 outlines the research methodology, Section 3 presents empirical findings, Section 4 discusses key observations, and Section 5 concludes with a summary of the most significant results and policy recommendations.

2. Materials and Methods

The methodology is based on a structured literature review combined with summary statistics from publicly available energy audit and emission data sources. The study follows a specific methodological framework throughout its investigation:

1. This research begins with the compilation of extensive global datasets on fossil CO_2 emissions, categorized by source (coal, oil, natural gas) and region. Data on economic indicators, including GDP, industrial output, energy consumption, and population demographics, are gathered from reputable international sources and national statistical agencies (Table 1). The analysis considers data spanning from 1950 to 2023 to track historical trends and future projections of CO_2 emissions, shedding light on the evolving relationship between energy use, economic growth, and environmental sustainability (Figures 1 and 2).
2. A comparative analysis is undertaken to compare the fossil CO_2 emissions intensity of European countries with global counterparts. The analysis identifies the primary factors driving differences in emission intensity, including industrial structure, energy mix, technological innovation, and policy frameworks. These cross-country comparisons provide valuable insights into best practices and offer lessons for mitigating CO_2 emissions while fostering sustainable economic growth. The findings aim to inform policies that balance environmental goals with economic competitiveness.
3. To evaluate the potential impact of policy changes and technological advancements, scenario analysis is conducted. Various scenarios are designed based on different assumptions about economic growth, energy transition pathways, and policy interventions. Sensitivity analysis is used to test the resilience of the results under these diverse scenarios and to pinpoint key uncertainties that could affect future emissions trajectories. This analysis is crucial for understanding how different policy measures could help meet global climate goals while ensuring economic development remains on track.

Table 1. The connection between global population growth and fossil CO_2 emissions.

Year	World Population (millions)	CO_2 Emissions (million tons)	GDP per Capita (USD)	Population Deviation (%)	CO_2 Deviation (%)	GDP per Capita Deviation (%)
1940	2300	1500	1000	-	-	-
1950	2500	1800	1200	8.7	20.0	20.0
1960	3000	2200	1500	20.0	22.2	25.0
1970	3700	3000	2000	23.3	36.4	33.3
1980	4400	4500	3000	18.9	50.0	50.0
1990	5327	5500	4500	21.0	22.2	50.0
2000	6100	6800	5500	14.5	23.6	22.2
2010	6900	9000	6500	13.1	32.4	18.2
2020	7800	10,000	7000	13.0	11.1	7.7

Source: on the basis of [8,9,20,21,30,37–40].

The world population has consistently increased from 2.3 billion in 1940 to 7.8 billion in 2020, with significant growth seen in the latter half of the 20th century. CO_2 emissions have similarly risen, from 1.5 billion tons in 1940 to 10 billion tons in 2020, reflecting the global industrial expansion. GDP per capita grew steadily, reaching USD 7000 in 2020 from USD 1000 in 1940, indicating significant economic development over the decades.

Deviations in population growth and CO_2 emissions show acceleration in the latter part of the 20th century, particularly after 1980, highlighting the impacts of industrialization and economic globalization [8,20,21,37–39,41].

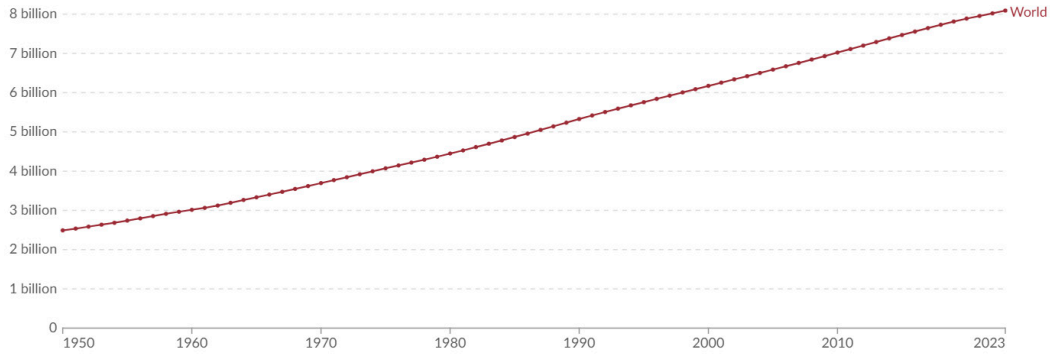

Figure 1. Population of the world. Source: on the basis of [7,20,30].

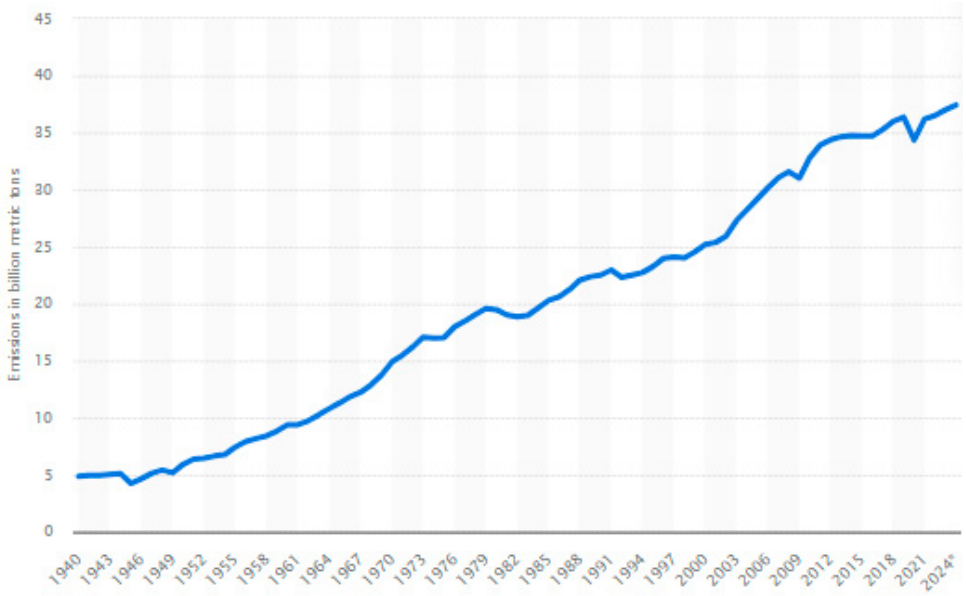

Figure 2. Annual carbon dioxide (CO_2) emissions worldwide from 1940 to 2024. Source: on the basis of [4,8,21,37–39,42]. * Data for 2024 is still being refined throughout 2025.

3. Results

CO_2 emissions from fossil energy sources are one of the main obstacles to achieving sustainable development. However, there are several economic and environmental approaches that can help reduce this impact. First, transitioning to renewable energy sources can significantly reduce CO_2 emissions. Economic data analysis shows that although investments in clean energy technologies may be high at the outset, long-term benefits, such as lower energy costs and reduced environmental harm, can far outweigh these costs [29]. Second, promoting energy efficiency is an essential aspect of achieving sustainable development. Reducing energy consumption through the implementation of energy-efficient technologies in industry, construction, and transport can reduce CO_2 emissions while maintaining economic growth [6]. The results reveal a significant and positive relationship between population growth and CO_2 emissions, confirming that higher population densities contribute to increased environmental impact. However, the magnitude of this effect varies across EU member states, with countries like Germany and Poland displaying distinct emission profiles.

The European Environment Agency [43] provides a comprehensive overview of progress towards climate and energy targets across the continent, emphasizing significant disparities in national achievements. The report highlights that while the EU as a whole made advancements in reducing greenhouse gas emissions by 30% compared to 1990 levels, some member states still face structural barriers to decarbonization, especially in sectors like transport and buildings [43]. The 2021 trends underline the importance of sustained investment in energy efficiency and renewable energy integration to meet the 2030 climate objectives. Furthermore, the role of governance and policy consistency is noted as a critical factor in achieving emission reduction across diverse economic contexts [43].

Q.Wang and M.Su [40] investigated the global drivers behind the decoupling of economic growth from carbon emissions, analyzing data from 186 countries. Their empirical analysis reveals that technological innovation, energy structure optimization, and improvements in energy intensity are key contributors to successful decoupling. Particularly in developed nations, structural changes in the economy—shifting from industry to services—have also played a significant role [40]. This study provides a strong quantitative basis for understanding how economies can maintain growth while reducing their environmental footprint, thereby supporting climate policy design.

A.Markandya and M.González-Eguino [26] delve into the complexities of financing climate adaptation, specifically addressing loss and damage in vulnerable regions. Their integrated assessment framework considers the multi-layered nature of climate risk, recommending a differentiated approach to financing that includes public funds, private investment, and insurance mechanisms. They emphasize the moral imperative for high-emitting countries to support adaptation in less developed nations, linking financial responsibility with historical emissions and adaptive capacity [26].

In a different yet related context, K.W. Knight et al. [42] explore the potential environmental benefits of reduced working hours in OECD countries. Using a cross-national panel dataset from 1970 to 2007, the authors find that shorter working weeks are associated with lower carbon emissions per capita, primarily due to reductions in energy-intensive consumption and transport [42]. This provocative finding challenges conventional growth paradigms and suggests that labor policy could be an underexplored avenue for climate mitigation. Similarly, V.Ahonen et al. (2024) contribute to this discussion by examining efforts of higher education institutions toward carbon neutrality, revealing significant implementation gaps despite high aspirations [22]. Their findings highlight the need for more rigorous monitoring frameworks and institutional support mechanisms to turn sustainability goals into measurable outcomes.

Additional important aspects include carbon taxes on CO_2 emissions and funding for research in new technologies. European countries are actively using financial instruments to encourage the development of eco-friendly technologies, which helps reduce overall CO_2 emissions without harming the economy [25,39,43–45].

Many EU countries have committed substantial investments in renewable energy and green technologies as part of their sustainable development strategies. Germany, Italy, and Spain are some of the largest investors, with a combined EUR 1 trillion in green investments expected over the next several decades (Table 2). This table provides valuable cross-country insights and observes that nations with high GDP per capita, such as Germany and France, have significantly reduced emissions through aggressive investment in renewable energy, whereas lower-income economies still struggle with decarbonization. This suggests that financial and technological support from the EU could accelerate emission reductions in lagging countries.

Table 2. Comparison of CO_2 emissions and sustainable development policies in EU countries.

Country	Fossil Fuel CO_2 Emissions	Sustainable Development Policies	Carbon Pricing Mechanisms	Transition to Renewable Energy	Key Challenges	Financial Data CO_2 Emissions
Austria	Low to moderate, decreasing	Climate neutrality by 2040, renewable energy target	EU ETS participation, carbon taxes	High share of hydroelectric energy, increasing wind and solar	Energy storage and grid integration, balancing renewables	EUR 5 billion investment in green energy and infrastructure (2020–2030) (Austrian Government)
Belgium	Moderate, with a focus on natural gas	Strong focus on reducing emissions and renewable integration	Participation in EU ETS	Moderate renewable energy growth, with solar and wind	Managing nuclear phase-out, energy security concerns	EUR 4 billion in renewable energy subsidies (2020–2025) (Belgian Government)
Den-mark	Low, significant reduction in fossil fuels	Leading in clean energy transition, climate neutrality by 2050	High carbon tax, participation in EU ETS	Strong wind energy, offshore wind industry	High energy costs, balancing wind variability	DKK 100 billion (approx. EUR 13 billion) in renewable energy investments (2020–2030) (Danish Government)
Ger-many	High, but decreasing (due to coal phase-out)	Strong commitment to the European Green Deal and energy transition	Emissions Trading System (ETS), carbon tax on vehicles	Significant growth in wind and solar energy	Coal phase-out, dependence on industrial sectors, energy prices	EUR 1 trillion investment required for energy transition (2020–2050) (German Federal Ministry for Economic Affairs and Energy)
France	Moderate, low per capita emissions	Energy transition, focus on nuclear and renewable energy	Participation in the EU ETS, carbon tax on fossil fuels	High nuclear energy share, increasing renewables	Nuclear dependency, balance of renewables and nuclear energy	EUR 1 trillion investment required for energy transition (2020–2050) (German Federal Ministry for Economic Affairs and Energy)
Finland	Low to moderate, decreasing fossil fuel use	Carbon neutrality target by 2035, circular economy model	Carbon tax, EU ETS participation	Focus on wind energy, bioenergy, and nuclear	Energy security, transition from nuclear and biomass	EUR 10 billion investments in renewable energy (2021–2030) (Finnish Government)

Table 2. *Cont.*

Country	Fossil Fuel CO_2 Emissions	Sustainable Development Policies	Carbon Pricing Mechanisms	Transition to Renewable Energy	Key Challenges	Financial Data CO_2 Emissions
Italy	Moderate, with significant reliance on natural gas	Focus on renewable energy integration and energy efficiency	EU ETS participation, carbon tax initiatives	Growth in solar and wind, but still reliant on gas	Balancing energy security with transition to renewables	EUR 70 billion investment in energy transition (2030–2050) (Italian Ministry of Ecological Transition)
Poland	Very high, reliance on coal	Slow progress in energy transition, but increasing EU pressure	Participation in EU ETS, coal sector subsidies	Growing interest in wind and solar, but coal remains dominant	Coal dependence, social resistance to change, energy security	EUR 60 billion in EU funds for energy transition (2021–2027) (Polish Government)
Spain	Moderate to high, but declining	Strong commitment to decarbonization and renewable energy targets	Participation in EU ETS	Leading in solar power, growth in wind energy	Energy storage, grid infrastructure development	EUR 22 billion investments in renewables (2020–2025) (Spanish Government)
Sweden	Low, strong environmental performance	Ambitious climate goals, carbon neutrality by 2045	Carbon tax, participation in EU ETS	Strong reliance on hydroelectric and wind energy	Achieving carbon neutrality in industrial sectors	EUR 45 billion (SEK 500 billion) green investments by 2030 (Swedish Government)
Nether-lands	High, but declining	Strong push towards sustainability, green growth agenda	Participation in EU ETS, carbon tax	Significant investments in wind energy and solar	Infrastructure investment for renewables integration	EUR 13 billion investments in offshore wind by 2030 (Dutch Government)
United King-dom	Decreasing, strong decline in coal usage	Strong policies under the Climate Change Act, net-zero target by 2050	Carbon pricing through Carbon Price Floor (CPF)	Rapid growth in wind energy, offshore wind leadership	Managing regional economic impacts, energy security risks	GBP 30 billion (approx. EUR 35 billion) investment in green technologies (UK Government, 2020)

Source: author's work based on [2,7–9,11,16–18,23,28,33,38,40,46–50].

Countries like Denmark, Sweden, and Spain are heavily investing in renewable energy infrastructure, particularly wind and solar, to meet their carbon neutrality targets. The financial data summarized in a Table 2, indicate that the transition to cleaner energy is a significant financial undertaking. Challenges such as balancing energy security with renewable integration, coal dependence (e.g., Poland), and nuclear phase-out (e.g., Belgium) continue to require substantial financial and policy interventions [1,41,51,52].

Carbon emissions from fossil fuels have been closely linked to population growth, as increased population generally leads to higher energy demand, industrial production, and transportation needs, all of which rely heavily on fossil fuels. As the global population expands, particularly in developing nations, the demand for energy grows, often outpacing the adoption of cleaner energy technologies. This results in higher emissions of carbon dioxide, contributing to climate change and environmental degradation. Industrialization, urbanization, and increased consumption are major drivers of this trend [26,34,51–53].

However, sustainable development offers a viable path to mitigate this ecological problem. By emphasizing the transition to renewable energy sources, improving energy efficiency, and adopting green technologies, it is possible to decouple economic growth from environmental degradation. Policies that promote sustainable practices, such as the widespread use of solar, wind, and hydropower, as well as the implementation of carbon pricing and stricter environmental regulations, can significantly reduce CO_2 emissions. Additionally, fostering sustainable urban planning, efficient transportation systems, and circular economies can help curb emissions despite population growth. Ultimately, through a global commitment to sustainable development, it is possible to stabilize emissions, ensuring a healthier planet for future generations while accommodating population growth.

The analysis of the CO_2 emissions from energy use in the European Union demonstrates carbon intensity among the countries, reflecting different approaches to economic development and climate action. The state of carbon dioxide emissions in EU countries in 2022 is represented in Figure 3. These data highlight variations in national emission trends. Bulgaria and Portugal experienced emission increases due to delayed transitions to renewable energy and heavy reliance on fossil fuels in industrial sectors. By contrast, countries like Denmark and Sweden have successfully implemented green policies, resulting in lower emissions.

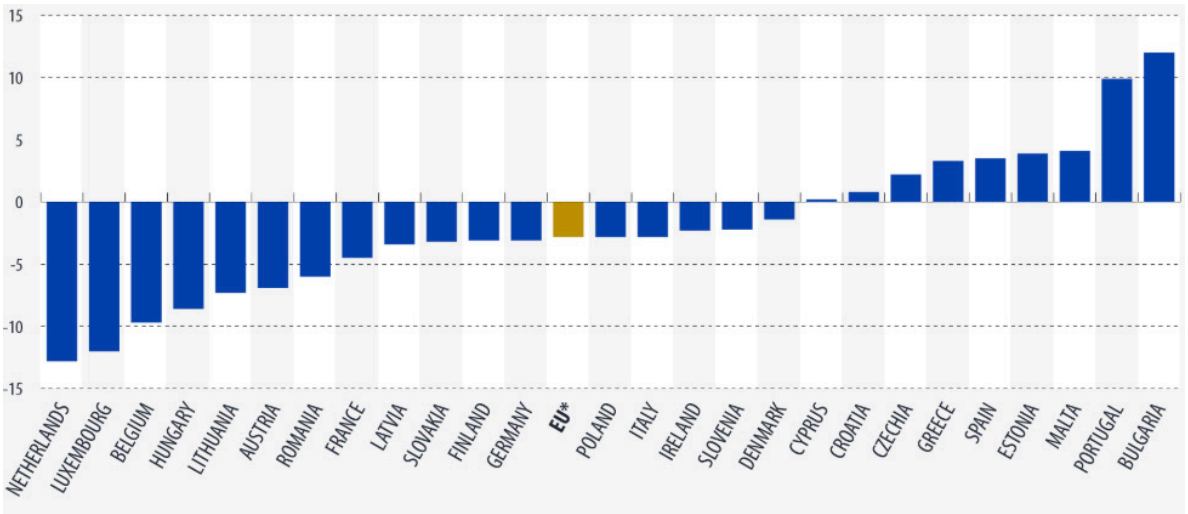

Figure 3. CO_2 emissions from energy use in 2022 in European Union. * Average data for the entire European Union. Source: based on data from [1,2,8,17,25,26,31,39,41,50,54].

The figures and tables illustrate the impact of GDP per capita and energy policy variations. For example, Germany's transition towards renewable energy has mitigated its emissions, whereas Poland's reliance on coal continues to drive higher CO_2 output. Furthermore, scenario analyses highlight how different policy interventions can alter emission trajectories. The Aggressive Emission Reduction scenario projects a 35% reduction in CO_2 by 2040, suggesting that stronger regulatory measures can substantially curb environmental impact. These findings have critical policy implications. The results emphasize the need for more stringent carbon pricing mechanisms, particularly in high-emission economies like Poland. Additionally, targeted investments in renewable energy could accelerate emission reductions in countries with slower transitions. That is why this study underscores the importance of country-specific policy frameworks, reinforcing that a one-size-fits-all approach may not be effective in reducing CO_2 emissions across the EU.

According to official statistics, CO_2 emissions in 2022 significantly decreased in EU countries: in the Netherlands by 12.8%, in Luxembourg by 12%, in Belgium—9.7%, and in Hungary—8.6%. However, some countries increased their CO_2 emissions, for example, Bulgaria by 12% and, similarly, Portugal by 9.9% and Malta by 4.1%. Germany also remains a significant polluter, since a quarter of total CO_2 emissions in the EU from burning fossil fuels for energy use are carried out here. Italy and Poland are slightly lagging behind in this negative trend, each accounting for 12.4% of total emissions. France had 10.7% of total CO_2 emissions in the EU in 2022 [41,43].

In Europe, in 2023, GHG emissions in the EU-27 were 33.9% lower than in 1990, reaching 3.22 Gt CO2eq. Compared to 2022, emissions in the EU-27 decreased by 7.5% (−261 Mt CO2eq), and the EU-27 share of global emissions decreased from 6.8% in 2022 to 6.1% in 2023 (Figure 4). Emissions from international aviation and shipping, which account for 0.9% and 1.4% of global GHG emissions, increased by 19.5% and 1.1% in 2023.

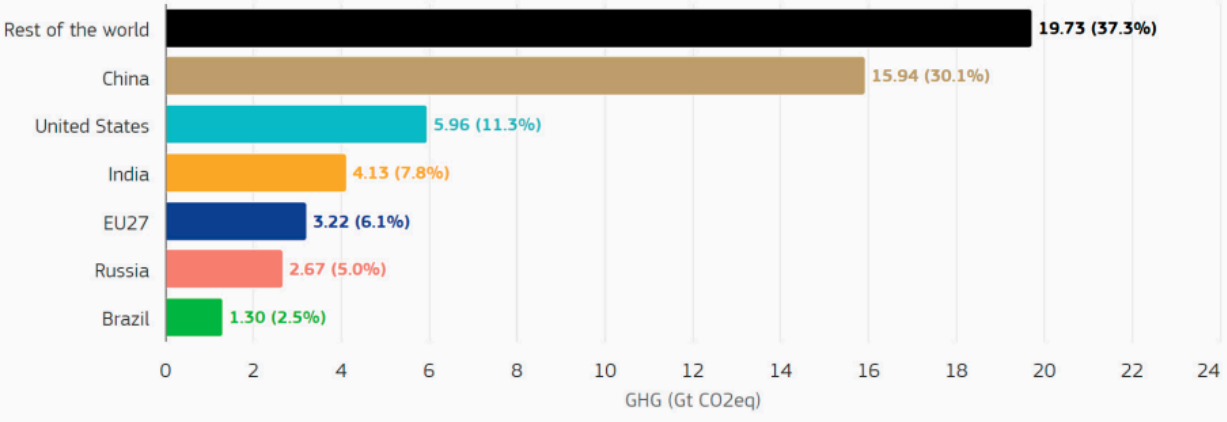

Figure 4. Percentage of CO_2 emissions in 2023, Gt CO_{2eq}. Source: based on data from [1,8,22,52,53].

The data from this Figure 4 confirm earlier studies suggesting that economic growth and urbanization amplify emissions but also reveal that stringent EU environmental policies mitigate these effects in certain member states. Policy implications emerging from these findings indicate that EU countries must adopt more targeted strategies to balance population growth with sustainable development. For instance, enhancing carbon pricing mechanisms in high-emission countries like Poland while expanding renewable energy incentives in regions with lower adoption rates (e.g., Bulgaria and Portugal) could optimize CO_2 reduction efforts. Moreover, countries with aging populations, such as Germany and Italy, must develop sustainable infrastructure that supports energy efficiency without hindering economic growth. One major limitation is the reliance on reported CO_2 data, which may vary in accuracy due to differences in national reporting standards.

Germany stands as one of the leading examples of energy transition in Europe, known as the "Energiewende". This national policy framework emphasizes a shift from fossil fuels and nuclear energy to renewable sources while significantly enhancing energy efficiency across sectors. In the context of office buildings, Germany has implemented stringent energy performance standards and incentivized deep energy retrofits. As a result, German office buildings have progressively reduced their energy demand, achieving compliance with both national and EU-level sustainability targets [23].

According to Eurostat and the German Federal Environment Agency, the country has achieved a notable reduction in CO_2 emissions in the building sector over the last decade. This success is largely due to improved thermal insulation, adoption of smart energy management systems, and the increasing use of renewable heating technologies such as biomass boilers and heat pumps. These efforts serve as a benchmark for countries such as Ukraine, highlighting effective practices in climate mitigation policy implementation in the built environment. Germany's data also demonstrate the long-term benefits of consistent investment in building modernization, underscoring the importance of political will and regulatory stability [23].

As Figure 5 shows, a whopping 750 million metric tons of carbon dioxide were emitted into the air in 2022 from transportation. Electricity and heat generation in the utilities sector came in second place with a total of 730 Mt CO_2. Together, these two sectors accounted for more than 50% of total net CO_2 emissions. This underscores the need for enhanced investments in electric mobility, grid decarbonization, and public transportation systems. By focusing policy efforts on these high-emission sectors, the EU can achieve more efficient and equitable CO_2 reduction.

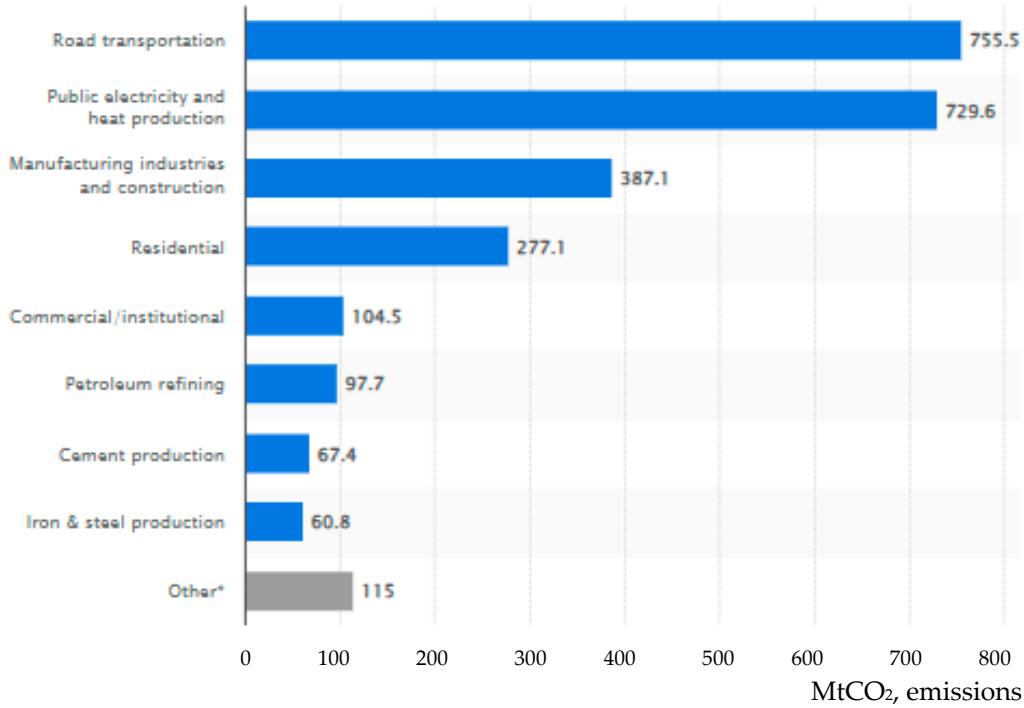

Figure 5. Carbon dioxide emissions in the EU in 2022 (by key source). Source: based on the data from [2,12,20,39,41,43,46,55]. * Others high-emission sectors in the EU.

The power industry is the largest contributor, accounting for 38.1% of total emissions, followed by transportation at 20.7% and industrial combustion at 17%. Other significant sources include buildings (8.9%), industrial processes (8.4%), and fuel exploitation (6.6%). Agriculture, with only 0.4%, has the smallest share [2,8,39–41]. These figures highlight the

major role of energy production and transportation in emissions, suggesting that policies targeting these sectors could have the greatest impact on reducing overall emissions.

4. Discussion

Several European Union (EU) countries have made significant strides in addressing the issue of carbon emissions from fossil fuels while managing the challenges of population growth. These countries are implementing a variety of policies and investing heavily in sustainable development practices to reduce their carbon footprints while also addressing the impacts of growing populations on emissions.

Germany acknowledges that as its population grows, energy demand will inevitably increase, leading to higher emissions if fossil fuels remain dominant. However, through its Energiewende (energy transition), Germany aims to decouple economic growth and energy consumption from CO_2 emissions [1,9,32,46]. The country is investing heavily in renewable energy technologies, particularly wind and solar, as well as energy storage and grid modernization to handle the variable nature of renewables. Smart grids and energy efficiency technologies in buildings and industry are also central to the strategy. By 2030, Germany aims to have 65% of its energy from renewable sources, significantly reducing emissions despite population growth [1,8]. Furthermore, the implementation of carbon pricing mechanisms, such as the EU Emissions Trading System (ETS), incentivizes industries to reduce their carbon footprints. Germany's approach combines technological innovation, policy incentives, and public awareness to manage emissions growth in parallel with a growing population [38,41].

France's approach to managing emissions in the face of population growth involves a strong reliance on nuclear energy and renewables. Nuclear power provides a significant share of the country's low-carbon energy, while wind, solar, and hydropower also contribute to reducing fossil fuel dependency. The French government has implemented carbon taxes on fossil fuels, which not only help reduce emissions but also provide financial resources for further investments in clean technologies. France evaluates the impact of increasing population size on emissions through comprehensive carbon footprint assessments, which highlight sectors such as transportation and residential energy consumption as key contributors. As part of its efforts to meet EU climate goals, France has committed to electrifying transportation, supporting electric vehicle infrastructure, and energy-efficient building standards. These efforts are essential for mitigating emissions as the population grows [4,6,28,41,43].

The United Kingdom has made significant progress in reducing carbon emissions despite a growing population, particularly through the decarbonization of the power sector. The UK has seen a dramatic reduction in coal use, shifting toward offshore wind, solar, and nuclear power [32,44,56,57]. The UK government has implemented policies to phase out gasoline and diesel cars, with a ban on new sales set for 2030. Moreover, the UK's Carbon Price Floor (CPF) has provided a financial incentive to phase out fossil fuels in the energy sector [8]. The UK government acknowledges that population growth increases energy demand, but it aims to offset this through technological advancements, such as smart meters and energy storage systems that increase the efficiency of energy use. As part of the UK's long-term strategy to reach net-zero emissions by 2050, it is also heavily investing in hydrogen technology and carbon capture and storage (CCS) to reduce industrial emissions.

Poland faces significant challenges in managing rising CO_2 emissions with its growing population, given the country's reliance on coal for energy [1,53]. The government has acknowledged that population growth exacerbates emissions from industrial sectors, residential heating, and transportation, which rely heavily on coal and other fossil fuels. To address this, Poland is beginning to shift toward renewable energy, focusing on wind

and solar power, and has set ambitious goals to increase the share of renewables in its energy mix. However, coal remains a dominant energy source, and substantial financial support is required for a successful transition [47,52]. Poland's participation in the EU Emissions Trading System provides some flexibility in emission reduction, but the country has also introduced energy efficiency measures and carbon pricing initiatives [15,41,51]. To counteract rising emissions, Poland is working on energy diversification and integrating green technologies such as biomass and district heating systems.

Denmark has long recognized the impact of population growth on emissions, especially in urban areas. The country has been at the forefront of renewable energy adoption, primarily focusing on wind power, both onshore and offshore, which now represents a significant portion of its electricity generation. The Danish government has committed to carbon neutrality by 2050, aiming to offset the impacts of population growth through sustainable urban planning, green transportation, and increased energy efficiency [50,58]. Denmark's smart grids and energy storage solutions help ensure that energy consumption from renewables is maximized, reducing the need for fossil fuels even as the population expands. Additionally, electric vehicles (EVs) are being widely promoted, with incentives for their use and the establishment of EV infrastructure. Sustainable agriculture and circular economy initiatives are also part of Denmark's strategy to address emissions from land use and waste management as the population grows.

Sweden has committed to being carbon neutral by 2045, recognizing that population growth puts pressure on energy systems, transportation, and housing, all of which are major sources of CO_2 emissions [8,13,17]. The country focuses heavily on renewable energy, especially hydroelectric power, wind energy, and bioenergy. Sweden's policy includes carbon taxes, which incentivize both individuals and industries to reduce their carbon footprints. District heating systems, which provide efficient thermal energy to multiple households, and high-efficiency buildings have been widely implemented. Sweden's transport sector is transitioning to electric vehicles, and the country is also heavily investing in carbon capture and storage (CCS) technologies [39,52]. Sweden's combination of taxes, technology, and renewable investments enables it to manage both the challenges of growing emissions and a rising population.

Spain faces a similar challenge in managing emissions growth, particularly in sectors like transportation and residential energy consumption. However, Spain has committed to expanding its renewable energy capacity, with solar and wind power leading the way. The government has made significant investments in solar power infrastructure and offshore wind, which are expected to play a key role in reducing emissions, despite population increases [1,24]. Additionally, Spain has set ambitious goals for energy efficiency in the residential and industrial sectors, with a focus on low-carbon technologies and smart buildings. Policies to promote electric mobility and green public transport are central to reducing emissions from the transportation sector. Spain also integrates energy storage systems to accommodate renewable energy sources, which will help meet the demands of a growing population without increasing emissions.

These countries are increasingly aware that population growth will lead to higher energy demand and emissions unless proactive measures are taken. Through investments in renewable energy, energy efficiency technologies, and green transportation, they are developing innovative solutions that balance the demands of growing populations with the need for sustainability. Moreover, carbon pricing and the adoption of smart technologies allow for the decoupling of emissions from economic growth, demonstrating that sustainable development is achievable even in the context of rising population numbers.

The following section will present a number of key perspectives on reducing the negative impact of CO_2 from fossil fuels, together with the references to the authors' sources

(see Table 3). This table outlines various instruments and perspectives aimed at reducing the negative impact of CO_2 emissions from fossil fuels. It includes renewable energy sources like wind, solar, hydropower, and geothermal, which replace fossil fuels with cleaner alternatives. Energy efficiency measures such as smart grids and green building standards help optimize energy use and reduce waste.

Table 3. Instruments and perspectives on reducing the negative impact of CO_2 emissions from fossil fuels.

Category	Instrument	Description	Impact	Source
Renewable Energy	Wind and Solar Power	Replacing fossil fuels with sustainable energy sources	Reduces emissions, increases sustainability	European Green Deal (2019) [17]; Wang Q., et al. (2016) [40]; Tenga, X., et al. (2020) [4]; A. Golub, et al. (2013) [57]; Brundtland, G.H. (1987) [16]; Creutzig, et al. (2015) [31].
	Hydropower and Geothermal	Utilizing natural energy sources for electricity generation	Lowers carbon footprint	Markandya, A., et al. (2019) [26]; Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; Van Vuuren, D. P., et al. (2017) [55]; Yakymchuk A., et al. (2025) [25].
Energy Efficiency	Smart Grid Technology	Optimizing energy distribution to minimize waste	Improves energy efficiency	C. Hamilton (2011) [48]; Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; C.Böhringer, et al. (2006) [50]; Global Debt Report (2024) [3]; Kropp T., et al. (2022) [23].
	Green Building Standards	Energy-efficient materials and technology in construction	Reduces energy consumption	Jędrzejowska, K., & Wróbel, A. (2022) [46]; Agenda 2030 for Sustainable Development (2015) [34]; Wang, Q., & Su, M. (2020) [40]; European Green Deal (2019) [17]; Ahonen, V., et al. (2024) [22].
Carbon Capture and Storage (CCS)	Direct Air Capture	Removing CO_2 from the atmosphere	Reduces greenhouse gases	Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; C. Böhringer, et al. (2006) [50]; Xiangyu Tenga, et al., (2020) [4]; Markandya, A., & González-Eguino, M. (2019) [26].
	Carbon Sequestration	Storing CO_2 underground or using it in industry	Prevents emissions from entering the air	Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; Xiangyu Tenga et al. (2020) [4]; Gambhir, A., et al., (2023) [5]; Qingyun Zhao, et al., (2024) [4]; Smith, A., & Johnson, B. (2020) [36].
Sustainable Transportation	Electric Vehicles (EVs)	Replacing internal combustion engines with electric motors	Lowers transportation-related CO_2 emissions	Kropp T. (2022) [23]; European Green Deal (2019) [17]; Wang Q., et al. (2016) [40]; C. Böhringer, et al. (2006) [50]; Knight, K.W.; et al. (2013) [42]; Hamilton, L. (2010) [48].
	Public Transit Expansion	Increasing public transport options to reduce car dependency	Reduces traffic-related emissions	Griffiths, I., et al. (2024) [32]; Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; C. Böhringer, et al. (2006) [50]; Distribution of Carbon Dioxide Emissions Worldwide in 2022 (2024) [11]; Davis, S.J., et al. (2010) [30]; Smith, A., & Johnson, B. (2020) [36].
Policy and Regulation	Carbon Pricing (Tax, Cap-and-Trade)	Financial incentives to reduce CO_2 emissions	Encourages businesses to cut emissions	Edenhofer, O., et al. (2006) [33]; Wang Q., et al., (2016) [40]; Yakymchuk A. (2024) [7]; Kropp, T., et al. (2022) [23].
	Green Technology Subsidies	Government support for renewable energy and innovations	Accelerates transition to clean energy	Schneider, M. (2018) [27]; Baumol, W.J., & Oates, W.E. (1988) [14]; Daly, H.E. (1977) [15]; Brundtland, G.H. (1987) [16], Ellerman, A.D., & Marcantonini, C. (2016) [19]; European Commission (2023) [41]; Hasselmann, K. (2007) [18]; Zhou, D. (2020) [29]; Parry, I.W.H. (2018) [45].

Table 3. *Cont.*

Category	Instrument	Description	Impact	Source
Industrial Decarbonization	Hydrogen Fuel Development	Using green hydrogen as a clean energy alternative	Decreases reliance on fossil fuels	Smith, A., & Johnson, B. (2020) [36]; Fouquet, R. (2023) [28]; Le Quéré, C., et al. (2020) [13]; Daly, H.E. (1977) [15]; Ellerman, A.D., & Marcantonini, C. (2016) [19]; European Commission (2023) [41]; Hasselmann, K. (2007) [18]; Parry, I.W.H. (2018) [45]; Sovacool, B.K. (2021) [24]; How Has World Population Growth Changed (2025) [20].
	Circular Economy Practices	Recycling and waste reduction in production	Reduces resource depletion	Daly, H.E. (1977) [15]; Brundtland, G.H. (1987) [16], Ellerman, A.D., & Marcantonini, C. (2016) [19]; European Commission (2023) [41]; Hasselmann K., (2007) [18]; Zhou, D. (2020) [45]; Sovacool, B.K. (2021) [24]; Yakymchuk, A., et al. (2025) [25].
Nature-Based Solutions	Reforestation and Afforestation	Planting trees to absorb CO_2	Increases carbon capture	Parry, I.W.H. (2018) [45]; Sovacool, B.K. (2021) [24]. Brundtland, G.H. (1987) [16], Ellerman, A.D., & Marcantonini, C. (2016) [19]; European Commission, (2023) [41]; Hasselmann, K. (2007) [18]; Zhou, D. (2020) [45]; Stern, N. (2024) [6].
	Blue Carbon Ecosystems	Protecting coastal and marine habitats that store carbon	Enhances natural carbon sinks	Creutzig F., et al. (2015) [31]; Wang Q., et al. (2016) [40]; Yakymchuk A. (2024) [7]; Stern, N. (2024) [6]; Fischer, C, & Newell, R. (2008) [35]; Jiang, Y., et al. (2024) [47]; Smith, A., & Johnson (2020) [36]; Kropp T., et al. (2022) [23].

Source: compiled by the authors.

Carbon capture and storage technologies, along with sustainable transportation solutions like electric vehicles and expanded public transit, contribute to lowering emissions in industrial and transport sectors. Policy frameworks, such as carbon pricing and subsidies for green technologies, alongside nature-based solutions like reforestation, play key roles in mitigating emissions and promoting environmental sustainability.

The following are just a few of the key perspectives held by scientists regarding the reduction in CO_2 emissions and the implementation of the Green Deal. This topic is complex and multifaceted, requiring a comprehensive approach to effectively tackle the issue.

5. Conclusions

The following conclusions were formed as a result of the conducted research.

1. This study underscores the need for EU countries to enhance carbon pricing mechanisms, increase renewable energy investments, and tailor policies to national economic structures. Specifically, high-emission countries should prioritize stronger emission reduction strategies, while low-emission nations should focus on sustaining their progress through continued policy support. The findings of this study emphasize the intricate interplay between population dynamics and fossil CO_2 emissions, underscoring the necessity for multifaceted approaches to address climate change and promote sustainable development. By comprehending the drivers and ramifications of the mounting reliance on fossil fuels, policymakers can devise targeted interventions aimed at decoupling economic growth from carbon emissions and catalyzing a transition towards renewable energy sources. For Europe, there are several prospects in terms of reducing the negative impact of CO_2 emissions: these include an increase in renewable energy usage, the stimulation of energy efficiency, the implementation

of carbon targets, a transition to transport models, and the promotion of a circular economy. The authors highlight the significant role of economic growth and urbanization in driving emissions while demonstrating the effectiveness of EU environmental policies in mitigating these effects.

2. The economic analysis of CO_2 emissions from fossil energy sources is an important tool for developing effective policies that promote sustainable development. The European Union is actively working to reduce emissions through various economic and political mechanisms, focusing on innovation, renewable energy sources, and energy efficiency. At the same time, it is essential to ensure a fair transition to sustainable development, which will require integrating economic, environmental, and social aspects into decarbonization processes. These findings contribute to global climate change mitigation efforts by emphasizing the importance of regional policy differentiation and cooperation. As the EU strives to meet its sustainability targets, our study reinforces the urgency of integrating climate action into economic and demographic planning.
3. Many EU countries have committed substantial investments in renewable energy and green technologies as part of their sustainable development strategies. Germany, Italy, and Spain are some of the largest investors, with a combined EUR 1 trillion in green investments expected over the next several decades. Countries like Denmark, Sweden, and Spain are heavily investing in renewable energy infrastructure, particularly wind and solar, to meet their carbon neutrality targets. The financial data summarized in this study indicate that the transition to cleaner energy is a significant financial undertaking. Challenges such as balancing energy security with renewable integration, coal dependence (e.g., Poland), and nuclear phase-out (e.g., Belgium) continue to require substantial financial and policy interventions.
4. Demographic factors play a major role in carbon emissions, highlighting the need for targeted interventions to address the environmental impacts of population expansion. To combat climate change, strategies should not only focus on technological advancements and policies but also incorporate population dynamics, ensuring more effective mitigation of emissions. Addressing the link between population growth, economic development, and environmental sustainability requires integrated approaches. Policies should prioritize investments in renewable energy, energy efficiency, and sustainable urban planning while also promoting access to education, healthcare, and family planning services to manage population growth responsibly. Additionally, understanding the economic and health impacts of CO_2 emissions is crucial for planning preventive measures at all levels, from international to local. Finally, due to the global nature of climate change, addressing the relationship between population growth and CO_2 emissions requires international collaboration. Effective mitigation strategies and a transition to a low-carbon economy can be supported by sharing best practices, transferring technology, and mobilizing financial resources across borders.
5. In the next publication, the authors plan to develop a correlation regression model to assess the impact of population on fossil CO_2 emissions, which will highlight the importance of data-based analysis for effective policymaking. The correlation coefficient will be found, indicating the relationship between population growth and increased emissions, and the variables and vectors will be tested for multicollinearity. The model will include data from 1940, i.e., for the last 85 years, which will confirm the adequacy of the study. Future studies should focus on exploring the influence of socio-economic factors, technological innovations, and policy frameworks in shaping emission patterns across various regions and timeframes. By considering aspects of sustainable development, such as renewable energy adoption, energy efficiency,

and inclusive growth, these studies can offer evidence-based recommendations for designing policies that align environmental goals with economic and social development. This approach will ensure that climate action is informed by a comprehensive understanding of the factors influencing emissions, supporting more effective and sustainable mitigation strategies.

6. Foresight is defined as the systematic exploration of possible future scenarios to inform decision-making and policy development. In the context of CO_2 emissions and climate change, foresight can play a crucial role in identifying emerging trends, assessing future risks and opportunities, and designing proactive strategies to mitigate CO_2 emissions and adapt to climate impacts. The employment of foresight methodologies, such as scenario analysis, trend analysis, and stakeholder engagement, enables policymakers, businesses, and civil society organizations to anticipate potential trajectories of CO_2 emissions, explore alternative pathways for sustainable development, and identify innovative solutions to address climate challenges. The integration of foresight into decision-making processes related to CO_2 emissions has the potential to enhance resilience, stimulate innovation, and facilitate the transition to a low-carbon and climate-resilient future. Policymakers must act swiftly to align population growth with emission reduction goals. Investing in clean technologies, enforcing stricter regulations, and promoting sustainable urban development will be essential in achieving long-term environmental sustainability.

Further research should also explore the role of technological innovation in mitigating emissions and examine the impact of sector-specific policies on different economic structures within the EU. Future research could improve upon this by incorporating non-linear models and alternative datasets, such as satellite-based emissions tracking.

Author Contributions: Conceptualization, A.Y. and M.A.R.; methodology, A.Y.; validation A.Y.; formal analysis, A.Y.; resources, M.A.R. and A.Y.; writing—original draft preparation, A.Y.; review M.A.R. and A.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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