Czech University of Life Sciences Prague

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Bachelor's Thesis

Carbon emissions trends in Europe: a comparative analysis

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BACHELOR THESIS ASSIGNMENT

Ezhena Dmitrieva

Landscape Technical and Administration Services in Environment

Thesis title

Carbon emissions trends in Europe: a comparative analysis

Objectives of thesis

This comprehensive study aims to analyze and evaluate the historical trends and patterns of carbon dioxide (CO_2) emissions across various European countries. The objective of this thesis is to gain a deeper understanding of Europe's contribution to global CO_2 emissions over time and compare the differences among European countries. It will provide insights that could inform future policies and strategies for emission reduction in the region.

Methodology

The historical data on carbon dioxide emissions from all European countries will be collected till 2022. Specifically, the carbon dioxide emissions from cement, land-use change, and energy will be selected. Meanwhile, the population and gross domestic product will be collected as well. The difference in carbon dioxide emission per capita from all European countries will be compared, and it will be visualized by ArcGIS.

The proposed extent of the thesis

40

Keywords

Carbon emission, Carbon dioxide, Europe

Recommended information sources

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Prague on 27. 03. 2024

Declaration

I hereby declare that I have done this final thesis entitled „Carbon emissions trends in Europe: a comparative analysis“, independently, all text in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

Prague, 28.03.2024

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Ezhena Dmitrieva

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Carbon emissions trends in Europe: a comparative analysis

Abstract

This research conducts a comprehensive trend analysis of carbon emissions across European nations, with a particular focus on the period from 1990 to 2022, during which significant alterations were observed. Throughout this timeframe, a noteworthy reduction in carbon emissions by 41 million tonnes (Mt) was identified, underscoring the positive impact of measures implemented by both the European Union and individual member states. The study meticulously examines the primary sources and types of carbon emissions, identifying electricity and heating consumption, transportation, and the construction sector as the main contributors.

The analysis is underpinned by data sourced from Our World in Data, which facilitated an exploration of the interplay between various factors such as population size, the economic development measured by GDP, and per capita carbon emissions. The findings reveal no straightforward correlations, suggesting a complex interrelationship among these variables.

Furthermore, the study proposes a range of measures for the European Union to adopt, both globally and individually, aimed at reducing carbon emissions.

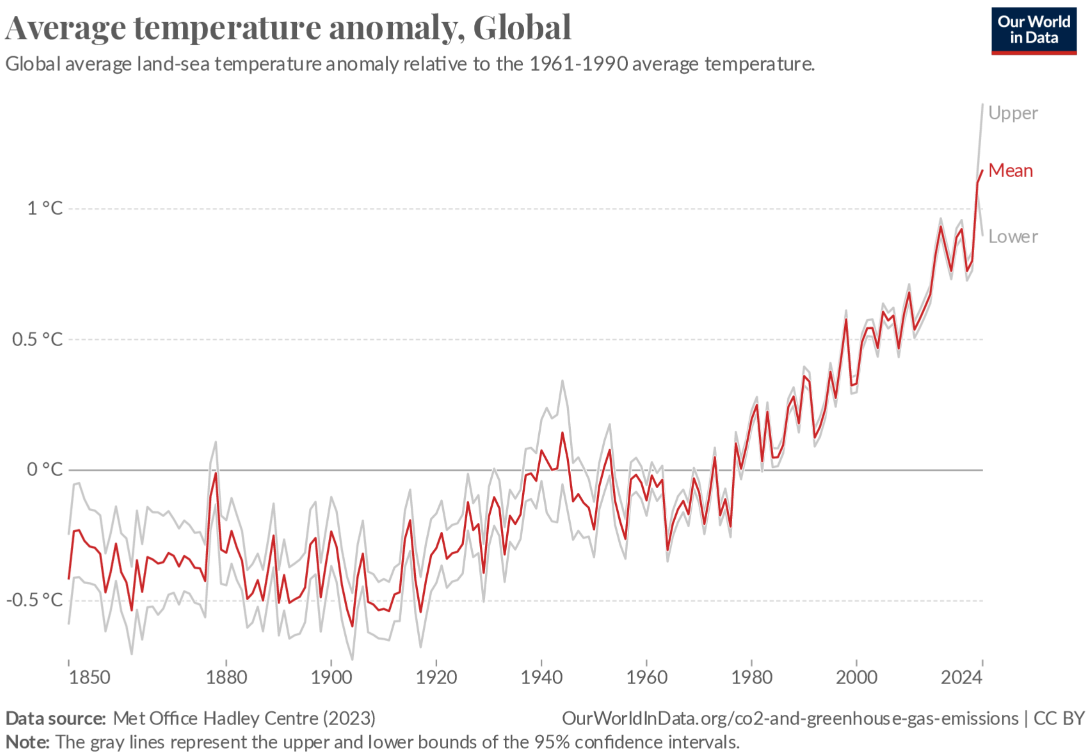
Key words: Carbon emission, Carbon dioxide, Europe.

LIST OF FIGURES

1 Introduction

In recent years, it's become clear that our pursuit of more energy has led to a significant increase in the Earth's temperature. The main culprits are the burning of fossil fuels, industrial activities, and deforestation, all of which release large amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. Annually, these emissions amount to about 40 billion tons of CO_2, along with significant quantities of methane (CH_4) and nitrous oxide (N2O). This heavy reliance on fossil fuels has resulted in over 2 trillion tons of CO_2 being emitted, with about half being absorbed by the world's vegetation and oceans, and the other half increasing the atmospheric concentration. This has led to a nearly 1.2°C rise in global temperatures over the last 150 years, a rate of increase that is historically unprecedented and signals a rapid and intensifying shift in the global climate (Figure 1.1).

Figure 1.1 Average temperature anomaly, Global



Source: Met Office Hadley Centre (2023). OurWorldInData.org/co2-and-greenhouse-gas-emissions

Recent data showing a 20% to 50% reduction in global greenhouse gas emissions in the early months of 2020 might suggest a potential for slowing down global warming. However, the effect of this reduction is likely minimal due to the prolonged presence of CO_2 in the atmosphere and the slow response of Earth's climatic system to changes. This situation highlights the challenges in mitigating climate change and the importance of adopting effective climate action urgently. Projections indicate that if the concentration of CO_2 continues to double every 22 years, the planet could see an additional temperature increase of around 4.5°C.

The European Union (EU) has acknowledged the urgency of addressing climate change and has implemented various measures, including the European Green Deal, to reduce emissions. This thesis takes a comparative look at emission trends across Europe, examining how economic, energy, and technological differences influence these trends. It evaluates the impact of both national and EU-wide environmental policies, aiming to understand the gap between their objectives and the actual results. The recent drop in emissions, while a positive sign, underscores the ongoing need for robust and effective policies to tackle the complex challenge of global warming and climate change comprehensively.

2 Purpose of work and methodology

2.1 Purpose of the work

The purpose of this research is to conduct a detailed analysis and evaluation of the historical trends and patterns of carbon dioxide (CO_2) emissions across various European countries. This study is driven by the objective to understand Europe's contribution to global CO_2 emissions over time and to delineate the variances in emission trends among European nations. Through this analysis, the research aims to uncover insights that could guide the development of future policies and strategies aimed at reducing CO_2 emissions within the region.

The research is structured around several core objectives:

Historical Trend Analysis

To document and analyze the progression of CO_2 emissions in Europe, identifying significant trends over the years. This includes understanding the context behind fluctuations in emissions, such as economic growth phases, policy implementations, and technological advancements.

Comparative Analysis

To compare CO_2 emissions across European countries by examining factors such as economic structures, energy policies, industrial outputs, and the mix of energy sources. This comparison aims to highlight the effectiveness of different national and regional strategies in managing emissions.

Policy Evaluation

To assess the impact of past and present environmental policies on CO_2 emissions trends in Europe. This involves a review of international agreements and regional initiatives to understand their role in shaping emission trajectories.

Informing Future Strategies

By analyzing historical and current emission trends, the research intends to offer recommendations for future emission reduction strategies. Identifying successful practices and areas needing improvement will inform the development of more effective policies.

The significance of this study lies in its potential to enhance the understanding of emission trends within Europe, offering a foundation for informed policy-making aimed at emission reduction. By identifying the key drivers of emissions and assessing policy effectiveness, this research contributes to the broader goal of mitigating climate change impacts.

In conclusion, this thesis seeks to provide a comprehensive overview of CO_2 emissions in Europe, facilitating a deeper understanding of the region's role in global emissions and identifying strategies for future reductions. This analysis is intended to support policymakers, environmental organizations, and other stakeholders in formulating targeted actions to address the challenge of climate change.

2.2 Methodology

This thesis is divided into two main sections. The first part involves conducting a literature review aimed at providing a deeper understanding of the issues related to global warming and gas emissions. This review includes an examination of previous studies, analyses of emission trends across European countries, and identification of key historical events relevant to the topic. The goal is to offer a comprehensive overview of the subject matter.

The second practical part of this research involves the analysis of existing data - CO_2 and Greenhouse Gas Emissions dataset available on Our World in Data (https://ourworldindata.org/). The background for this study is informed by the observed trend in carbon dioxide emissions from 1750 to 1990, where a steady increase was noted, peaking in 1990. Given the significance of the period from 1990 to 2022, marked by notable political, technological, and event-driven impacts on carbon emissions, the study focuses on this timeframe. This period is characterized by substantial developments in global politics, technology, and events that have influenced carbon emission rates, necessitating a focused analysis to understand their implications on climate change.

This study focusing specifically on emissions from cement production, land-use changes, and the energy sector. Additionally, relevant socio-economic indicators such as population sizes and Gross Domestic Product (GDP) figures will be collected to contextualize the emissions data. The aim is to compare carbon dioxide emissions on a per capita basis across European countries, employing ArcGIS for data visualization to elucidate the geographic distribution and trends of these emissions.

Data

The data for this thesis was sourced from the extensive CO_2 and Greenhouse Gas Emissions dataset available on Our World in Data (https://ourworldindata.org/). This key dataset, which is crucial for understanding global climate change progress, includes detailed emissions data alongside scripts for analysis, all accessible through the Our World in Data GitHub repository.

The graphs and charts were plotted in the R program. The data contained many variables, of which I used items 1-44 to focus on the most important. I filtered the data for the period 1990-2022 and the EU-27 countries to include the following: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

Variable's Overview:

CO_2 Emissions from Cement Production (cement_co2) the variable representing CO_2 emissions from cement production is measured in metric tons annually. This data is essential for understanding the role of cement manufacturing in the total CO_2 emissions of a nation.

CO_2 Emissions from Land-Use Change (land_usage_co2)

The variable concerning CO_2 emissions from land-use changes quantifies the yearly emissions in metric tons, resulting from activities like deforestation and development for agriculture or urbanization. This metric is fundamental for evaluating how changes in land use influence a country's CO_2 emissions.

CO_2 Emissions from Energy (energy_co2)

thr variable measures the total yearly emissions from energy use in sectors like electricity, heating, and transportation, in metric tons. This is a key indicator, as it represents the majority of CO_2 emissions, highlighting the significant role of energy consumption in determining the emissions profile of European countries.

CO_2 Emissions Per Capita (co2_per_capita) is derived by dividing the total CO_2 emissions by the population size, providing a standardized measure for comparing emissions across countries. This metric reflects the average emissions per person, facilitating the evaluation of emissions efficiency and the impact of lifestyle and policy decisions on a nation's emissions.

Population (population) provides the total number of inhabitants in each country per year, serving as a fundamental demographic indicator. It is essential for calculating per capita emissions, allowing comparisons across countries of different sizes and understanding the demographic factors influencing CO_2 emissions.

Gross Domestic Product (gdp) adjusted for purchasing power parity (PPP) in international dollars, reflects the economic activity of each country. Analyzing GDP alongside

CO_2 emissions reveals the dynamics between economic growth and environmental impact, highlighting opportunities for sustainable development and the potential to decouple economic growth from increased emissions.

3 Literature Review

3.1 Overview of Carbon Emissions

The phenomenon of global warming, largely attributed to the increase in greenhouse gas (GHG) emissions, has garnered significant attention within the scientific community and beyond. Among the GHGs, carbon dioxide (CO_2) is the most prominent, primarily emitted through the combustion of fossil fuels, deforestation, and various industrial processes. The implications of rising CO_2 levels on global temperatures, weather patterns, and ecosystems necessitate a comprehensive understanding and strategic intervention to mitigate these effects.

CO_2, along with methane (CH4), nitrous oxide (N2O), ozone (O3), water vapor (H2O), and fluorinated gases, plays a crucial role in the greenhouse effect, which is essential for life on Earth by keeping our planet warm enough to sustain life. However, anthropogenic activities have significantly increased the concentrations of these gases in the atmosphere, enhancing the natural greenhouse effect, which leads to warming of the Earth's surface and the lower atmosphere. Among these gases, CO_2 is particularly significant due to its abundance and long life in the atmosphere, making it the primary focus of efforts to reduce GHG emissions.

The combustion of coal, oil, and natural gas for energy and transportation constitutes the largest source of CO_2 emissions globally. Industrial processes, such as cement production, also contribute significantly to CO_2 emissions. Moreover, deforestation and land use changes further exacerbate CO_2 levels in the atmosphere, disrupting the natural carbon cycle that includes absorption of CO_2 by plants during photosynthesis.

Methane, another potent greenhouse gas, is released during the production and transport of coal, oil, and natural gas, as well as by livestock and other agricultural practices. Nitrous oxide emissions result from agricultural and industrial activities, and the combustion of fossil fuels and biomass. Ozone at ground level, formed from the reaction of sunlight with pollutants from vehicle emissions and industrial activities, contributes to the greenhouse effect and is a component of smog.

The escalation of GHG concentrations has led to a warming of the climate system, with CO_2 being responsible for approximately three-quarters of the increase in radiative forcing over the past decade. The interactions between these gases and the climate system are complex, involving feedback mechanisms that can either amplify or mitigate the greenhouse effect.

Types of carbon emissions and their sources

Among the key greenhouse gases and their respective proportions, water vapor ($H_2O(g)$) makes up 36–70%, carbon dioxide (CO_2) accounts for 9–26%, methane (CH4) ranges from 4–9%, and nitrous oxide (N_2O) contributes 3–7%, alongside other trace gases (Figure 3.1).

CO_2 and CH4 are identified as major contributors to the Earth's rising average surface temperature. These gases result from both natural processes and human activities. Methane, the second most impactful greenhouse gas after carbon dioxide, is the simplest alkane and a primary component of natural gas, formed through the anaerobic decomposition of organic matter in the environment.

Methane is emitted through both natural and human-induced activities. Natural sources of methane include wetlands, termites, wildfires, grasslands, coal beds, and lakes. On the human side, significant contributions come from municipal solid waste (MSW) landfills, rice paddies, coal mining, oil and gas drilling and processing, cattle ranching, manure management, agricultural products, wastewater treatment plants, and rising main sewers.

In detail, agriculture, fossil fuel production, and waste management are primary contributors to methane emissions. Livestock, through a process called 'enteric fermentation', and rice cultivation, through 'methanogenesis' in waterlogged fields, are significant agricultural sources. Methane is also produced from the incomplete combustion of biomass and the decomposition of organic waste in landfills, known as 'fugitive emissions‘ in the context of oil and gas extraction.

Comparatively, methane's warming potential is much higher than CO_2's. Over a 100-year period, a tonne of methane generates 28 times more warming than a tonne of CO_2, making methane responsible for about one-quarter of radiative forcing since 1750, despite its lower emission volume. Methane's atmospheric lifespan is relatively short, about 12 years, meaning that efforts to reduce methane emissions can quickly diminish its concentration in the atmosphere and, subsequently, its warming effects. This presents an efficient strategy for mitigating climate change impacts within decades.

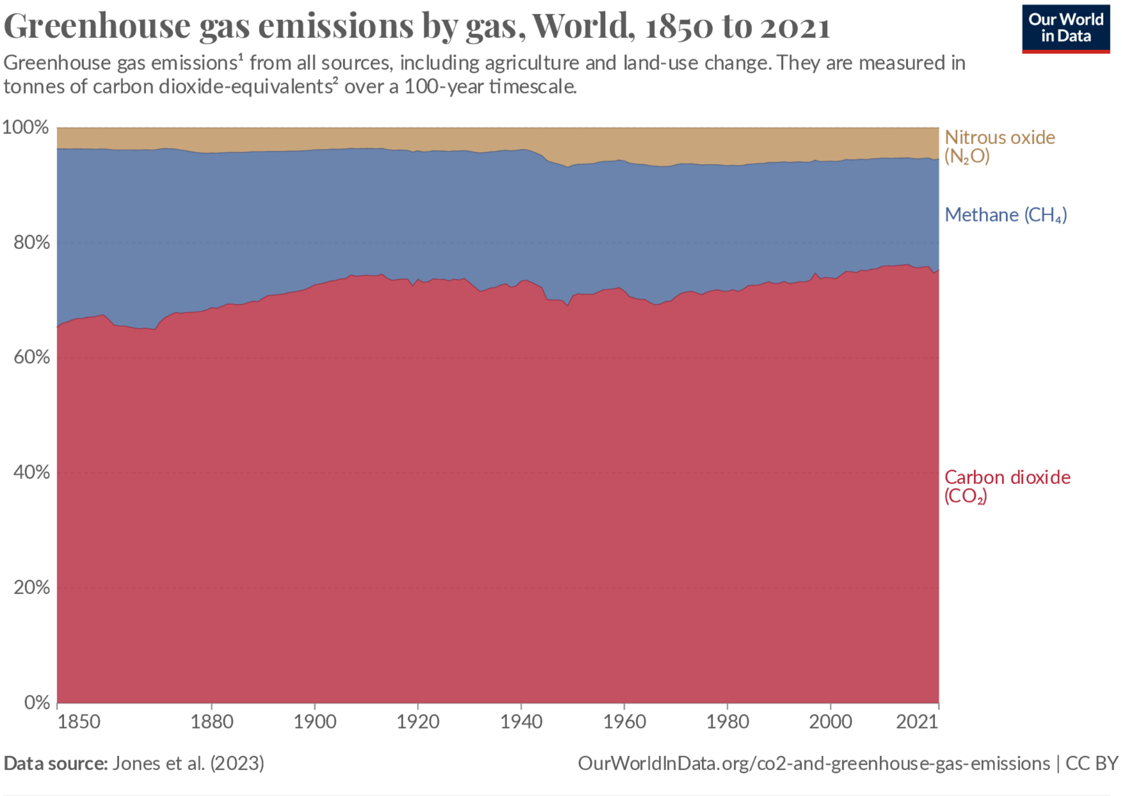
Nitrous oxide (N_2O) emissions are significantly driven by agricultural activities, especially through the use of synthetic and organic fertilizers, manure management, and soil cultivation practices. These agricultural sources contribute the majority of N_2O emissions, highlighting the impact of farming practices on this potent greenhouse gas.

Carbon dioxide (CO_2) emissions are significantly influenced by a complex interplay of factors, including economic development, energy production and consumption patterns, technological advancements, population growth, urbanization, land use practices, agricultural activities, governmental policies, societal behaviors, and natural processes. This multifaceted nature of contributors necessitates a holistic approach to understand and address the challenges associated with managing and mitigating carbon emissions.

Economic growth leads to more CO_2 emissions. This is because industries that make things like steel and cement use a lot of energy, mainly from burning fossil fuels like coal. Coal releases a lot of CO_2 when burned, linking industrial growth directly to more emissions.

The energy sector's reliance on fossil fuels also increases CO_2 emissions. From 2000 to 2008, these emissions went up by 29% because of higher energy demands in fast-growing economies and global trade. This shows how complex the issue is, as it involves energy use, economic activities, and trade all over the world.

Figure 3.1. Greenhouse gas emissions by gas, World, 1850 to 2021



Source: Jones et al. (2023). OurWorldInData.org/co2-and-greenhouse-gas-emissions

As populations grow and more people move to cities, CO_2 emissions rise. This is because more people means more demand for energy in homes, businesses, and transportation. Urban development needs more energy for buildings and services, which adds to the emissions.

Changing how we use land, like cutting down forests for farming or logging, adds CO_2 to the atmosphere. These activities release carbon stored in plants and soil. Although new growth and soil can capture some carbon back, the overall impact is still a problem.

Technology and improving energy efficiency have a mixed effect on CO_2 emissions. They can lead to more energy use and emissions through industrial growth. But they also offer ways to cut emissions through renewable energy, better technologies, and capturing carbon. Moving to cleaner energy and being more efficient is important for reducing emissions.

Government policies and working together internationally are key to managing CO_2 emissions. Policies that support renewable energy, energy saving, and cutting emissions can make a big difference. The role of international trade, especially in exports from emerging economies, shows the global nature of the problem.

Understanding all the factors that affect CO_2 emissions is important for coming up with ways to reduce them. We need a broad approach that includes using renewable energy, protecting forests, improving energy efficiency, and strong policies.

3.2 Historical Context

In the second half of the 20th century, the environmental situation significantly deteriorated, and one notable phenomenon was the pollution of the atmosphere associated with acid rain. As a result of burning organic fuels such as coal and oil, coupled with an increase in the production of combustion by-products, namely sulfur and nitrogen, in the 1950s and 1960s, entire forests, populations of wildlife, and lakes began to perish in Europe and North America. Human health suffered, leading to respiratory diseases and other problems. It was only after these devastating consequences that humanity realized the real threat and began taking measures to address the situation.

In the 1970s, developed countries experienced a crucial phase where people engaged in creating new technologies and restoring nature. This was influenced by an energy crisis, making questions of rational use of natural resources and environmental protection particularly relevant. People began to realize that a good quality of life includes the ability to live in a clean environment with fresh air and water, as well as to enjoy nature untouched by urban development.

By the end of the 1970s, strict environmental protection laws were enacted. New technologies in the economy emerged, allowing a reduction in pollution during production. These included environmentally friendly manufacturing processes that minimized the amount of hazardous waste and increased worker safety.

A significant event in the development of environmental policy was the Geneva Convention on Acid Rain in 1979, laying the foundation for international cooperation in solving problems and controlling transboundary air pollution in Europe. Initially focused on sulfur dioxide emissions, the acid rain treaty has since been refined to address other issues and pollutants.

Gradually, successes were achieved in eliminating hazardous factors affecting human health and the environment. Air and water pollution significantly decreased. The issue of acid rain, which previously destroyed forests, became almost irrelevant. Previously polluted Great Lakes in North America and lakes in Scandinavia, on the brink of disappearance, returned to normal.

By the 1990s, developed countries began taking measures to restore the environment at local and regional levels. Industrial emissions related to the combustion of coal, oil, and gas were significantly reduced. Additionally, there was a noticeable decrease in emissions of heavy metals during the production of steel and other metals.

On a more global scale, steps were taken to preserve nature. Measures were implemented to reduce the destruction of the ozone layer and lower emissions of climate-affecting gases. For example, in 1992, the UN Convention on Biological Diversity was adopted. The Kyoto Protocol, an international treaty, set mandatory targets for developed countries to reduce emissions and provided mechanisms for international cooperation in achieving these goals. The protocol became a driving force in global efforts to combat climate change, although its effectiveness was a subject of debate.

In 2015, considering the limited results of the Kyoto Protocol, the Paris Agreement was signed, aiming for a more effective solution to the global warming problem. The full implementation of the agreement began in 2020.

The agreement outlines an ambitious and specific objective to limit global warming to levels "well below 2°C above pre-industrial levels" and to strive for "efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (Article 2(1)(a)). Additionally, it includes ambitious, albeit somewhat vague, targets for climate adaptation and finance. These three objectives signify a reinterpretation of the UNFCCC's core mission, which is to prevent hazardous climate change. Notably, the Paris Agreement is groundbreaking as the first climate regime instrument to incorporate stand-alone provisions for climate adaptation, loss and damage, conservation and enhancement of greenhouse gas sinks, climate finance, technology development and transfer, and capacity building.

What sets the Paris Agreement apart is its innovation in establishing a universal obligation for states to formulate and communicate nationally determined climate contributions. It introduces a sophisticated oversight system comprising an enhanced transparency framework, periodic collective climate action assessments, and a mechanism to facilitate implementation and promote compliance. These oversight mechanisms are designed to collaboratively foster ambitious climate initiatives.

Moreover, the Paris Agreement is significant because it is the inaugural legal instrument in this domain to incorporate concepts such as a "just transition of the workforce," human rights, the rights of Indigenous peoples, and gender equality in its preamble.

COVID-19 Impact

The impact of COVID-19 on carbon emissions and the environment has been significant both globally and within the EU. During the COVID-19 crisis, environmental pollution, including CO_2 emissions, declined dramatically due to quarantines that severely reduced transport and industrial activity. However, this reduction in emissions had little effect on the steady rise in CO_2 concentrations in the atmosphere. A study published in Nature Climate Change estimated a reduction of 17% in daily emissions in early April 2020, with greenhouse gas emissions reducing by 17 percent from a year earlier. This was a time when China, the United States, India, and other major carbon-emitting countries were under significant levels of quarantine. On average, daily carbon dioxide emissions decreased by 8.6% between January and April compared to the same period in 2019.

3.3 Existing practices and strategies to reduce carbon emissions

The global community is actively working on strategies to combat climate change, with a special focus on the development and implementation of international agreements. The main document defining the course of action in this area is the UN Framework Convention on Climate Change (1992), which aims to stabilise greenhouse gas concentrations in the atmosphere. An important step in this direction was the Kyoto Protocol, which entered into force in 2005 and provides for binding emission reduction targets for developed countries. The most significant modern document is the Paris Agreement (2015), which sets global targets to limit the growth of the planet's average temperature.

Kyoto Protocol

The Kyoto Protocol, adopted in 1997 as an extension to the United Nations Framework Convention on Climate Change (UNFCCC), was the first international treaty to mandate country-specific emissions reductions, setting binding targets for 37 industrialized countries and the European community to reduce greenhouse gas emissions to an average of 5% below 1990 levels during the commitment period of 2008 to 2012.

It specifically listed Annex I countries, primarily developed nations and economies in transition, obligating them to emission reductions, while Non-Annex I countries, mostly developing nations, were not subject to these binding targets but encouraged to participate in emission reduction efforts, notably through the Clean Development Mechanism (CDM).

The Protocol covered six greenhouse gases including carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), and introduced three market-based mechanisms for cost-effective emission reductions: International Emissions Trading, the CDM, and Joint Implementation (JI).

A Compliance Committee was established to ensure adherence to commitments, with specific consequences for non-compliance, and required Annex I countries to submit annual greenhouse gas inventories and undergo regular emissions reviews. Despite its groundbreaking approach, the Protocol saw notable exclusions and withdrawals, with the United States, a signatory, never ratifying it due to concerns over the exclusion of major developing countries like China and India from binding targets, and Canada withdrawing in 2011, citing the inefficacy of the Protocol in the absence of commitments from major emitters. This set the stage for further international climate negotiations, leading to the Paris Agreement of 2015.

Paris Agreement

The Paris Agreement, established under the UNFCCC in 2015, necessitates action from all nations to combat climate change. It sets a global temperature goal to keep the rise in average temperature well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Every participating country is required to submit their own nationally determined contributions (NDCs) which outline their plans for reducing emissions. The Agreement mandates both developed and developing countries to participate, marking a departure from the Kyoto Protocol's approach which primarily targeted developed countries for emission reductions.

The Paris Agreement introduces a robust transparency framework for monitoring and reporting on emissions and efforts, along with a global stocktake every five years to assess progress. Financial mechanisms are established to support developing nations in their climate actions, promoting technology transfer and capacity building. Adaptation to climate change and addressing loss and damage are also key components of the Agreement.

One of the Agreement's innovative features is the ratchet mechanism, which encourages countries to progressively enhance their commitments over time. While the submission of NDCs is mandatory, the targets within them are not legally binding at the international level. As of its adoption, 196 countries have signed the Agreement, committing to collective efforts towards a sustainable future.

European Green Deal 2050

The European Green Deal, initiated by the EU Commission, aims to make the European Union climate-neutral by 2050. This ambitious goal necessitates increasing the current target of reducing emissions from 40% to 65% compared to 1990 levels by 2030, emphasizing a shift towards 100% renewable energy sources. The transition away from nuclear power, coal, natural gas, and crude oil is crucial. Model calculations project that to meet these targets, significant investments in renewables and energy efficiency are required, potentially leading to substantial savings by avoiding fossil fuel imports.

Furthermore, EU funds and economic stimulus programs are being directed to support climate neutrality and renewable energy initiatives. The German EU Council Presidency is highlighted as having a pivotal role in merging climate change mitigation with economic recovery efforts. The Deal covers multiple sectors, with the energy sector playing a key role due to its significant contribution to greenhouse gas emissions. Achieving decarbonization involves not only massive investment in renewable energy (approximately 3000 billion euros) but also expects to yield nearly 2000 billion euros in savings from not importing fossil fuels.

Complete substitution with renewable energy is identified as the most cost-effective and environmentally friendly path forward. This includes rapidly phasing out fossil fuels and increasing investments in renewable energy, energy efficiency, and sector coupling. The document also notes the necessity for the EU to adopt a common strategy to implement the Green Deal as part of national economic stimulus packages.

In May 2021, the International Energy Agency (IEA) in its report proposed to ban the sale of gas boilers for home heating from 2025 and to give preference to hydrogen-fueled equipment. The agency's experts insist on large-scale modernization of the heating infrastructure already available in Europe and complete exclusion of carbon fuel from the operation of future heating systems. IEA also advocates reformatting the construction sector, pointing out that it should focus on energy-efficient housing technologies that will reduce domestic heat consumption. The idea that achieving climate neutrality is not possible if the need for building sector reforms is ignored is gaining popularity.

Strategies of European countries

Several countries have been identified that have significantly reduced their carbon emissions between 1990 and 2022. Some of these countries will be discussed below: Germany, Estonia, Belgium.

Germany

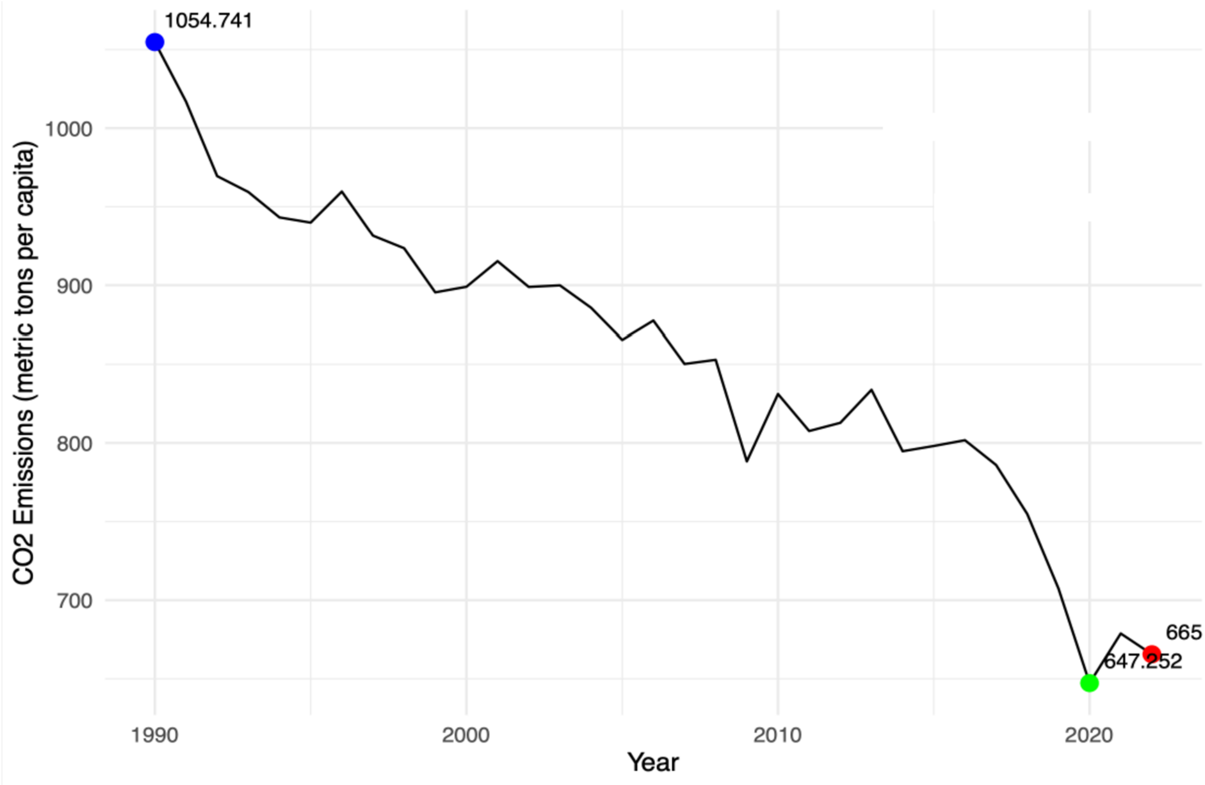
Germany embarked on a targeted initiative to reduce its greenhouse gas emissions by 40% from 1990 levels by the year 2022. This effort was aligned with its commitment to combat climate change and fulfill its obligations under the Paris Agreement. To achieve this goal, Germany implemented a comprehensive strategy focused on increasing the use of renewable energy, enhancing energy efficiency, and enforcing stricter environmental regulations.

The German government deployed a multifaceted strategy to achieve its emission reduction targets. Central to this strategy was a significant shift towards renewable energy sources, enhancing energy efficiency across various sectors, and implementing stringent environmental regulations. The Energiewende, or "energy transition," has been a cornerstone policy, aiming to transform Germany's energy system to rely heavily on renewable energies, such as wind, solar, and biomass.

A key aspect of this transition was the reduction in coal-fired power generation and the gradual phase-out of nuclear energy, replaced by cleaner and more sustainable energy sources. Additionally, Germany invested heavily in energy efficiency measures, including the renovation of existing buildings to reduce heating demands and the promotion of energy-efficient appliances and vehicles.

The results of these comprehensive efforts are evident in the empirical data collected over the period. By 2020, Germany achieved a reduction of approximately 38% in its CO_2 emissions compared to 1990 levels (Figure 4.1). Despite facing various challenges, including economic and industrial factors, the country continued its pursuit of the set target.

3.2. Germany's CO_2 Emissions from 1990 to 2022



Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Estonia

Estonia's strategies for CO_2 emission reduction focus on transforming the energy sector to balance economic growth with environmental and social sustainability. Central to its strategy is leveraging oil shale, which supplies about two-thirds of the nation's primary energy, alongside a growing reliance on renewable resources like wood.

Key measures include adhering to EU directives requiring the upgrade or closure of older, less efficient oil shale combustion plants by 2015, shifting towards more efficient technologies such as circulating fluidized bed combustion (CFBC), and looking into pressurized fluidized bed combustion (PFBC) for future enhancements in energy conversion efficiency.

Estonia aims to increase the share of renewables in electricity production and emphasizes energy conservation across all sectors. The country is adjusting to the rising prices of natural gas to align with European levels, which affects the choice of energy sources and technologies, and has implemented environmental taxes to promote pollution reduction.

Through scenarios exploring different levels of intervention, Estonia shows a preference for natural gas and renewables to achieve more aggressive CO_2 reduction targets.

These efforts demonstrate Estonia's commitment to meeting its Kyoto obligations, spurred by significant emissions reductions since the 1990s due to economic restructuring and heightened energy price awareness.

Belgium

Belgium is proactively tackling carbon emissions in alignment with the European Union's climate objectives, which target a significant decrease in greenhouse gases by 2050, aiming for Belgium to cut its CO_2 emissions by 59%. To achieve these ambitious goals, Belgium has embarked on substantial shifts in its energy consumption, making considerable investments in green technologies and enhancing energy efficiency across multiple key sectors including energy production, industrial processes, transportation, and building construction.

Central to Belgium's strategy is the management of energy demand and the promotion of technological innovation. Efforts have been concentrated on curbing the growth in energy requirements for industrial activities and transport, while also advocating for the adoption of energy-efficient technologies. This strategy is encapsulated in the Belgian TIMES model, exploring various pathways including the use of nuclear energy and carbon capture and storage (CCS). CCS, in particular, is identified as critical for meeting emission reduction targets, especially in scenarios contemplating a phase-out of nuclear power, where the absence of nuclear and CCS options is predicted to significantly increase annual welfare costs, thus underscoring the economic challenges associated with transitioning to a more sustainable economy.

Investments in renewable energy sources play a pivotal role in Belgium's emission reduction efforts. The transition towards renewables, such as wind and solar power, is aimed at diminishing reliance on fossil fuels and reducing emissions. This transition is economically justified, with analyses favoring scenarios that incorporate nuclear energy and CCS due to their lower associated welfare costs.

Looking forward, Belgium's strategy to further reduce carbon emissions and meet its 2050 objectives includes continuous investments in renewable energy technologies, enhanced energy efficiency measures, and the fostering of technological innovations. These strategies are supported by policy and regulatory frameworks designed to incentivize energy savings and the deployment of low-carbon technologies. Additionally, Belgium is committed to international cooperation in climate action, participating in EU-wide initiatives and global agreements to ensure a coordinated and effective response to climate change.

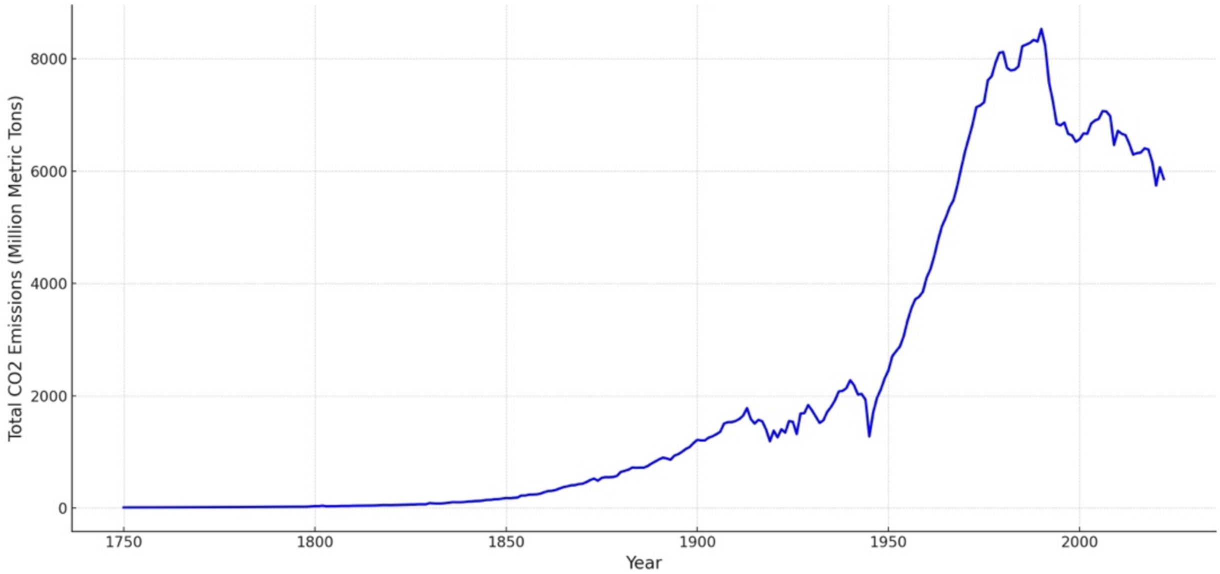
4 Results

4.1 Timeline of Total CO_2 Emissions in EU

As you can see from the graph, the total number of emissions has gradually increased each year. The highest point in CO_2 emissions across European countries around 1990 could likely be attributed to several key factors. This period was marked by significant economic and political transitions in Europe, including the reunification of Germany and the dissolution of the Soviet Union, leading to shifts in industrial and energy production practices. These events may have temporarily increased CO_2 emissions due to the expansion or restructuring of industrial activities and energy systems to accommodate political changes and economic growth.

Moreover, the late 1980s and early 1990s were a time of heightened awareness about environmental issues, leading up to the Earth Summit in Rio de Janeiro in 1992. However, the implementation of policies and technologies aimed at reducing emissions often lagged behind this growing awareness, possibly contributing to the peak in emissions before more concerted efforts to reduce CO_2 output took effect.

Figure 4.1. Timeline of Total CO_2 Emissions for European Countries (1750-2022)



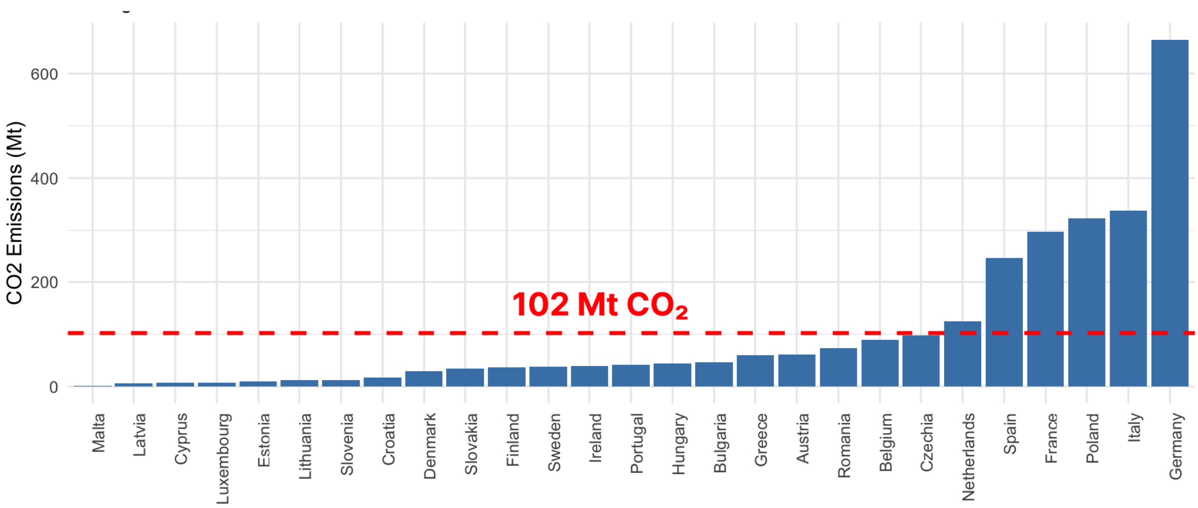
Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

4.2 Carbon dioxide emissions trends in EU-27 1990-2022

This research examines the trends in annual carbon dioxide (CO_2) emissions across various sectors, excluding changes in land use, quantified in millions of tonnes (Mt) over the period from 1990 to 2022, in 27 European countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

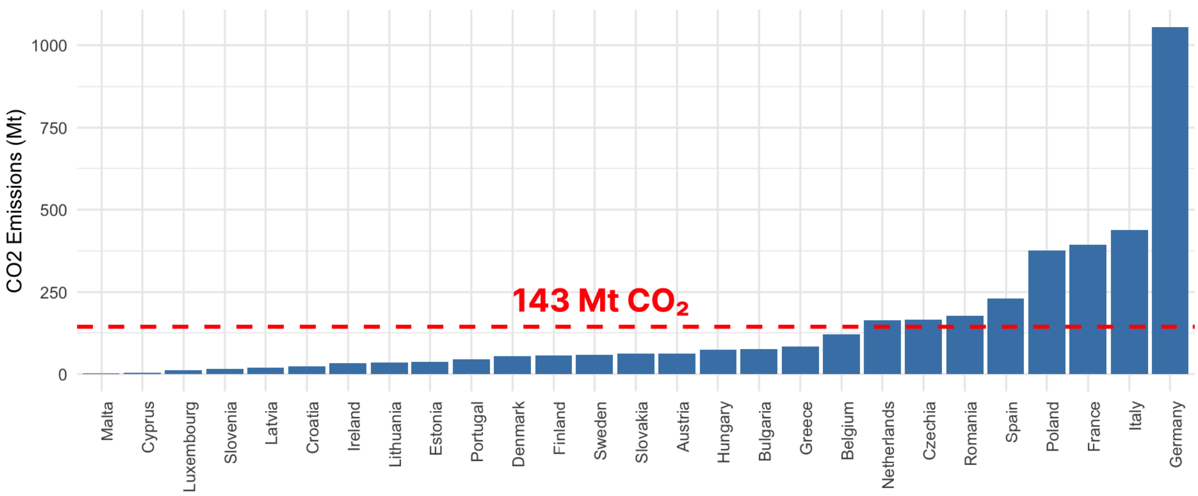
The average annual CO_2 emissions in 2022 amounted to 102 million tonnes (Mt) of CO_2, as illustrated in Figure 4.2. Furthermore, Figure 4.3 showcasing the average emissions for the year 1990, which were notably higher at 143 Mt. Figure 4.4 also shows a comparison between carbon emissions in 1990 and in 2022 in European countries, where you can observe only three countries that have increased emissions in 2022 – Spain, Ireland, Cyprus.

Figure 4.2. Annual CO_2 emissions in EU-27 for 2022



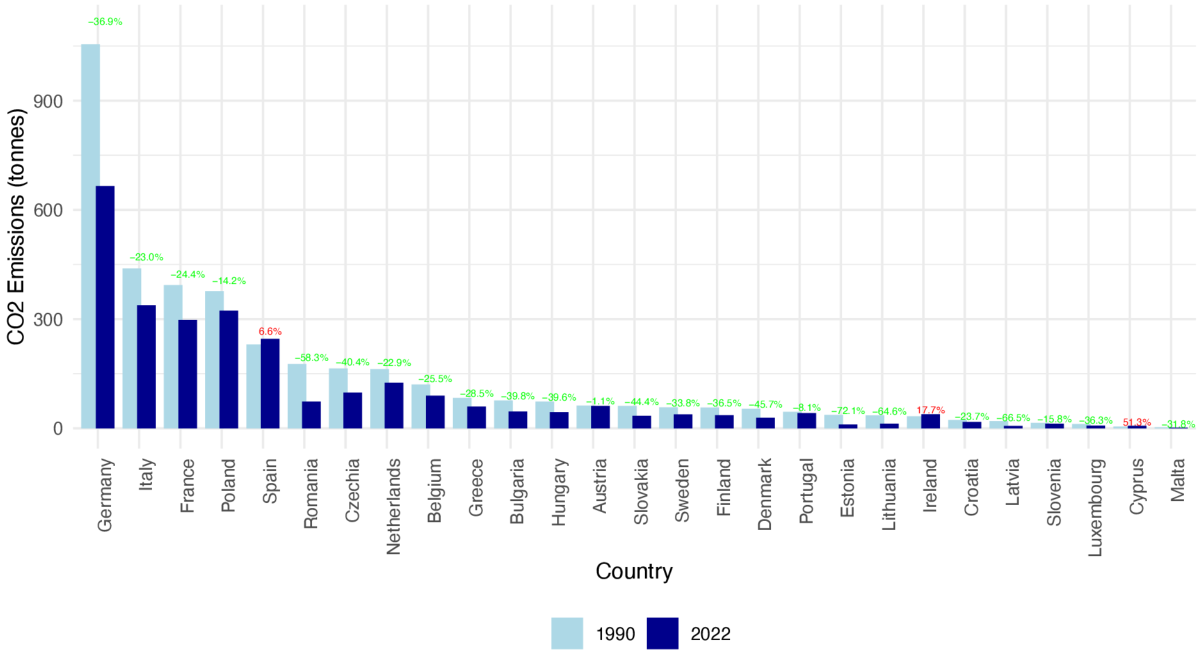
Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Figure 4.3. Annual CO_2 emissions in EU-27 for 1990



Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

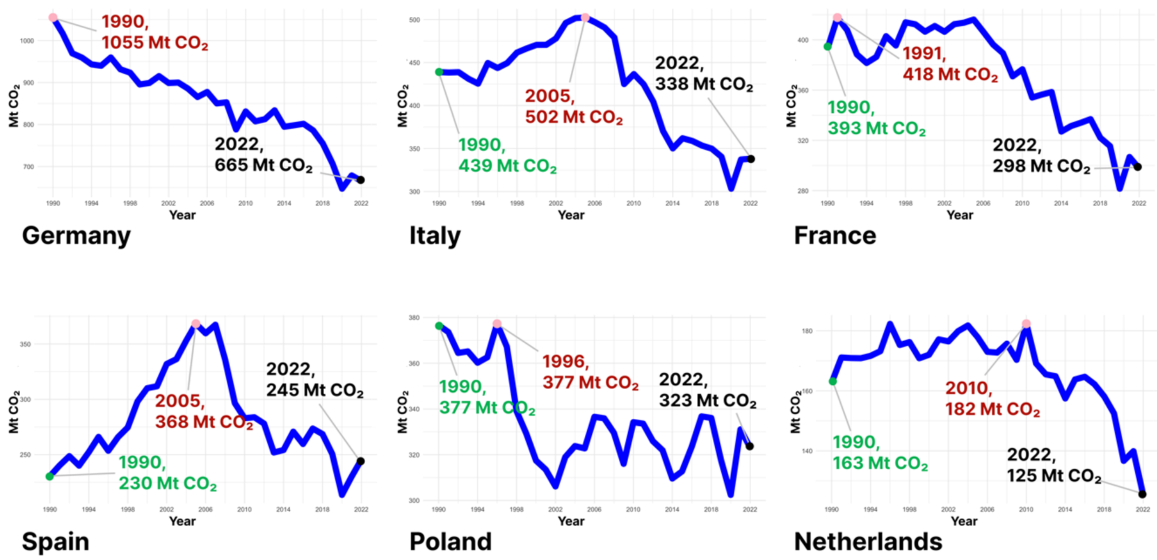
Figure 4.4. CO_2 emissions comparison in EU-27 in 1990 and 2022



Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Figure 4.5 illustrates that in 2022 Germany, Italy, France, Spain, Poland and Netherlands led in CO_2 emissions with a total of 665 Mt CO_2, 338 Mt, 298 Mt, 245 Mt, 323 Mt and 125 Mt respectively. All of the above countries had annual CO_2 emissions above the total average emissions for 2022.

Figure 4.5. CO_2 emissions by countries 1990-2022

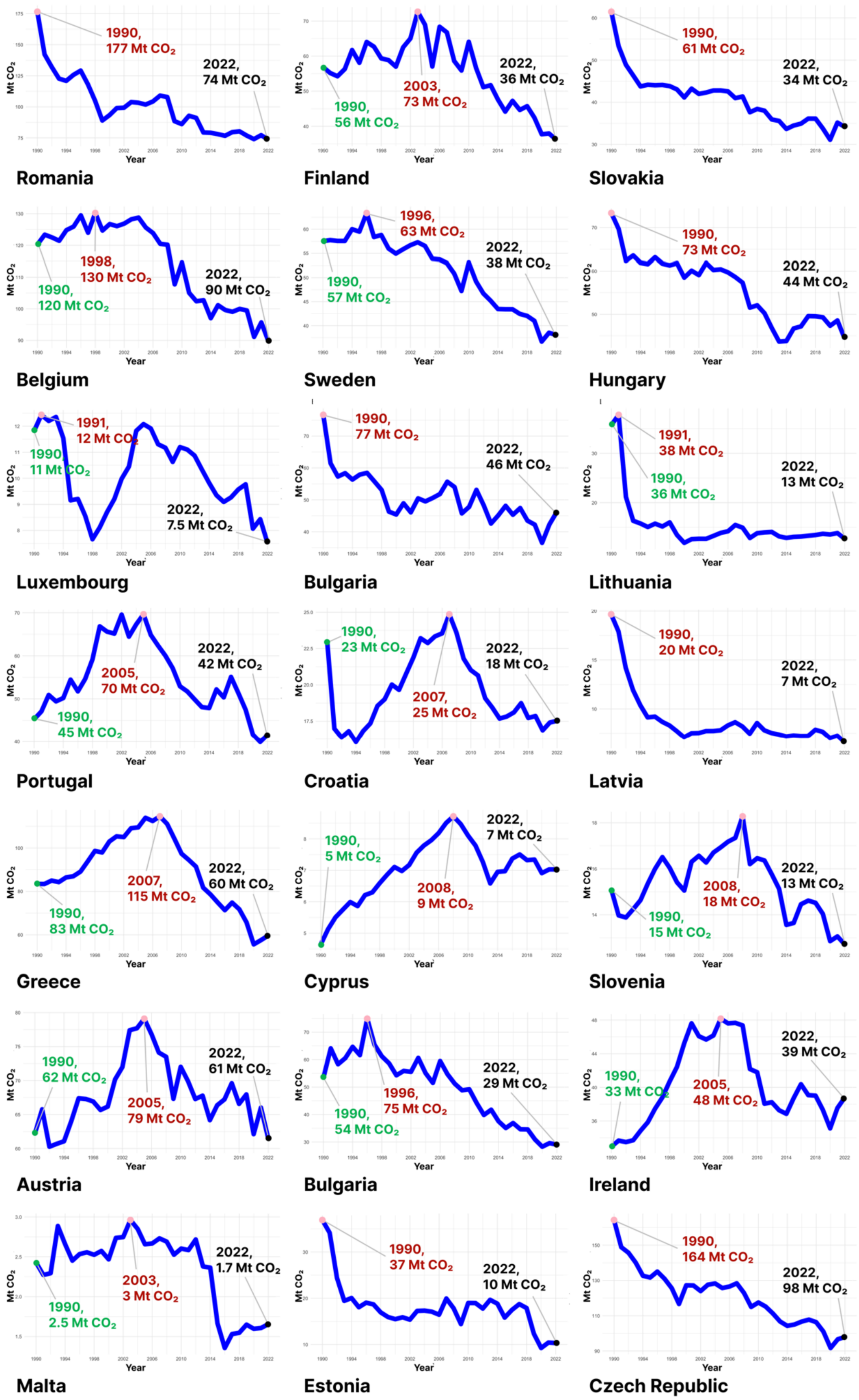


Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

The remaining 21 countries had annual emissions below the EU average, as can be observed in Figure 4.6.

The most substantial decline in CO_2 emissions between 1990 and 2022 was observed in Germany, where emissions were reduced by 398 million tonnes (Mt). Romania ranked second with a decrease of 103 Mt CO_2, closely followed by Italy with a reduction of 101 Mt. France and Poland also showed significant reductions, amounting to 96 Mt and 54 Mt, respectively (Table 1).

Figure 4.6. CO_2 emissions by countries 1990-2022



Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Table 1. CO_2 emissions decrease between 1990 and 2022 in EU-27

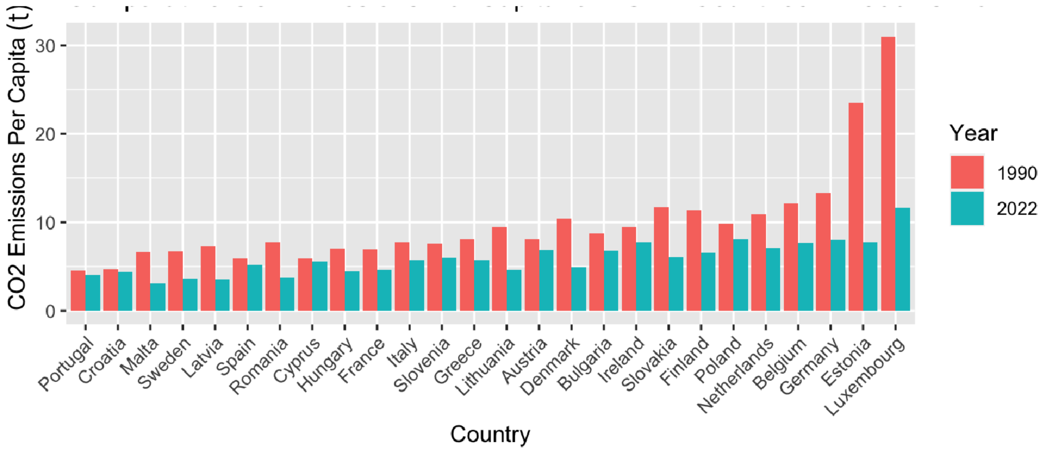
Country	1990	2022	Decrease Mt CO_2
Germany	1055	666	389
Romania	177	74	103
Italy	439	338	101
France	393	298	96
Poland	377	323	54
Netherlands	163	125	37
Belgium	120	90	31
Bulgaria	77	46	30
Hungary	73	44	29
Slovakia	61	34	27
Estonia	37	10	27
Denmark	53	29	24
Greece	83	60	24
Lithuania	36	13	23
Finland	57	36	21
Sweden	58	38	19
Latvia	20	7	13
Croatia	23	18	5
Luxembourg	12	8	4
Portugal	45	42	4
Slovenia	15	13	2
Malta	2	2	1
Austria	62	61	1
Cyprus	5	7	-2
Ireland	33	39	-6
Spain	230	246	-15

Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Emissions per capita were also meticulously calculated. Based on this analysis, Luxembourg emerged as the leading country. However, all countries have managed to significantly reduce their per capita emissions in year 2022 (Figure 4.7).

Per capita carbon emissions data were visualized to prove that there is no strong correlation between the size of a country and its per capita emissions, as illustrated in the Figure 4.8 and Figure 4.9.

Figure 4.7. Comparative CO_2 emissions per capita in EU-27 in 1990 vs. 2022



Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Figure 4.8. CO_2 emissions per capita in EU-27 for 1990

Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

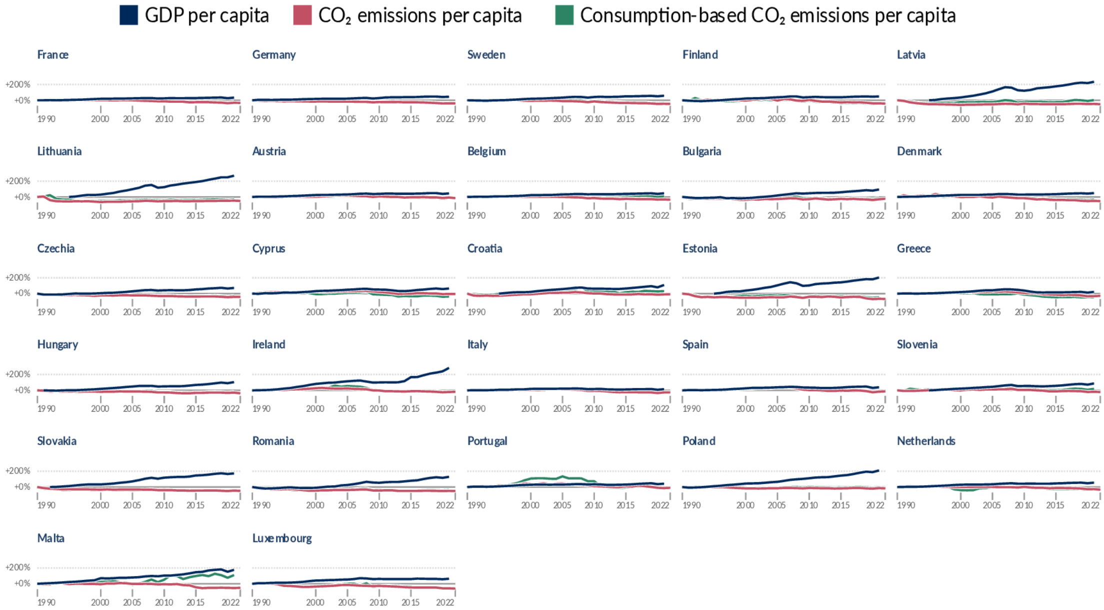
Figure 4.9. CO_2 emissions per capita in EU-27 for 2022

Data source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

4.3 Correlation between economic growth and CO_2 emissions

The correlation between economic growth and CO_2 emissions has been observed to shift, with many countries achieving economic growth without proportional increases in emissions, effectively decoupling the two. This change, highlighted by Ritchie (2021), is evidenced by nations such as the UK, France, Germany, and others, where GDP growth has not been accompanied by higher emissions since 1990. Two main drivers for this decoupling are the stabilization or reduction of total energy use despite economic growth, and the transition towards low-carbon energy sources. This suggests that economic advancement does not necessitate increased carbon emissions, challenging the historically linear relationship between wealth and emissions (Figure 4.10 and Figure 4.11).

Figure 4.10. Change in per capita CO_2 emissions and GDP



Source: World Bank (2023); Clobal Carbon Budget (2023); Population based on various sources (2023). OurWorldInData.org/co2-and-greenhouse-gas-emissions

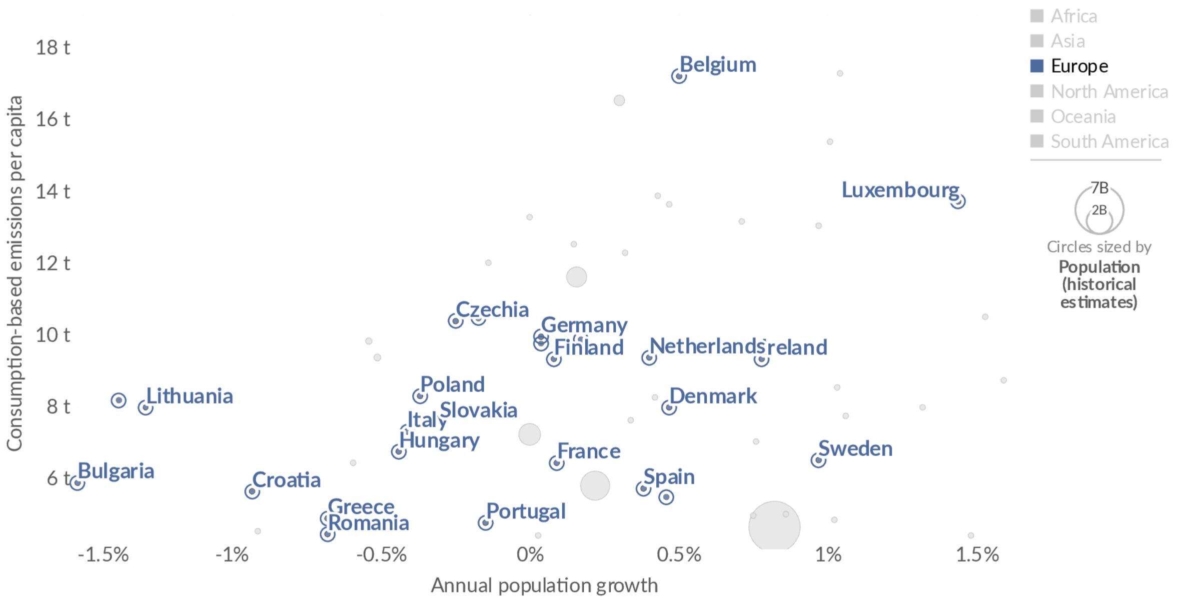
Figure 4.11. Decoupling: Countries that achieved economic growth while reducing CO_2 emissions, 2005-2020

Source: Global Carbon Project & World Bank. OurWorldInData.org/co2-and-greenhouse-gas-emissions

4.4 Correlation between population size and per capita CO_2 emissions

In analyzing the correlation between population size and CO_2 emissions, the article by Liddle (2014) reveals a nuanced relationship. Variations in findings across studies suggest that while population growth has a potential impact on emissions, this relationship is complex and influenced by multiple factors, such as economic development and urbanization. High-density urban living can offer energy efficiencies through compact living arrangements and public transportation, yet the overall effect of urbanization includes increased demand for energy and resources. This dynamic underscores the importance of considering urban planning and development strategies that minimize environmental impacts while accommodating urban growth (Liddle, 2014). This conclusion is further substantiated by the analysis presented in Figure 4.12.

Figure 4.12. CO_2 emissions per capita vs. population growth, 2021

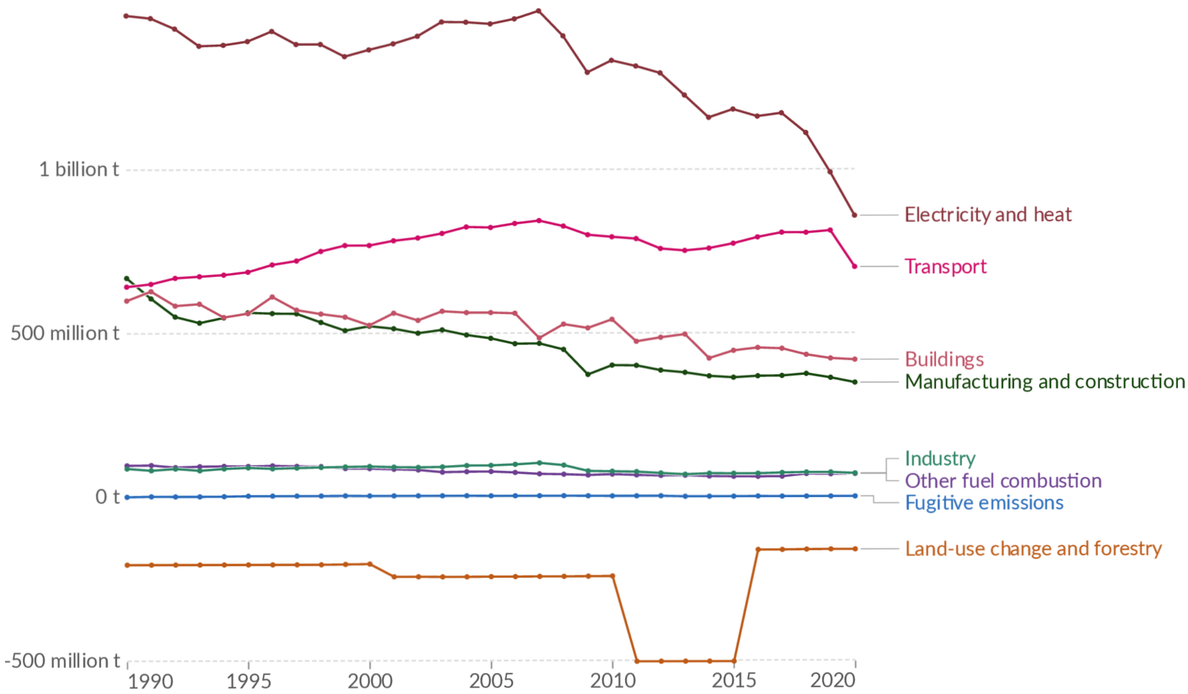


Source: Global Carbon Budget (2023); Population based on various sources (2023); UN, World Population Prospects (2022). OurWorldInData.org/co2-and-greenhouse-gas-emissions

4.5 Source and Sectors of carbon emissions

Emissions are significantly influenced by several key sectors, with electricity and heat production leading, followed by transportation, industry, and agriculture (Figure 4.13). These sectors' contributions to global greenhouse gas emissions underline the importance of targeted strategies for mitigation and transition towards more sustainable practices.

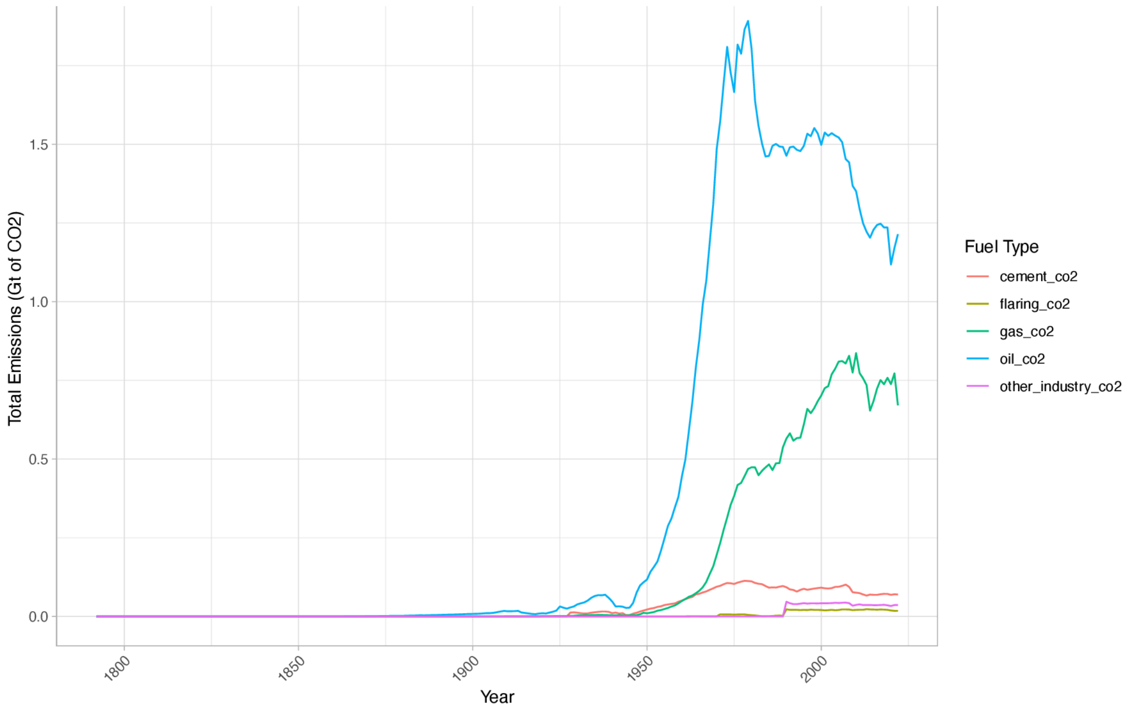
Figure 4.13. CO_2 emissions by sector, European Union (27)



Source: Climate Watch (2023). OurWorldInData.org/co2-and-greenhouse-gas-emissions

The release of carbon dioxide from energy and industrial activities involves many different types of fuel. The amount each source contributes has changed a lot over time, showing big differences between regions. Figure 4.14 shows a detailed look at how much CO_2 each source, like coal, natural gas, oil, flaring, and cement production.

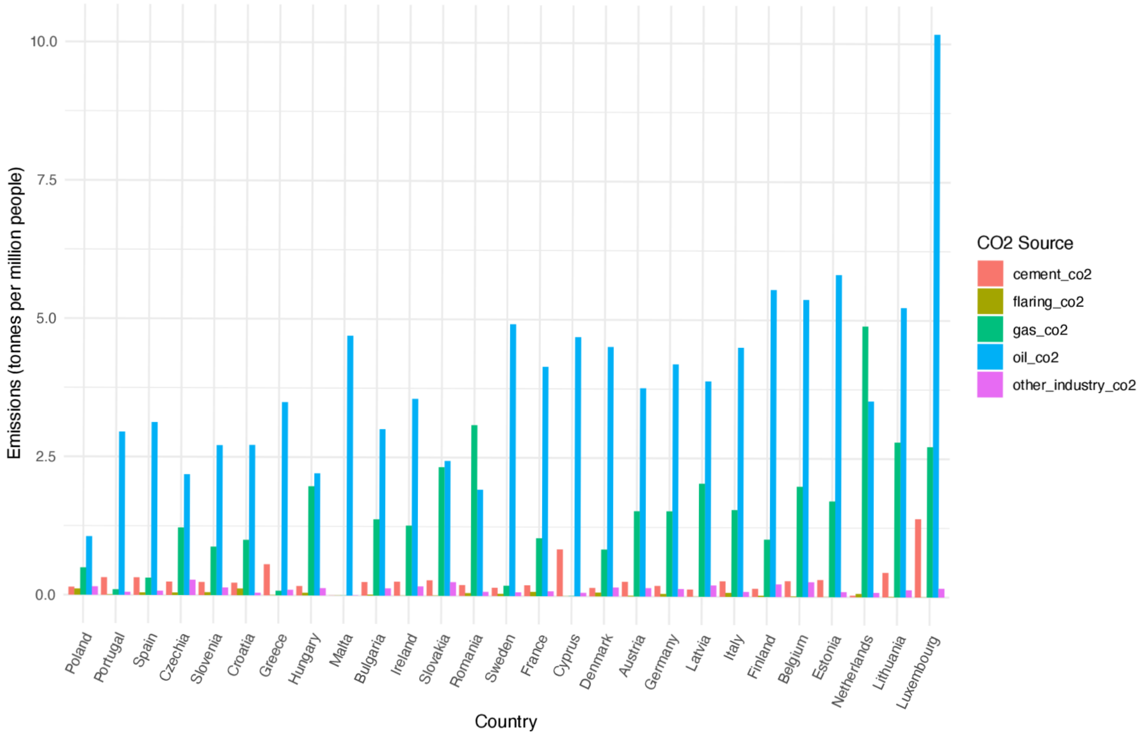
Figure 4.14. CO_2 emissions by fuel or industry type, European Union (27)



Data Source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

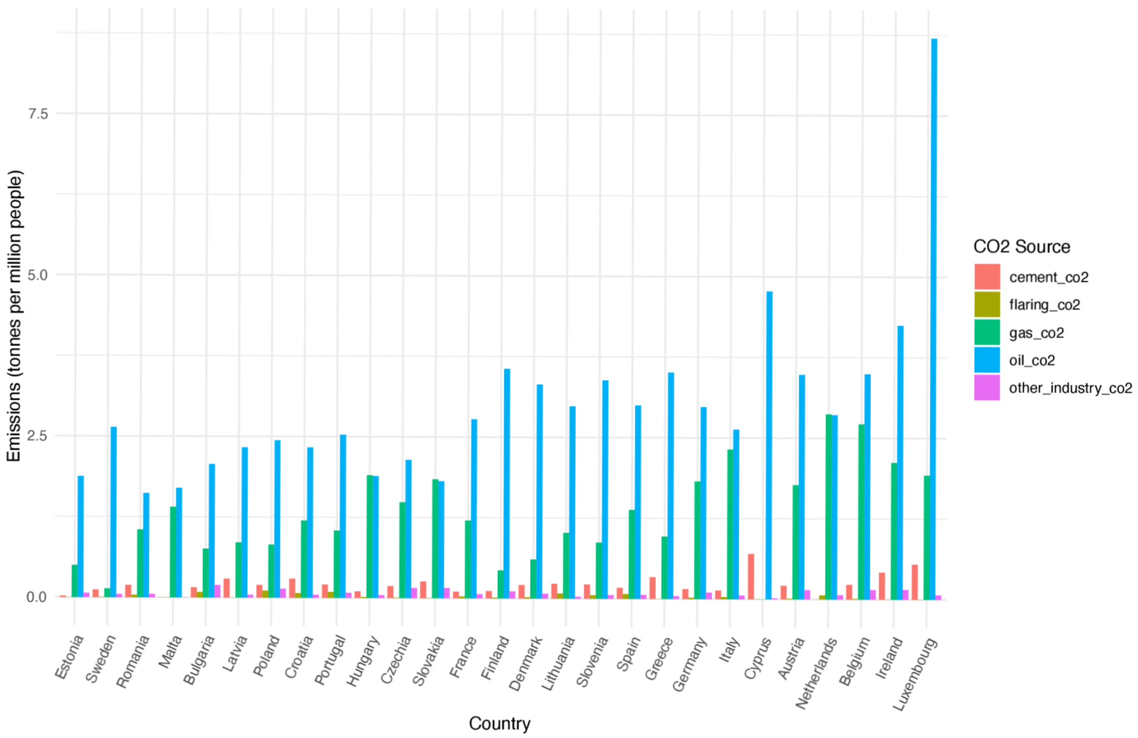
Upon comparing the sources of emissions within the European Union for the years 1990 and 2022, it is observed that there have been significant shifts in the composition of carbon emissions by source in certain member states. For instance, in 1990, Luxembourg's carbon emissions were predominantly derived from coal consumption. However, by 2022, a substantial proportion of its emissions originated from oil. Similarly, Poland has increased its production and, consequently, emissions from oil. Conversely, in Estonia and the majority of other countries within the EU, the proportion of emissions from various sources has remained relatively consistent over the examined period (Figure 4.15 and 4.16).

Figure 4.15. Per capita CO_2 emissions by source, 1990



Data Source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

Figure 4.16. Per capita CO_2 emissions by source, 2022



Data Source: OurWorldInData.org/co2-and-greenhouse-gas-emissions

5 Discussion and Conclusions

The analysis has elucidated the intricate dynamics and multifaceted nature of the factors contributing to carbon emissions within the European Union. By examining the interconnections among carbon emissions, population size, economic growth, and the effectiveness of various policy interventions across different nations, it becomes evident that there is no straightforward correlation among these variables. The complexity of relationships underscores the challenges in identifying universal strategies for emissions reduction.

Notably, international initiatives such as the Paris Agreement have played a pivotal role in influencing carbon emissions trends across the EU. The observable reduction in the average annual carbon emissions from 143 million tonnes (Mt) to 102 Mt attests to the significant impact of such measures. This achievement highlights the importance of sustained efforts by member states in addressing the challenges posed by global warming.

Given the predominance of electricity and heating as major sources of emissions, it is imperative for EU countries to pivot towards energy-efficient solutions. This shift should be envisaged both from a global standpoint—through initiatives like the renovation of buildings, enhancement of public transportation networks, and the development of electric vehicle infrastructure—and at the individual level, by promoting energy-saving practices among citizens. For instance, encouraging the use of energy-efficient light bulbs and optimizing refrigerator settings can contribute to energy conservation.

The transportation sector is also critical to carbon emissions. This impact can be reduced, for example, by replacing personal transportation with bicycles. An excellent alternative for traveling short distances.

Furthermore, expanding public transportation systems is essential. By improving their efficiency and reliability, and transitioning to clean energy sources, public transport can become a viable alternative to personal car use. This approach not only reduces congestion and emissions but also supports a shift towards more sustainable urban mobility.

Investing in sustainable transport infrastructure, such as electric vehicle (EV) charging stations, and promoting policies that favor low-emission vehicles and practices, can further encourage the move away from fossil fuels. Additionally, advocating for reduced travel through remote work and virtual meetings can significantly lower the need for business travel, aligning with environmental goals.

These recommendations advocate for a comprehensive approach that integrates both global changes and individual actions to further reduce carbon emissions in the EU.

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